UNITED STATES EARTHQUAKES 1940

SERIAL No. 647

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

U. S. DEPARTMENT OF COMMERCE
JESSE H. JONES, Secretary
COAST AND GEODETIC SURVEY
Leo Otis Colbert, Director

Serial No. 647

UNITED STATES EARTHQUAKES

1940

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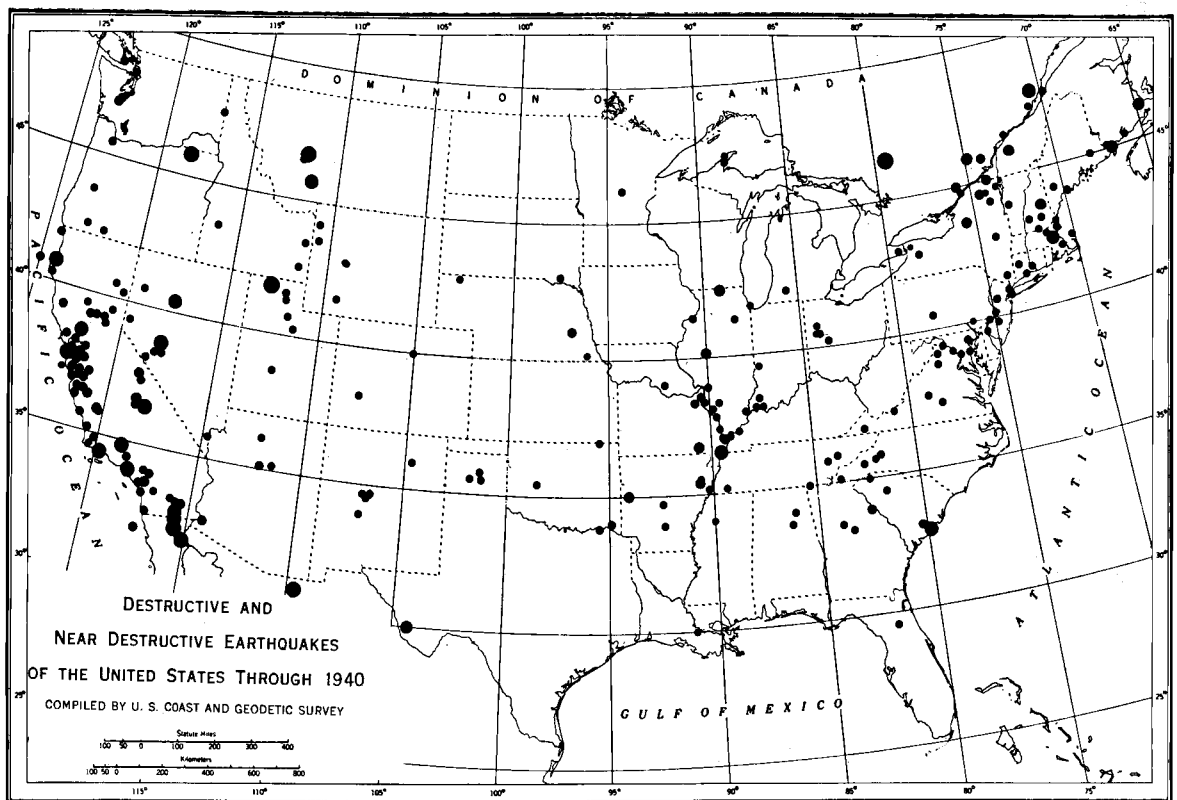

FIGURE 1.—Destructive and near destructive earthquakes of the United States through 1940.

UNITED STATES EARTHQUAKES, 1940

INTRODUCTION

This publication is a summary of earthquake activity in the United States and the regions under its jurisdiction for the calendar year 1940. A history of the more important shocks of the country appears in Serial 609 of the Survey, "Earthquake History of the United States: Part I.—Continental United States (Exclusive of California and Western Nevada) and Alaska," and "Part II.—Stronger Earthquakes of California and Western Nevada, Revised (1941) edition."

The history of minor activity is covered largely in a series of references listed in Serial 609, in recent reports of the United States Coast and Geodetic Survey, and in a recent bulletin of the Seismological Society of America.[1] The last two references give very detailed information for all California earthquakes. The last one contains all of the information appearing in the early catalogs published by the Smithsonian Institution.

Earthquakes of volcanic origin in the Hawaiian and Philippine Islands are not included, and only the stronger shocks are included in the case of the Philippine Islands. Complete reports are published by local seismological institutions. Earthquakes adjacent to the United States and felt within its borders are described only in a general way when detailed descriptions are published elsewhere.

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, as such cooperation will be to the mutual advantage of everyone concerned. The Survey is willing to furnish investigators all information at its disposal, consisting principally of seismographic records and postcard questionnaires obtained in many instances through special canvassing of affected areas. In return it is requested that advance notices be furnished of results obtained so that abstracts and references may be inserted in these reports. An advance notice of a planned investigation might save considerable overlapping of effort and would give wider publicity to the work of the investigator.

Earthquake information services.—The Coast and Geodetic Survey maintains a field party in San Francisco, the Seismological Field Survey, which in addition to other duties collects earthquake information in the Pacific Coast and Western Mountain States. In this work the Seismological Station of the University of California, Berkeley (Dr. Perry Byerly in charge), and the Seismological Laboratory of the California Institute of Technology, at Pasadena, cooperate actively. Among the commercial agencies on the west coast rendering valuable services are telephone, power, oil, railroad, and especially, insurance companies. Certain concerns interested in the manufacture of earthquake-resistant building materials are also active together with various organizations of structural engineers and architects.

[1] Descriptive Catalog of Earthquakes of the Pacific Coast of the United States, 1769 to 1928. S. D. Townley and M. W. Allen, Bulletin of the Seismological Society of America, vol. 29, No. 1, January 1939.

Outside of California the following Collaborators in Seismology served as agents of the Coast and Geodetic Survey in collecting earthquake information in their respective States in 1940:

Arizona.—Dean G. M. Butler, University of Arizona, Tucson.

Idaho.—Prof. Vernon E. Scheid, University of Idaho, Moscow.

Montana.—Dr. Francis A. Thomson, Montana School of Mines, Butte.

Nevada.—Prof. Vincent P. Gianella, University of Nevada, Reno.

Oregon.—Dean E. L. Packard, Oregon State Agricultural College, Corvallis.

Utah.—Prof. Hyrum Schneider, University of Utah, Salt Lake City.

Washington.—Dr. Harold E. Culver, Washington State College, Pullman.

In other parts of the country the Jesuit Seismological Association was active in cooperative projects. The central office of the association at St. Louis University (Rev. Dr. J. B. Macelwane, S. J., in charge) collected information and made special studies in the central Mississippi River valley area, and the Seismological Station at Weston College, Massachusetts (Rev. Daniel Linehan, S. J., in charge) undertook similar work in the Northeastern States under the auspices of the Northeastern Seismological Association and in close collaboration with the Harvard Seismological Observatory.

Other sources of information used in compiling this report included: (1) The United States Weather Bureau, whose observers prepare periodic reports on local seismic activity; (2) telegraphic information collected by Science Service, Washington; (3) bulletins of the Seismological Society of America; (4) bulletins of the Northeastern Seismological Association; (5) special bulletins of the Jesuit Seismological Association; (6) Earthquake Notes; (7) press dispatches published by Georgetown University Seismological Station; (8) reports of the Hawaiian Volcano Observatory; (9) reports of the Weather Bureau of the Philippine Islands; and (10) reports from many interested individuals.

Note on the regional earthquake lists.—The destructive features of all 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. More detailed descriptions of earthquakes on the west coast will be found in the mimeographed reports available at the San Francisco Field Station of the Survey.

Beginning with the 1931 number of this series, Serial 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 unless otherwise designated. 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, Vol. 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 creaking 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— 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.

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 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. When the coordinates of epicenters are given, the sources of information are stated when the epicenters are determined by other organizations such as the Seismological Station of the University of California under the direction of Prof. Perry Byerly or the Seismological Laboratory of the California Insti-

tute of Technology, at Pasadena. The bulletins of these institutions should be consulted for further details and often for data on additional shocks.

Time is indicated as continuous from 0 to 24 hours, beginning and ending at midnight. Local standard time is used.

Within the United States the same regional arrangement has been followed as in Serial 609 previously mentioned.

Special quarterly report.—Attention is invited to a special quarterly report issued by the Seismological Field Survey, with headquarters at San Francisco, entitled "Abstracts to Earthquake Reports for the Pacific Coast and the Western Mountain Region." The reports are in mimeographed form and tabulate in unabridged style all information contained in noninstrumental reports collected in the region indicated.

Epicenter maps.—Figures 1 and 2 are designed to show earthquake distribution in the United States at a glance but the reader is cautioned in accepting all epicenter locations as correct. In a few cases, especially offshore epicenters and others in uninhabited areas, where instrumental control is not satisfactory or where results of investigations are overdue, the plotted epicenters may be in error. The maps must therefore be accepted as showing, in some cases, the existence of epicenters rather than their precise locations. The text of the publication should be consulted to appraise any individual case. This same condition prevails also, to some extent, in the case of isoseismal and "affected area" maps. In figure 2 the relative intensity of a shock is indicated by the size of the dot.

Teleseismic results.—On page 35 is a list of Survey and cooperating teleseismic stations for which the Survey publishes results. Immediate epicenter determinations are frequently made through the cooperation of Science Service, the Jesuit Seismological Association, the Coast and Geodetic Survey, and individual stations and the results broadcast without delay to Europe and points in the Pacific. Postal card reports are also issued.

Strong-motion results.—The introductory remarks in the chapter on this subject explain in detail the purpose of the work, which is primarily to furnish engineers exact information concerning ground movements in the central regions of strong earthquakes. The instrumental equipment is essentially different in type from teleseismic equipment although the principles involved are the same. Strong-motion instruments are installed mostly in the urban areas of California, and operate only when actuated by the movements of a strong earthquake.

The interpretation of strong-motion results is one of the duties assigned to the Survey in connection with a broad cooperative program of seismological research being carried out on the Pacific coast between the Survey and a number of local organizations and institutions interested in the engineering aspects of the earthquake problem. The details of this program are fully described in the Survey's Special Publication No. 201, "Earthquake Investigations in California, 1934–35," which is obtainable from the Superintendent of Documents, Washington, D. C., for 35 cents.

Preliminary reports on strong-motion results are issued in quarterly mimeographed bulletins and sometimes in special mimeographed reports. They appear in revised form in this publication.

NONINSTRUMENTAL RESULTS

EARTHQUAKE ACTIVITY IN THE VARIOUS STATES

Arizona: Local shocks on May 19, June 5, and October 16. The Imperial Valley earthquake of May 18 was felt strongly in Arizona.

California: The Imperial Valley earthquake of May 18, intensity X, was the outstanding earthquake of 1940 in the United States. In northern and central California the more important shocks of intensity V or VI occurred on February 13, September 17 and 27, October 22, November 16 and 19, and December 20; and near Reno, Nev., on February 8. In southern California shocks of similar type were felt in the Los Angeles area on October 10 and 31, and in other areas on May 17 and 21, June 4, and August 27.

Colorado: Light local shock on April 8.

Connecticut: Light shocks in the Moodus area on March 1 and 12.

Florida: Disturbance of questionable seismic origin reported on December 26 at Tampa.

Georgia: Moderate shock on October 19 felt in northwest Georgia and southeast Tennessee.

Idaho: Light local shock on March 28.

Illinois: Weak shock in Paducah, Ky., area on May 31 also felt in Illinois.

Indiana: Weak shocks in Louisville, Ky., and Evansville areas felt in both States on January 8 and December 28.

Kentucky: Local shocks on January 8, May 27, May 31, and December 28, three of which were felt in neighboring States.

Louisiana: Local shock on December 2.

Maine: Light local shock on March 28. The New Hampshire earthquakes of December 20 and 24 were strongly felt in parts of Maine.

Massachusetts: Intensity IV shock in Buzzards Bay area on January 28. Light local shock on January 1. The New Hampshire earthquakes of December 20 and 24 were felt strongly in parts of Massachusetts.

Missouri: Local tremor on February 4.

Montana: Intensity VI shock at Helena on December 23. Local shocks occurred in the State on January 18, April 29, May 21, August 19, and December 25. There were also a number of light aftershocks in the Helena area.

Nevada: Moderately strong shocks in Pahranagat Valley area on March 17, 18, and 30. Light local shocks occurred in State on May 18 and October 12. No outstanding activity occurred in Boulder Dam area.

New Hampshire: Intensity VII shocks in the Lake Ossipee area on December 20 and 24 marked the outstanding disturbance of the year east of the Rockies. There were a large number of aftershocks.

New Mexico: Light local shock on May 16.

New York: The New Hampshire earthquakes of December 20 and 24 were felt strongly in the eastern part of New York State. Local tremors occurred on May 19 and September 26.

North Carolina: Light shocks on December 24 and 25.

Ohio: Light tremor on May 31. Tremors were reported from one point on June 15, July 28, August 15 and 18.

Oregon: Moderate shock on coast on May 25.

Pennsylvania: Light tremor reported at Harrisburg on May 28.

Rhode Island: The New Hampshire earthquakes of December 20 and 24 were widely felt in Rhode Island. A light local shock occurred on January 2.

South Carolina: A sharp disturbance occurred in the Charleston area on January 5 followed by lighter activity on October 7 and December 27.

Tennessee: Moderate shocks in the western part on November 23. One in southeastern corner, on October 19, was also felt in Georgia. Other local activity in eastern part on December 24 and 25.

Utah: Local shock on February 28.

Vermont: The New Hampshire earthquakes of December 20 and 24 were strongly felt in Vermont.

Virginia: Moderate shock on March 25.

Washington: Widespread shock in Puget Sound area on October 27. Weaker shocks occurred on March 23 and November 13; and light local shocks on January 5, April 25, November 18 and 25.

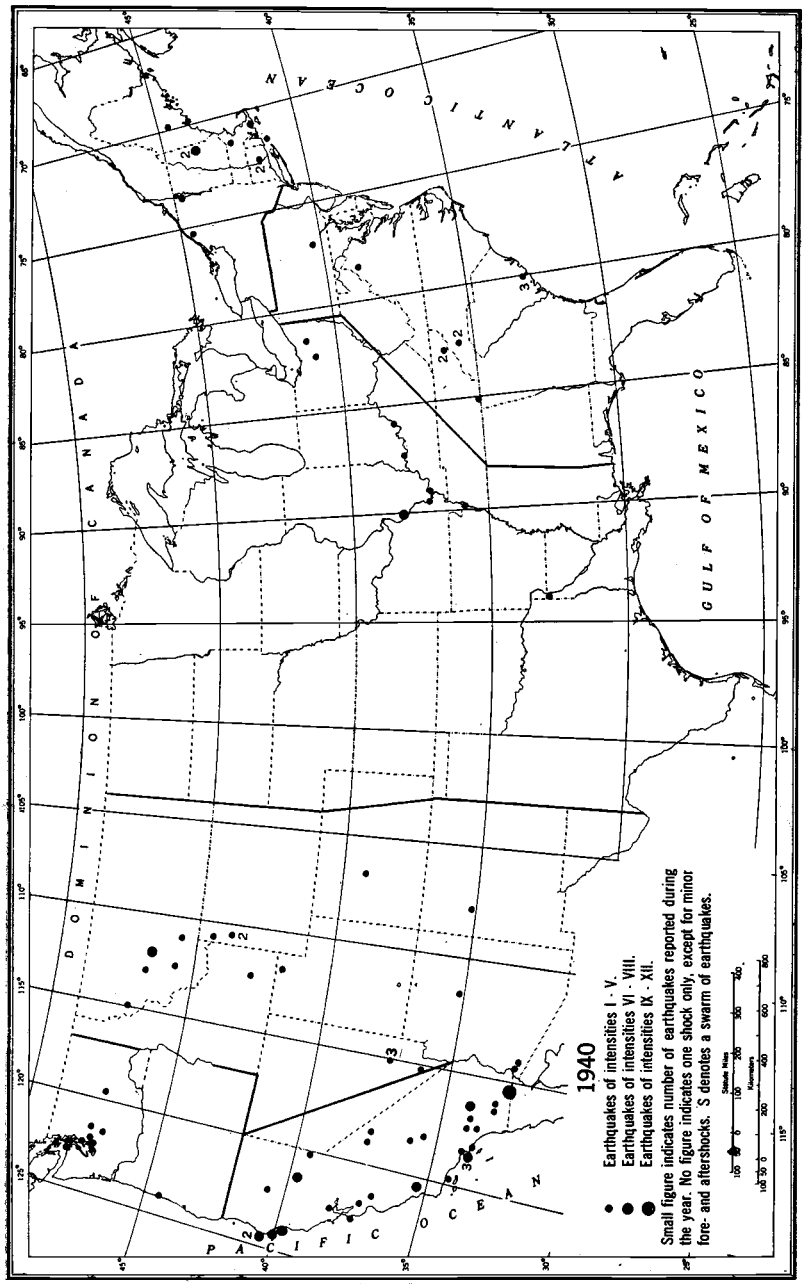

FIGURE 2.—Earthquake epicenters, 1940.

Wyoming: Moderate shocks on May 24; light local shocks on October 22 and November 1.

Alaska: Moderately strong shock in the McKinley Park area on March 5. A strong submarine earthquake on August 21 was felt at Dutch Harbor and Unalaska. Minor activity centered in the Fairbanks region.

Hawaiian Islands: A strong submarine shock on June 16 was felt on all islands.

Philippine Islands: No outstanding activity.

Puerto Rico: No shocks reported felt.

Panama Canal Zone: Minor activity only.

NORTHEASTERN REGION

(75TH MERIDIAN OR EASTERN STANDARD TIME)

NOTE.—See bulletins of all seismographic stations in the region for additional information. "NESA" refers to the Northeastern Seismological Association.

January 1: 20:06. Massachusetts. 42.5° north, 71.5° west, according to the NESA bulletin. Felt in Littleton, Mass.

January 2: 20:30 and 21:00. Block Island, R. I. Weather Bureau microbarograph showed 2 jars but no motion was felt. Felt by 2 persons 3 miles away.

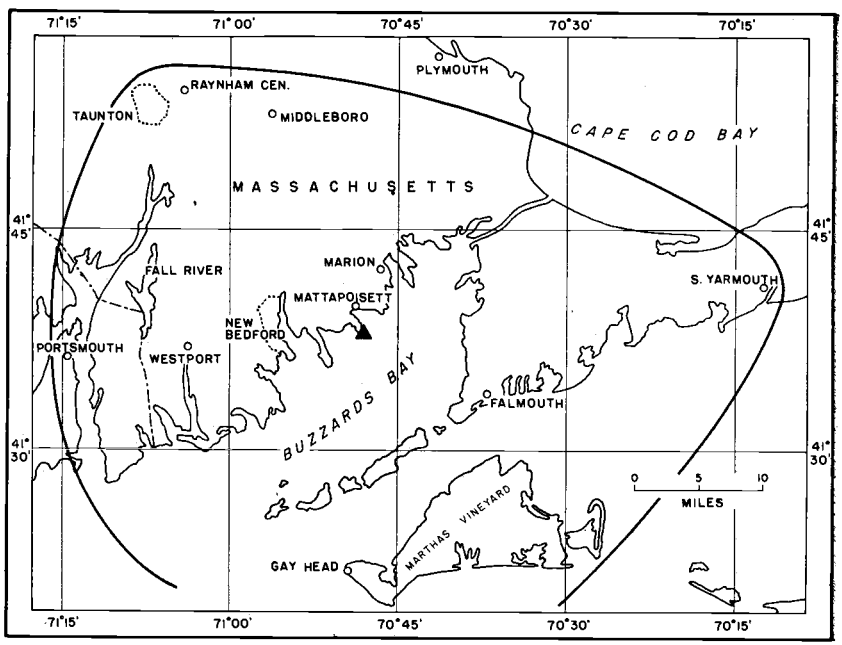

FIGURE 3.—Area affected by Buzzards Bay, Mass., earthquake of January 28, 1940. Map prepared at Weston College Seismological Station.

January 28: 18:12*. Buzzards Bay, Mass. Epicenter 41°38′ north, 70°48′ west according to the NESA bulletin. A canvass of the affected area was made by the Weston College Seismological Station. The map and the descriptive material following have been furnished through the cooperation of that station.

The shock was evidently strongest in the vicinity of Marion, Mattapoisett, Fairhaven, and New Bedford on the northwest shore of the bay, and near Pocasset and Falmouth on the southeast shore. Near Mattapoisett it "took the plugs out of the electric light sockets" and shook some houses rather severely. Books fell from the shelves of a library in Fairhaven. It was evidently felt throughout Martha's Vineyard.

The sound of the earthquake was its most noticeable feature in some places. Falmouth, for example, reports the rumble was gradual, then ended abruptly like an explosion. At more distant points the noise was more like distant thunder.

INTENSITY IV:

Acushnet, Antassawanock Neck, Bourne, Cataumet, East Falmouth, Fairhaven, Falmouth, Forestdale, Gay Head, Hatchville, Lakeville, Marion, Mattapoisett, New Bedford, Nobska Point, Onset, Pocasset, Russels Mills, Sconticut Neck, South Dartmouth, Westport, and Woods Hole.

INTENSITY I TO III:

Bridgewater, Carver, Cotuit, Dartmouth, East Fairhaven, East Wareham, Martha's Vineyard, Mashpee, Menemsha, Middleboro, Monument Beach, Nonquitt, North Dartmouth, Oak Bluffs, Osterville, Point Independence, Portsmouth, Rayuham Center, Rochester, Sagamore, Chilmark, South Yarmouth, Segreganset, Waquoit, Wareham, and West Wareham.

Felt with intensity about II at Portsmouth, R. I.

Not felt at Attleboro, Cape Cod Canal, Centerville, Harstons Mills, Hyannis, Manomet, Mansfield, Mantucket, Orleans, Plymouth, Provincetown, Rockland, Sandwich, Siasconset, Whitman, and Yarmouth.

March 1: 23:16.* Near Moodus, Conn. Epicenter 41.5° north, 72.5° west, according to the NESA bulletin. At Westbrook windows rattled and a lumber pile in a cellar was reported upset. Accompanied by noise like a thunderclap.

March 12: 20:29.* Near Moodus, Conn. Epicenter 41.5° north, 72.5° west, according to the NESA bulletin. Reported felt.

March 28: 6:43.* Maine. Epicenter 44.7° north, 69.9° west, according to the NESA bulletin. Felt in Stark and New Vineyard.

May 19: 20:26. Canton, N. Y. Slight local tremor.

September 26: 18:30.* Lake Champlain area. Epicenter 44.7° north, 73.5° west, according to the NESA bulletin. Felt in Plattsburg, N. Y. Recorded on seismograph of University of Vermont, at Burlington.

December 20: 2:27.* Near Lake Ossipee, N. H. Epicenter 43.8° north, 71.3° west, according to the NESA bulletin. Maximum intensity VII. Land area affected in the United States, nearly 150,000 square miles. Felt 350 miles from epicentral area. A special article on this earthquake will appear in an early issue of the Bulletin of the Seismological Society of America under the authorship of Daniel Linehan, S. J., and L. Don Leet.

The maximum intensity was apparently in the lower range of VII. There were no casualties, and the total damage did not exceed a few thousand dollars at most. The affected area was canvassed in part by the Coast and Geodetic Survey, the Northeastern Seismological Association with headquarters at Weston College, Massachusetts, and by local observers of the United States Weather Bureau. Mr. R. L. Arringdale, Director of the Seismographic Station at Portland, Maine, affiliated with the Harvard Seismographic Station, surveyed the epicentral area. The evidence pointed to the appearance of ground cracks in the region of Tamworth, N. H., where the shocks seem to have been the strongest, but the presence of snow made accurate appraisal of the extent of the cracking extremely difficult. There seems to have been no specific point or line where the ground disturbance was outstanding.

Two major shocks of approximately the same intensity featured this disturbance. A second important shock occurred at 8:44* on December 24, with epicenter in the same general region. A review of the original reports and newspaper clippings indicates that the second shock, on the 24th, was less prolonged but somewhat more intense than that of December 20. There is no doubt that damage resulting from the second shock was made greater because of weakening effects of the earlier shock. In analysing the reports for the two shocks, the situation appeared so confused that it was decided to combine the reports for both and construct only one map showing the affected area. The map on page 10 is based on a preliminary plotting of intensity data at the Weston College Observatory.

An unusual phenomenon was reported from Westbrook, Maine, where an observer crossing a bridge noticed waves "raised" in the Presumpscot River at the time of the December 24 shock. Some tall buildings were shaken rather severely in Boston, Mass., and Albany, N. Y. by the earlier shock.

The usual number of aftershocks were recorded in the epicentral area, 129 having been reported by one observer through January 31, 1941. The Northeastern Seismological Association determined instrumental epicenters in this area for the following earthquakes: December 20, 2:27; December 24, 8:00, 8:44, 9:33, and 13:12; December 25, 0:04; January 1 (1941), 22:43; January 4, 6:10;

January 18, 18:25; January 20, 21:28; January 22, 19:15; and February 12, 17:24.

Intensity VII in New Hampshire:

Tamworth.—In valley. Twenty old chimneys reported damaged, some thrown down. Tombstones rotated. Some walls were cracked and a few pipes were broken. Much stucco was thrown from outside walls. and there was some damage to light structural parts. Plaster fell. Some furniture was broken and there was considerable damage to china, glassware, and brick-a-brack. Clocks stopped. Dead branches were shaken from trees and many cracks appeared in the crusty snow. Some cracks were reported in the ground. Well water was muddy for several days. One observer reported 129 aftershocks through January 31, 1941. Second shock "more terrifying" and "closer" than main shock.

Wonalancet.—Old house of heavy timber construction shifted a foot with damage to foundation. Heavy furniture shifted a foot; a heavy kitchen stove moved over 6 inches. Twenty-five pieces of china and brick-a-brack were broken; all pictures fell and everything slid from mantels. Cracks appeared in snow and ground. Most of the damage occurred during the earthquake of December 24.

Intensity VI in New Hampshire:

Bloomfield.—Slight damage in old masonry; chandeliers and Christmas tree swayed. (December 24 report.)

Center Ossippee.—Small objects overturned. "Drops" on telephone switchboard were released. Slight damage. Trees and bushes shaken strongly. Shock on 24th toppled chimneys and threw groceries from shelves.

Chocorua.—Six chimneys damaged. Merchandise thrown from shelves; heavy vases thrown from mantel. Clocks stopped.

Conway.—Chimneys were damaged and some plaster fell. Some dishes and pictures broken. Church bell rang. Telephone switchboard "drops" dislodged. (December 24 report.)

George's Mills.—Fireplace arches and plaster cracked. Slate cap on chimney displaced. Cracks found in ground 1 to 2 inches wide and 10 to 50 feet apart.

Keene.—Some brick walls and plaster cracked. Old cracks in brick city hall were enlarged. Auto toppled from jacks. Dishes and brick-a-brack shaken from many shelves; pictures swayed throughout town, and fire bell rang. Intensity higher than at nearby places on rock. Shock of 24th not so intense. Alluvium.

Lincoln.—Bricks fell from chimney. Reinforced concrete floor reported cracked. Merchandise and dishes fell from shelves. Pictures on walls displaced. Rain gage recorder pen vibrated through ⅜ inch. (December 24 report.)

North Conway.—One chimney toppled. Merchandise fell from shelves in most stores. Plaster fell in one old building. One house damaged by fire resulting from cracked chimney on December 24.

West Ossippee.—Three chimneys damaged.

Intensity VI in Maine:

Augusta.—Number of chimneys badly cracked. Some pipes loosened at junction with water tanks. Telephone exchange deluged with calls. (December 24 report.)

Denmark.—Vases overturned; dishes broken. (December 24 report.)

Waterville.—Knickknacks, books, and pictures fell; dishes and windows broken. On the 24th walls and plaster were reported cracked; damage slight.

Intensity V in New Hampshire:

Alton.—Clocks stopped. Chimney cracked.

Buxton.—Snow shaken from roofs.

Claremont.—Knickknacks fell.

Colebrook.—Small objects overturned; knickknacks fell in both shocks.

Concord.—Some plaster reported cracked; slight damage to glass and chimneys.

Dover.—Small objects moved.

Franklin.—All awakened; hanging objects swung.

Glen.—Small objects moved; all residents awakened.

Gorham.—Door opened; clocks stopped; all residents awakened.

Groveton.—Small objects moved.

Hanover.—A little plaster cracked; chimney of school 6 miles south of Hanover damaged. Small objects and pictures displaced. On December 24 tall

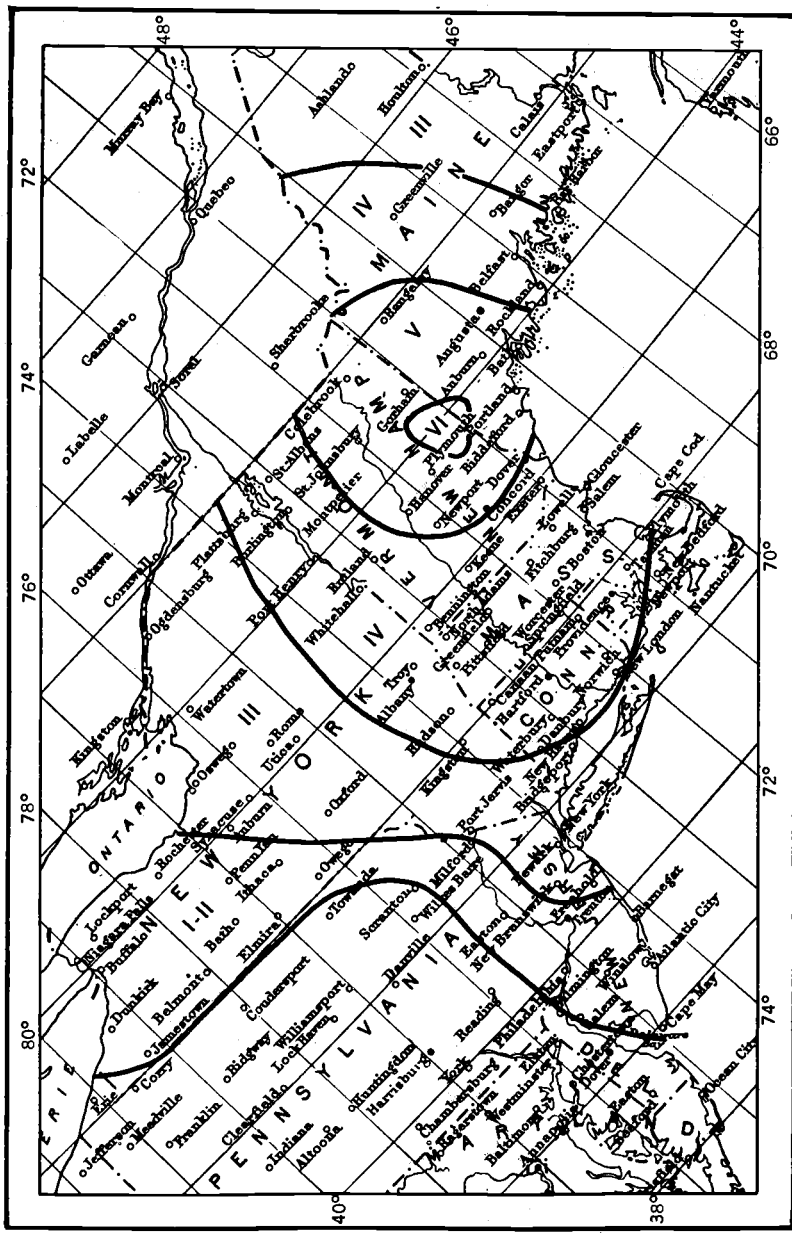

FIGURE 4.—Isoseismals of the New Hampshire earthquakes of December 20 and 24, based on investigations of Northeastern Seismological Association.

hospital chimney swayed visibly; rocking chairs rocked; trees were visibly shaken; and water in a brook swished back and forth.

Lancaster.—Chimneys and plaster cracked. Small objects moved.

Lincoln.—Bricks fell from chimneys. Wall pictures displaced. Rain gage recorder pen vibrated through ¼ inch.

Littleton.—Curtains, pictures, and furniture disturbed. Shock of 24th believed stronger than that of 20th.

Lisbon.—Chimneys and plaster cracked. Knickknacks fell.

Manchester.—Plaster reported cracked. A few light objects overturned. Shock of 24th reported stronger than that of December 20.

Meredith.—Some dishes broken. Awakened all residents.

Milan.—Plaster reported cracked. Awakened all residents.

Meriden.—Small objects moved; trees and bushes shaken. (December 24 report.)

Moultonboro.—Slight damage to chimneys. (December 24 report.)

Nashua.—Some plaster reported cracked and plants thrown from shelves on December 24. Pictures were displaced on the 20th.

Pittsfield.—Light objects overturned.

Rochester.—Hanging objects swung. All residents awakened. Trees and bushes shaken strongly.

Warren.—Dishes broken; knickknacks and pictures fell. Damage slight.

Wolfeboro.—Plaster cracked, knickknacks fell. Damage slight.

INTENSITY V IN MAINE:

Andover.—Liquids spilled from containers; church bell rang 3 strokes. All residents awakened. (December 24 report.)

Augusta.—Number of chimneys cracked; some pipes loosened from water tanks. Telephone exchange deluged with calls. (December 24 report.)

Bath.—All residents awakened. Trees and bushes shaken moderately.

Bethel.—Chimneys cracked; some reported fallen; damage slight. Stronger shock of December 24 cracked plaster, broke dishes, overturned some objects, and spilled water. Both shocks awakened everyone.

Denmark.—Pictures fell. Slight damage to brick construction.

Farmington.—Chimneys and plaster cracked. Pictures fell.

Fryeburg.—Small objects moved; trees and bushes shaken.

Gardiner.—Chimneys cracked; vases and small objects overturned; dishes broke; books and pictures fell.

Hiram.—One or two windows broken; knickknacks fell; objects overturned.

Jackman.—Knickknacks and pictures fell; plaster cracked. (December 24 report.)

Lewiston.—All residents awakened; trees and bushes shaken.

Limerick.—Small objects overturned; trees and bushes shaken.

Mexico.—Trees and bushes shaken. Many residents awakened.

Naples.—All awakened by shocks of December 20 and 24. During latter shock chimneys were cracked slightly.

North Bridgton.—Some objects fell. All residents awakened. Shock of 24th rated heavier but shorter than that of December 20.

Norway.—Clocks stopped; water spilled. Felt by all residents. (December 24 report.)

Parsonsfield.—Pictures fell. All residents awakened.

Peru.—Small objects moved. Slight damage. All residents awakened.

Portland.—Walls cracked in south Portland; dishes thrown from shelves at State School for Boys. Telephone poles swayed visibly. Both heavy shocks felt aboard ship in harbor. Shock of December 20 stronger but more damage appeared to result from shock of 24th.

Sanford.—Pictures and knickknacks fell.

Springvale.—Plaster cracked; knickknacks fell.

Wilbur.—Small objects moved. All residents awakened.

INTENSITY V IN VERMONT:

Bloomfield.—Top bricks displaced on some old chimneys. Pictures and chairs moved: ornaments fell from Christmas tree. (December 24 report.)

Brattleboro.—Knickknacks fell. Many residents awakened.

Burlington.—Some plaster cracked slightly, and a few dishes and windows were broken. (December 24 report.)

Bristol.—Clocks stopped. Many residents awakened.

Craftsbury Common.—Felt by nearly everyone. (December 24 report.)

Hardwick.—Plaster cracked; dishes broken; objects overturned. Felt by all. (December 24 report.)

Ludlow.—Dishes broken; small objects displaced. Shock of December 24 broke dishes, cracked plaster and ice, and overturned small objects.

Montpelier.—Objects moved. (December 24 report.)

Newport.—Hanging objects swung and pictures were displaced. Striking mechanism of clock in courthouse tower thrown out of gear. (December 24 report.)

North Troy.—Plaster cracked; vases overturned. Clocks stopped. (December 24 report.)

Rutland.—Small objects moved. Many residents awakened. Shock of December 24 reported shorter but more severe than that of the 20th.

St. Albans.—Stucco cracked on several houses. Chimneys swayed visibly. Many loose objects disturbed. (December 24 report.)

St. Johnsbury.—Walls and plaster cracked; damage slight. All residents awakened.

Vergennes.—Bed and chandelier moved; many residents frightened. (December 24 report.)

Windsor.—Small objects moved; all residents awakened. Trees and bushes shaken strongly. Practically same report for December 20 and 24.

INTENSITY V IN MASSACHUSETTS:

Alton.—Pictures displaced; many residents frightened. On December 24 cracks appeared in ceilings; all pictures in observer's home were askew; clock stopped. December 20 shock accompanied by strong roaring sound.

Athol.—Toilet articles thrown from shelves. (December 24 report.)

Bridgewater.—Plaster cracked; pictures fell; vases and small objects overturned. Slight damage.

Chicopee.—Water main reported ruptured on December 24.

Clinton.—Plaster and windows cracked. Slight damage.

East Boston district.—Windows were broken in one large plant. Rocking chairs set in motion.

Lynn.—Walls and plaster cracked; furnishings moved.

Newburyport.—Hanging objects swung; trees and bushes shaken moderately. (December 24 report.)

North Adams.—Some windows broken; clocks stopped. Many residents awakened.

Salem.—Statuary toppled from shelf on December 24.

Shelburne Falls.—Knickknacks and pictures fell; vases overturned. Trees and bushes shaken.

INTENSITY V IN NEW YORK:

Dannemora.—Plaster and window reported cracked; some dishes broken. Alarm clock overturned. (December 24 report.)

INTENSITY V IN RHODE ISLAND:

Newport.—Pictures reported knocked from walls.

INTENSITY IV:

New Hampshire.—Alstead, Antium, Berlin, Bethlehem, Charlestown, Chesterfield, Concord, Dummer, Franklin, Hanover, Keene, Laconia, Littleton, Manchester, Meredith, Mt. Washington Observatory, Nashua, Ossipee, Pembroke, Penacook, Pinkham, Grant, Portsmouth, Somersworth, Spofford, Wolfeboro, and Woodsville.

Maine.—Augusta, Bangor, Bridgton, Camden, Dexter, Eastport, Farmington, Greenville, Jackman, Limerick, Old Town, Paris, Portland, Rangeley, Rockland, Rumford, and Sanford.

Vermont.—Bellows Falls, Bethel, Enosburg, Fairlee, Hartford, Lyndonville, Montpelier, Northfield, Proctor, Randolph, Rochester, St. Albans, St. Johnsburg, Swanton, and White River.

Massachusetts.—Adams, Amherst, Amesbury, Ashfield, Athol, Boston, Brighton, Brockton, Brookline, Cambridge, Clinton, Concord, Dorchester, Fitchburg, Franklin, Gardner, Gloucester, Greenfield, Haverhill, Hyannis, Lowell, Mansfield, Milford, Nantucket, New Bedford, Newburyport, Northfield, Northampton, Norwood, Otis, Palmer, Peabody, Pittsfield, Plymouth, Quincy, Reading, Roxbury,

Salem, Somerville, Southbridge, Spencer, Springfield, Stoughton, Swampscott, Taunton, Ware, Watchman, Wellesley, West Chatham, Weston, Williamstown, Winchendon, Woburn, and Worcester.

New York.—Albany, Amsterdam, Auburn, Buffalo, Cortland, Glen Falls, Gloversville, Hudson, Huntington, Lake George, Plattsburg, Rome, Rouse's Point, and Watertown.

Connecticut.—Danbury, East Haddam, Lakeville, Mansfield, Meriden, New Haven, Putnam, Rockville, and Windsor.

Rhode Island.—Central Falls, Woonsocket, Newport, Pascoag, and Providence.

New Jersey.—Newark, Plainfield, and Salem.

INTENSITY I TO III:

New Hampshire.—Bethlehem, Bristol. Cambridge, Concord. Dublin, Dummer, Durham, Gorham, Hanover, Hillsboro, Hinsdale (south of), Lisbon, Manchester, Mount Washington Observatory, Newport, Portsmouth, Rochester, and West Chesterfield.

Maine.—Bar Harbor, Bridgton, Camden, Eastport, Farmington, Fort Kent, Houlton, Jackman, Arono, Portland, Presque Isle, and Westbrook.

Vermont.—Barre, Burlington, Craftsbury, Enosburg, Northfield, Hartford, Rochester. and Rutland.

Massachusetts.—Adams, Amherst, Barre, Boston, Brockton, Cambridge, Concord, Edgartown, Hyannis, Middleboro, Middleton, Millbury, Monson, Nantucket, Newton, Highlands, North Adams, Otis, Plymouth, South Barre, Taunton, Waltham, Weston, Worcester, and Woronoco.

New York.—Albany, Amsterdam, Auburn, Ballston Spa, Buffalo, Canton, Catskill, Glen Falls, Haverstraw, Hudson, Hudson Falls, Kenmore, Kingston, Malone, Massena, Mechanicville, Monticello, Nassau, Newburgh. New York, Norwich, Ogdensburg, Oneonta, Oswego, Port Jervis, Rochester, St. George, Schenectady, Suffern, Syosset, Syracuse, Tupper Lake, Utica, Watertown, and Whitehall.

Connecticut.—Hartford, Mansfield, Plainfield, Rockville, Stafford Springs, and Torrington.

Rhode Island.—East Providence, Kingston, New Shoreham, Providence, and Wakefield.

Pennsylvania.—Allentown, Ardmore, Honesdale, Milford, Philadelphia, Stroudsburg, and Tunkhannock.

New Jersey.—Asbury Park, Hawthorne, Little Falls, Newark, and Pompton Lakes.

North Carolina.—Shelby.

Not felt in New Hampshire at Hinsdale.

Not felt in Maine at Caribou and Houlton.

Not felt in Vermont at Rutland.

Not felt in Massachusetts at Dorchester and Lenox.

Not felt in New York at Binghamton, Buffalo, Canadaigua, Cortland, Dansville, Elmira, Fredonia, Fulton, Hornell, Jamestown, New York, Nyack, Olean, Owega, Poughkeepsie, Waverly, and White Plains.

Not felt in Connecticut at Norwalk.

Not felt in Pennsylvania at Allentown, Altoona, Bradford, Carbondale, Carlisle, Erie, Franklin, Gettysburg, Hazleton, Indiana, Kane, Lancaster, Lanesboro, Laporte, Lebanon, Lock Haven, Meadville, Montrose, Muncy, Norristown, Pittsburgh, Reading, Scranton, Shamokin, Sharon, Somerset, Sunbury, Towanda, Uniontown, Warren, Washington, Wellsboro, Wernersville, West Chester, Wilkes-Barre, Williamsport, and York.

Not felt in New Jersey at Atlantic City, High Bridge, Jersey City, Millville, Phillipsburg, Raritan, Red Bank, South Bend, Tom River, Trenton, and Whiting.

Not felt in other states at Cape Charles. Charlottesville. Harrisonburg, Richmond, Roanoke, and Winchester in Virginia; Annapolis, Baltimore, Cumberland, and Pocomoke in Maryland; Canton, Columbus, Marietta, Painesville, and Ravenna in Ohio; Weston in West Virginia; and Dover in Delaware.

Not felt in Canada at Montreal and Fredericton in New Brunswick.

December 24: 8:44. Near Lake Ossippee. This aftershock of the preceding earthquake was described by many as stronger than the first heavy shock at 2:27 on December 20. All of the descriptive material concerning it has been incorporated in the description of the earlier shock due to confusion in the reports received. The map on page 10, based on data processed at the Weston College Seismological Station, was developed by pooling the information for both shocks.

EASTERN REGION

(75TH MERIDIAN OR EASTERN STANDARD TIME)

January 5: 8:45. Summerville, S. C. Sharp shock felt by nearly all residents. Two jolts about a minute apart.

March 25: 22:28. Moderate shock felt at Edinburg, Toms Brook, and Woodstock, Va. Telephone exchange swamped with calls. Slight foreshock at about 21:00; weak aftershock on March 26 at 00:01.

May 28: 15:06. Harrisburg, Pa. Light shock reported felt and recorded on nearby seismographs, according to bulletin of Northeastern Seismological Association.

October 7: 22:20. Summerville, S. C. Slight shock.

October 19: 00:55. Chattanooga and Cleveland, Tenn., and Ringgold, Ga. Moderate shock. Loose objects disturbed. Telephone exchanges swamped with calls.

December 24: 20:50. Asheville, N. C. Very light shock.

December 25: 01:49.* Weak earthquake felt at Honeycutt and Asheville, N. C. Recorded on the seismograph at Cincinnati.

December 26: About 20:00. Tampa, Fla. Slight. Seismic origin very doubtful.

December 27: 4:32 Summerville, S. C. Slight.

CENTRAL REGION

(90TH MERIDIAN OR CENTRAL STANDARD TIME)

January 8: 14:05 (about). Louisville, Ky., and Jeffersonville, Ind. Slight tremor noticed by a few residents.

February 4: 11:33. Cape Girardeau and Commerce, Mo. Slight local tremor, recorded on local seismograph.

February 14: 5:10. Blytheville, Ark. Slight.

May 27: 2:30 (about). Louisville, Ky. Slight tremor felt only by observer.

May 31: 11:00–11:30. Akron, Ohio. Slight tremor felt by few.

May 31: 13:03. Paducah, Ky. Weak. Slight at Cairo, Ill. Recorded on nearby seismographs.

June 15: 20:30. Near Nankin, Ohio. On a farm north of Nankin a series of tremors, thought to be of seismic origin, continued at intervals through several months. The strongest on June 15 at 20:30 awakened an entire family. Other tremors reported on July 28 at 3:30; August 15 at 4:35; and August 18, at 21:30.

November 23: 15:15.* Felt throughout Illinois and neighboring States. Reported from Tiptonville and Memphis, Tenn. VI in epicentral region. Recorded on seismographs. Epicenter 38°13′ north, 90°04′ west, according to Jesuit Seismological Association.

December 2: 10:16 (about). Rodessa, La., IV. Dishes reported shaken from shelves in restaurant. Not felt in nearby towns canvassed for information.

December 24: 20:30. Greenville, Tenn. Light tremor felt by several.

December 25: 0:50. Greenville, Tenn. Moderate shock. Some residents awakened.

December 28: 20:30 (about). Evansville, Ind., and Owensboro, Ky. Very light shock reported by few residents.

WESTERN MOUNTAIN REGION

(105TH MERIDIAN OR MOUNTAIN STANDARD TIME)

NOTE.—Only the more important shocks felt at Boulder Dam, and the more important aftershocks in the Helena, Mont., area are listed. The unabridged records are published in Abstracts of Earthquake Reports for the Pacific Coast and Western Mountain Region. See Seismic Investigations in the Boulder Dam Area in 1940, by T. C. Mead and D. S. Carder, Bulletin of the Seismological Society of America, vol. 31, No. 4, p. 321.

January 18: 3:00 (about). Bozeman, Mont. Light shock of questionable origin reported by a few residents. Not recorded on Bozeman seismograph.

February 28: 21:47. Logan, Utah. Light shock felt by many in Logan and adjacent towns according to the press. Lightly suspended objects swung.

March 10: 11:02.* Pahranagat Valley, Nev. A moderately strong shock, felt by nearly everyone in Alamo as a sudden jolt, ushered in a series of lesser aftershocks of which 25 were recorded on the seismograph at Boulder City. The

records indicated epicentral distances of 80 to 85 miles and that, combined with other evidence, pointed to epicenters within a few miles of Alamo.

At Alamo the shock on the 10th rattled windows, doors, and dishes. Elsewhere a few clocks were stopped and dishes rattled. At Crystal Springs, 15 miles north of Alamo, it was felt as a gentle tremor. On April 7 a few persons at Hiko, 20 miles north of Alamo, felt a shock, and at Crystal Springs an observer noticed a low rumble to the south. At Alamo all the felt after-shocks were described as more or less sudden jolts.

March 28: 12:55. Pocatello, Idaho. Press reports light shock felt.

April 8: 10:00. Aspen, Colo. Light shock felt by several.

April 29: 12:23. Pleasant Valley, Mont. Light shock felt by several.

April: Pahranagat Valley earthquakes. See March 10.

May 16: 22:10. Grants, N. Mex. (25 miles south and southwest of). Light shock felt.

May 18: 18:00. Las Vegas, Nev. Light shock felt by several. Hanging objects swung.

May 19: 11:00. Wellton, Ariz. Small objects overturned; trees and bushes shaken.

May 21: 22:20 and 22:50 (about). Melrose, Mont. C. F. Seager and J. M. Conrow, geologists, report: "The Melrose earthquake was felt as two distinct tremors in that area included within an elliptical line running roughly through points 2 to 3 miles west of Melrose, 3 to 4 miles north of Melrose, the mining camp of Rochester some 8½ miles east of Melrose, and the foot of the southern slope of McCarthy Mountain." First shock felt as sharp thump; second was of oscillatory nature accompanied by faint rumbling noise. Felt by all residents who were awake. Dishes and windowpanes rattled.

May 24: 4:50, 5:10, 5:25, 8:55. Yellowstone Park, Wyo. Moderate shocks felt by nearly all in the Old Faithful area.

June 5: 22:42. Dome, Ariz. Two sharp jolts felt by all.

August 19: 0:09. Helena, Mont. Intensity IV.

October 12: Alamo, Nev. Light shock felt by many. Few residents awakened. Date and time doubtful.

October 16: 6:25. Flagstaff, Ariz. Many awakened. Windows and doors rattled.

October 22: 16:00. Jackson Hole, Wyo. Light shock. See note by B. T. Gale in Bulletin of the Seismological Society of America, Vol. 30, No. 1, page 85.

November 1: 23:00. Jackson Hole, Wyo. Light shock in Jackson. Strongest about 1 mile southwest.

December 23: 14:50. Helena, Mont. Felt in Montana over an area of about 7,000 square miles. At Helena the intensity was close to VI and minor damage was reported. The questionnaire coverage was supervised by Dr. Francis A. Thomson, president of the Montana School of Mines, and collaborator in seismology for the Coast and Geodetic Survey in Montana. A strong motion accelerograph record of the earthquake was obtained at Helena.

In the following compilation all places are in Montana unless otherwise stated.

In Helena one resident reported a wall cracked, and a few buildings showed cracked plaster. One resident reported broken plumbing. Many stores reported canned goods thrown from shelves, and some pictures were knocked off walls and from loose tables. Many clocks stopped. There was visible swaying of buildings. The shock was accompanied by a moderately loud rumbling sound. In East Helena windows were reported cracked.

Rocks were reported to have rolled from cliffs in Scratch Gravel Hills about 6 miles north of Helena. The flow of water into the Hale Reservoir from its source in the mountains of Oro Finch Gulch, south of Helena, increased 100,000 gallons per day, according to city officials.

At Butte chandeliers on the upper floors of high buildings swung. Small objects were moved at Poney; pictures fell and clocks stopped at Wickes. At Winston trees and bushes were shaken.

The earthquake was also reported felt at Canyon Creek, Cardwell, Clancey, Craig, Great Falls, Jefferson City, Marysville, Missoula, Radersburg, and White Sulphur Springs. Nearly 100 other places canvassed reported that the shock was not felt.

December 25: 20:30. Helmville, Mont. Moderate shock.

CALIFORNIA AND WESTERN NEVADA

[120TH MERIDIAN OR PACIFIC STANDARD TIME]

NOTE.—All places are in California unless otherwise stated. "B" written after the location of an epicenter means that the location was reported by the Seismological Station of the University of California at Berkeley; Perry Byerly in charge. The Berkeley data, however, are not available as this publication goes to press. "P" refers likewise to the Seismological Laboratory of the California Institute of Technology and the Carnegie Institution of Washington at Pasadena. More details will be found in Abstracts of Earthquake Reports for the Pacific Coast and Western Mountain Region. The Bulletin of the Seismological Society of America is referred to as "SSA Bulletin."

When more than 1 degree of intensity is reported from a town, the town is listed under the highest intensity reported.

January 10: 19:40.* Epicenter 33°47′ north, 118°08′ west, near Long Beach. One small foreshock and nine small aftershocks up to January 11, P. Light tremors and rumbling sounds heard at Long Beach. Hanging objects swung at Seal Beach. Also felt at Maywood and Torrance. Not felt at Riverside.

January 12: 23:49.* Epicenter 33°47′ north, 118°08′ west, near Long Beach, P. At Huntington Beach hundreds fled to street. Knickknacks fell. At Long Beach faint rumbling sounds were heard and doorbells rang. In Los Angeles hanging objects swayed and some persons reported rumbling sounds. At Lakewood Village a very hard jolt was reported. Trees and bushes were shaken at Compton. Also felt at Gardena, Garden Grove, Maywood, and Norwalk. Not felt at Riverside.

January 13: 19:00. Earthquake reported by residents of the Carneros district south of Napa. Cracks were reported in papered walls.

January 15: 22:05. Second earthquake within 24 hours felt in east San Francisco Bay region. Like an explosion.

January 17: 21:58.* Epicenter 33°46′ north, 118°06′ west, near Long Beach, P. Felt by a few at Seal Beach.

January 22: 21:11. Slight shock felt near San Jose.

January 26: 6:28.* Epicenter 35°37′ north, 118°12′ west, Sierra Nevada, vicinity of Weldon, P. At Onyx hanging objects swung and many persons were awakened. Felt also at Bodfish.

January 28: 12:34.* Epicenter about 33°38′ north, 118°12′ west, San Pedro Bay, P. Felt at Torrance.

January 28: 14:16. A series of small earth shocks reported from San Diego. Not recorded instrumentally.

February 4: 11:23. Lake Tahoe region. Hanging objects swung at Clio and Floriston. Also felt at Boca, Soda Springs, Tahoe, and Truckee. Not felt at Loyalton, Norden, Sierraville, Sparks, Nev., and Verdi, Nev.

February 4: 18:15. San Francisco. Slight shock reported from several parts of city.

February 8: 00:08. Northern California. An earthquake was felt over an area of approximately 28,000 square miles in the vicinity of Reno, Nev., as shown on map. Maximum intensity between VI and VII in several widely separated towns. Rumbling noises were reported from many points. Damage was confined to a few twisted and cracked chimneys, broken windows, broken dishes and vases. Several instances of road slides and dislodged rocks were reported.

INTENSITY VI:

Almanor.—Some small objects overturned.

Bangor.—Chimneys cracked. Damage slight.

Butte City.—Chimneys cracked, and heavy furniture moved.

Chico, 4 miles southeast of.—People downtown rushed into streets. Some chimneys and large windows broken. Heavy furniture moved. Trees and bushes shaken slightly.

Gridley.—Vases, small objects, and furniture reported overturned.

La Porte.—Communications disrupted in some sections of town.

Nevada City.—Vases and small objects overturned.

Paradise.—Chimneys twisted.

Tehama.—One chimney cracked. Trees and bushes shaken slightly.

Vinton.—Some plaster walls reported cracked. Liquids spilled from indoor containers. Trees and bushes shaken strongly.

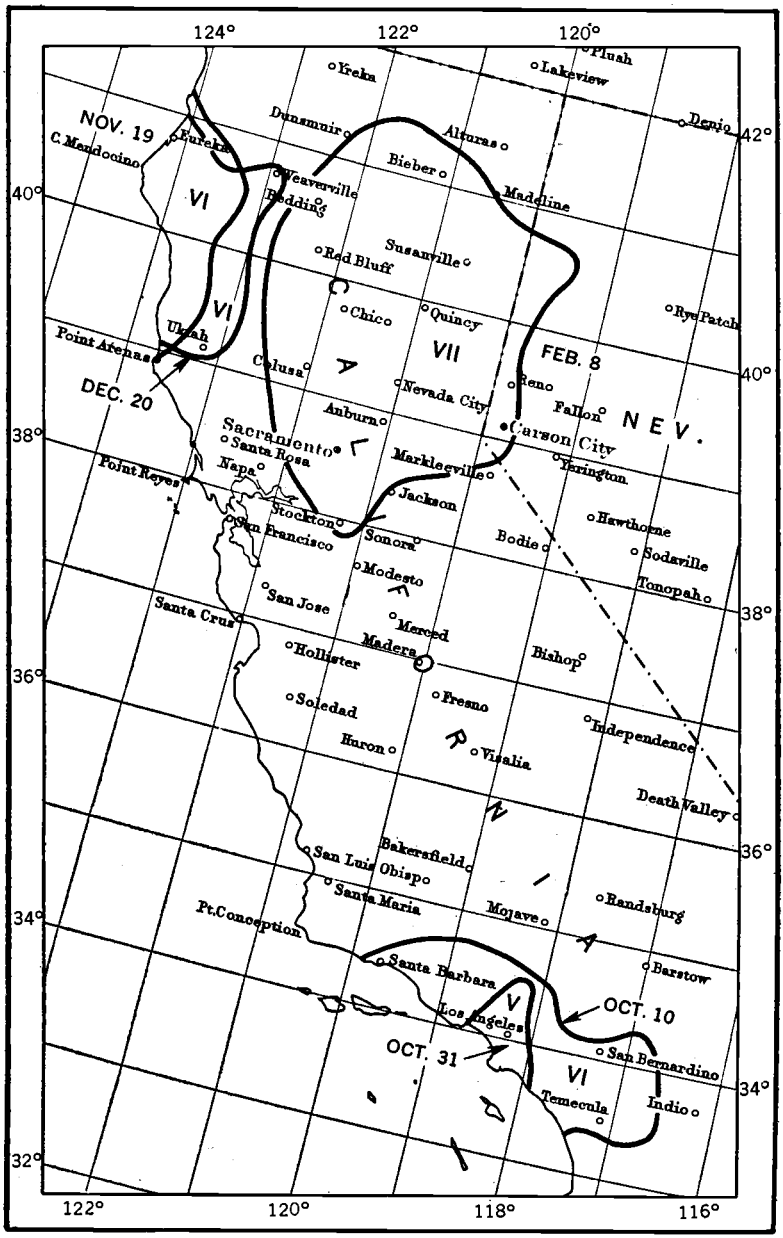

FIGURE 5.—Areas affected by the more important earthquakes of California and western Nevada in 1940 excluding the destructive Imperial Valley earthquake.

INTENSITY V:

Baxter.—Decided creaking of walls. All awakened.

Beckwourth.—Small objects moved. Trees and bushes shaken moderately.

Belden.—Small objects and furnishings moved. Many awakened.

Blairsden, Mohawk Ranger Station.—Pictures moved. Frames creaked. Trees and bushes shaken moderately.

Caribou (powerhouse).—Rocks rolled onto road from hillside. Loud, heavy roar accompanied shock. Felt strongly in powerhouse on bedrock.

Chester.—Building swayed in east-west direction. One pendulum clock stopped, and another started. Thunderous, roaring sounds heard at time of shock.

Corning.—Plaster cracked. Curtains swung furiously.

Crescent Mills.—Plaster cracked but damage slight.

De Sabla.—One bed on castors moved back and forth. In one house an attic door was knocked over.

Dutch Flat.—Plaster cracked but damage slight.

Feather River Canyon and other points.—Boulder falling on track near Keddie delayed train. Telegraph line was temporarily out of commission because of damage by falling rock.

Forest Ranch.—Walls creaked. Everyone awakened.

Graniteville.—Small objects moved. Many residents awakened.

Greenville.—Plaster cracked. No damage.

Grimes.—Clocks stopped. Small objects and furnishings moved.

Meadow Valley.—Small objects moved. Everyone awakened.

Milford.—Unsupported books on table knocked over. Many residents awakened.

Millville.—Small furnishings moved slightly.

Mineral.—Everyone awakened. Frightened all.

Oroville.—Moved small objects and furnishings. Windows shaken vigorously.

Portola.—Small objects disturbed. Hanging objects swung. Visible swaying of buildings and trees. Railroad telephone line service interrupted between Portola and Oroville.

Quincy.—Small objects moved. Clocks stopped. Nearly everyone awakened.

Seneca.—Small objects and furnishings moved. All residents awakened.

Sheridan.—Hanging objects swung. Few residents awakened.

Storrie.—Plaster cracked. Small objects overturned. All residents awakened.

Stirling City.—Windows, doors, and dishes rattled. Stopped pendulum clocks. One chimney cracked. Many residents awakened.

Weimer.—Vases overturned. Hanging objects swung. Liquid spilled from containers.

Westwood.—Visible swaying of trees and lighting fixtures. Beds and pictures displaced. Roaring subterranean sounds heard before shock.

Wheatland.—Small objects and furnishings moved. Trees and bushes shaken slightly.

Williams.—Small objects and furnishings moved. No one awakened.

Woodland.—Small objects moved.

Yolo.—Small objects and furnishings moved.

INTENSITY IV:

Adin, Allegheny, Applegate, Arbuckle, Berry Creek, Big Bend, Biggs, Blue Canon, Boca, Browns Valley, Camptonville, Chicago Park, Cisco, Clipper Mills, Colfax, Coloma, Colusa, Cottonwood, Delevan, Downieville, Doyle, Dunnigan, Durham, Feather Falls, Flanigan, Nev., Floriston, Forbestown, Forest, Forestlill, Georgetown, Gerlach, Nev., Glenn, Hamilton City, Hammonton, Hazel Creek, Honcut, Hood, Inwood, Ione, Isaiah, Isleton, Johnsville, Keddie, La Moine, Las Plumas, Live Oak, Lodi, Loyalton, Loomis, Marysville, Maxwell, McCloud, Meridian, Nelson, North Bloomfield, Nicolaus, North San Juan, Oregon House, Palermo, Paxton, Penryn, Perkins, Pike, Pittville, Placerville, Pleasant Grove, Princeton, Ravendale, Red Bluff, Redding, Reno, Nev., Rescue, Rich Bar, Richvale, Rio Oso, Robbins, Rocklin, Ryde, Sacramento, Sattley, Sierraville, Sites, Sloat, Standish, Steamboat, Nev., Strawberry Valley, Stonyford, Spring Garden, Susanville, Sutter, Taylorsville, Thornton, Truckee, Tudor, Veronas, Vina, Viola, Washington, Willows, Wolf, Woodleaf, Yankee Jims, Yuba City, Zamora.

INTENSITY I TO III:

Alturas, Antelope, Artois, Byron, Calpine, Capay, Carson City, Nev., Castella, Clipper Gap, Dobbins, Emigrant Gap, Etna, Florin, Flourney, Folsom, Garden Valley, Grass Valley, Lodoga, Los Molinos, Minden, Nev., Montgomery Creek,

New Castle, Orland, Pacific, Paynes Creek, Platina, Rio Linda, Roseville, Sierra City, Soda Springs, Sparks, Nev., Stirling City (6 miles north of), Stockton, Whitmore, and Wilton.

Not felt at Ankum, Bowman, Brooks, Callahan, Camino, Canby, Carrville, Cassel, Cayton, Clay, Cool, Covelo, Cana, Davis, Diamond Spring, Dixon, El Dorado, Elk Grove, Elmirs, Fairfield, Fern, French Corral, French Gulch, Fruto, Galt, Greenwood, Hat Creek, Hayfork, Holt, Igo, Ingot, Kennett, Knob Lake Mountain, Lathrop, Lincoln, Lower Lake, Lucerne, Middletown, Milton, Mills, Mount Shasta, Oakley, Peters, Pilot Hill, Plymouth, Potter Valley, Reiff, Ripon, Rio Vista, Rough and Ready, Ramsey, Shasta, Shingle, Sloughhouse, Stacy, Termo, Tracy, Upper Lake, Victor, Vista, Wallace, Weaverville, Weed, White House, Wilbur Springs, Winters; also in Nevada at Dayton, Fernley, Genoa, Nixon, Pyramid, Sutcliffe, Verdi, and Weeks.

February 8: 8:56.* Epicenter 33°42′ north, 118°04′ west, off Bolsa Chica, P. Windows rattled and lighting fixtures swayed in Long Beach. Slight at Seal Beach.

February 11: 11:24.* Epicenter 33°59′ north, 118°18′ west, southwest Los Angeles, P. Trees and bushes shaken at Mar Vista. At Redondo Beach plaster was reported cracked and small objects moved. Also felt at Hermosa, La Fresa substation near Gardena, Los Angeles, Manhattan Beach, and Venice. Not felt at Hollister, parts of Los Angeles, and Vista.

February 13: 15:53. Coast of northern California. Strongest at Branscomb where chimneys were reported cracked, vases overturned, and small objects and furnishing disturbed. Fairly strong at Elk, Ferndale, Scotia, Ukia, and Westport. Also felt at Benbow, Caspar, Comptche, Ettersburg, Manchester, Nashmead, Potter Valley, Spyrock, and Upper Mattole.

February 19: 4:06.* Epicenter 33°42′ north, 117°26′ west, Elsinore fault near Alberhill, P. San Bernardino Valley. Strongest at Beaumont, Cabazon, Lake Arrowhead, Mentone, Moreno, and Victorville. Subterranean sounds were heard at a number of places, and hanging objects swung. Also felt at Green Valley Lake, Banning, East Highlands, Elsinore, Hemet, Keen Camp, Lucerne Valley, Norco, Riverside, Romoland, San Bernardino, San Juan Capistrano, and Seven Oaks.

February 22: 2:38.* Epicenter 33°45′ north, 117°20′ west, the Gavilan district, P. Felt slightly at Moreno and Riverside.

February 24: 1:38.* Epicenter about 37°30′ north, 118°32′ west, Sierra Nevada, north of Bishop, P. Rocks dislodged in Owens River Gorge near Bishop. Trees and bushes strongly shaken. Felt by many.

February 24: 1:48.* Epicenter about 37°30′ north, 118°32′ west, Sierra Nevada, north of Bishop, P. Not quite as strong as the preceding shock. Furniture shaken at one point in Yosemite National Park.

February 25: 13:24.* Epicenter 33°40′ north, 117°33′ west, northwest of Elsinore, P. Reported felt in Silverado Canyon.

February 28: 9:28.* Epicenter 33°08′ north, 116°05′ west, San Jacinto fault, P. Small objects and furnishings moved at Westmoreland. Also felt at Descanso Ranger Station, Hipass, Riverside, San Diego, Santa Ysable, and Twenty-nine Palms.

March 2: 5:27. Monterey Bay. Strongest at Hollister and Morgan Hill. Many residents awakened. Also felt at Ben Lomond, Madrone, Pacific Grove, Salinas, San Francisco, San Martin, and Watsonville.

March 5: 13:56. Coast of northern California. Slight shock felt at Arcata, Fields Landing, and Trinidad.

March 10: 21:23. Northern central California. Strongest at Dunsmuir, Kennett, Mt. Shasta, and Redding. Many residents were awakened. Small objects were disturbed. In one case water was spilled from indoor container. Also felt at Bayles, Big Bend, Carrville, Castella, Clayton, Hazel Creek, and McCloud.

March 18: 16:16. Monterey Bay region. Slight shock reported from Hollister and Salinas.

April 8: 5:35.* Epicenter 37°35′ north, 118°25′ west, Mono County, P. Owens Valley. Objects were disturbed at Horse Shoe Bend, Laws, and Owens River Gorge near Bishop. Also felt at Big Creek, Bishop, Delpiedra, Dunlap, and Woodlake.

April 18: 2:30. Slight shock felt at San Jose, Santa Clara, Saratoga, Morgan Hill, and Madrone. Recorded on seismograph at the University of Santa Clara. Trees and bushes were shaken slightly in Madrone.

April 18: 10:35.* Epicenter 34°04′ north, 117°23′ west, P. San Bernardino Valley. Strongest at Riverside where windows rattled and some residents were frightened. It was reported particularly strong at the Patton State Hospital. Felt also at Los Angeles, San Bernardino, Beaumont, Lake Arrowhead, and Loma Linda. Three miles east of Riverside a rumbling noise preceded the shock.

April 18: 13:22.* Epicenter about 33.2° north, 115.5° west, P. Imperial Valley. Felt at Calipatria.

April 24: 5:17.* Epicenter 33°47′ north, 118°23′ west, San Pedro Hills, P. Felt slightly in Los Angeles, Hawthorne, Santa Monica, Venice, Redondo Beach, Hermosa Beach, Huntington Park, La Fresa substation, Lomita, and Torrance. Not felt at Maywood.

April 28: 22:58.* Epicenter about 32° north, 115° west, P. Imperial Valley. Felt at El Centro.

April 28: 23:38.* Epicenter about 32° north, 115° west, P. Imperial Valley. Reported felt at Calexico and El Centro.

April 29: 00:48.* Epicenter about 32°44′ north, 115°27′ west, P. Felt at El Centro.

May 10: 6:47.* Epicenter about 33°43′ north, 116°18′ west, near Indio, P. Felt at Thermal.

May 17: 21:04.* Epicenter 34°03′ north, 116°17′ west, Little San Bernardino Mountains, P. Felt generally up to 150 km. from epicenter. Pasadena reports about 50 aftershocks recorded during the following 8 hours. Maximum intensity between V and VI. At Banning large buildings swayed and many persons left theater. At Keen Camp there was slight damage to store fireplace and moving of small objects. Clocks stopped at Garnet, Grossmont, and Thermal. At Garnet trees and bushes were shaken strongly. Small objects were moved at Carlsbad, Elsinore, Moreno, Oceanside, and Palm Springs. Trees and bushes were shaken or hanging objects swayed at Aguanga, Amboy, Beaumont, Bell, Blythe, Cabazon, Carlsbad, Coachella, Crucero, Huntington Beach, Indio, Keen Camp, Long Beach, Lucerne Valley, Maywood, Mentone, Perris, San Clemente, San Diego, San Gorgonio Pass, San Marcos, Santa Ysabel, Spring Valley, Thermal, Twentynine Palms, and Warner Springs. Felt also at Anza, Big Bear Ranger Station (near Minnelusa), Big Bear City, Bonsall, Cajon, Compton, Daggett, Del Mar, East Los Angeles, Fullerton, Idyllwild, Inglewood, Lake Arrowhead, Ludlow, Mecca, Newport Beach, Ontario; Pala, Palo Verde, Pasadena, Redlands, Riverside, San Juan Capistrano, San Pedro, Santa Ana, Seven Oaks, Thousand Palms, Trona, Whittier, Wildomar, and Winchester.

May 18: 1:15.* Epicenter about 34°36′ north, 118°54′ west, north of Fillmore, P. Felt at Fillmore, Moorpark, and Santa Paula.

May 18: 1:26.* Aftershock of preceding earthquake felt at Fillmore.

May 18: 20:36:40.* The Imperial Valley earthquake. Maximum intensity X. Epicenter 32°44′ north, 115°27′ west, according to Pasadena. This is about 5 miles northeast of Calexico and 7 miles southeast of El Centro. It was felt over an area of about 60,000 square miles in the United States. Property damage amounted to 5 or 6 million dollars. Eight persons were killed, 20 were seriously injured, and there were many minor injuries. The outstanding feature of the disturbance was the appearance of a 40-mile fault with a maximum horizontal displacement of 14 feet 10 inches near the international boundary.

Detailed descriptions of the earthquake will be found in the following articles, each of which is amply illustrated:

1. Imperial Valley Earthquakes of 1940, by Franklin P. Ulrich. Bulletin of the Seismological Society of America, Vol. 31, No. 1, January 1941.

2. The Imperial Valley Earthquake, by F. P. Ulrich, C. N. Dirlam, and H. Colling. Building Standards Monthly, Vol. 9, No. 6, June 1940.

3. The Imperial Valley Earthquake and its Effect on Gas Service, by Charles Grunsky. Report of Technical Section of Pacific Coast Gas Association, 1940 Convention.

4. The Imperial Valley Earthquake, by N. H. Heck. Scientific Monthly, July 1940.

The waves emanating from the earthquake caused marked changes (3 seconds) in the levels attached to the zenith telescope of the Gaithersburg (Md.) Latitude Observatory forcing the observer to suspend operation over a 15-minute period. The magnetographs at Tucson, Ariz., Honolulu, T. H., and Cheltenham, Md. recorded the disturbance.

Fault.—Horizontal slipping on the northwest end of the fault began in the region about 1 mile northwest of Keystone (midway between Brawley and Im-

perial) and continued in a southeasterly direction into Mexico. The greatest slipping apparently occurred along the All-American Canal at a point about two-thirds of a mile east of the Alamo River crossing where the displacement was 14 feet 10 inches. The fault continued southeastward into Mexico through Cocopah on the Inter-California Railway where the track was shifted 7 feet. At one point near Kilometer 12 on the Solfatara Canal the slip was reported between 10 and 12 feet. The fault continues for an indefinite distance into the delta of the Colorado River.

Railroads.—The fault crossed the railroad at three points. At Grape the track was moved out of line, and just north of Grape about 1,000 feet of track settled. At Meloland the track was displaced about 18 inches, and at Cocopah there was a shift on 7 feet. Settling of the track occurred at many places, especially where the railroad was close to a river. The Mexican Government Railroad southeast of Pascualitos was damaged and one bridge was seriously damaged. Depots and steel tanks suffered only minor damage.

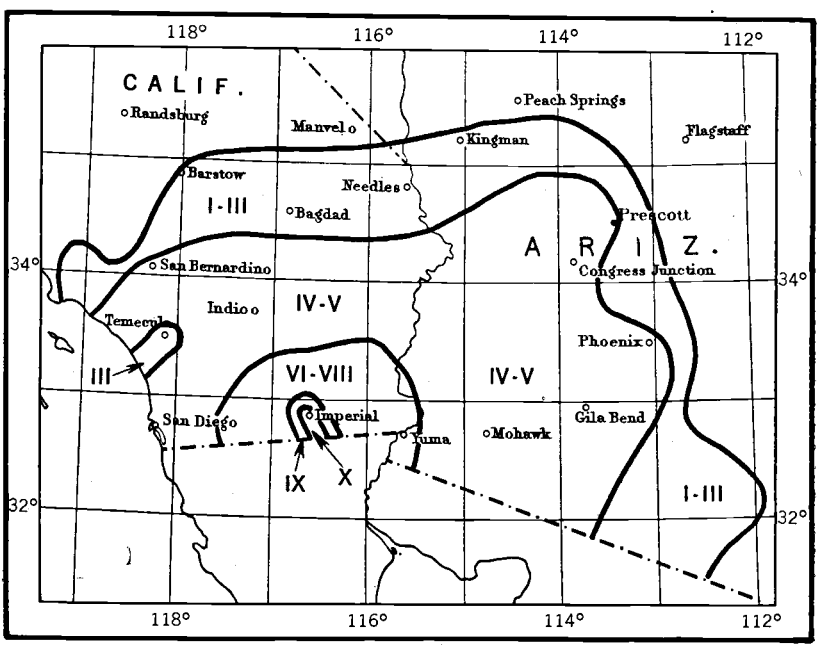

FIGURE 6.—Isoseismals of the Imperial Valley earthquake of May 18, 1940.

Canals.—Damage to irrigation canals was widespread and serious. Perhaps the greatest damage was in the region just west and south of Holtville to the border. Breaks occured over almost the entire length of the Ash Canal from Holtville to the border. About 7 miles of the Holtville Main Drain was damaged. In Mexico both banks of the Central and the Alamo Canals were broken over a length of 25 miles. At least one bank of the Solfatara Canal was destroyed over a length of 13 miles, also at least 4 miles of banks of the East Side High Line Canal. In all, approximately 60 miles of canal banks were damaged or destroyed. The New River Flume carrying the West Side Main Canal of the New River in Mexico was destroyed. An indefinite amount of damage to crops resulted from the shortage of water.

General damage.—On U. S. Highway 99 the bridge across New River shifted on its piling and settled so that traffic had to be stopped. The eastern approach was damaged by buckling. The highway north of Brawley and across the lowlands near New River was cracked and settled noticeably. About 7 miles east of Calexico, just west of the Alamo River, there was a slip of 10 to 12 feet in the roadway. The western part of the road apparently slipped northwestward as the pavement was buckled for several miles west of the fault.

Only short interruptions occurred in power line service at Calexico, Brawley, and Calipatria. In some other places the power was shut off as a safety measure. Except for very short breaks, telephone and telegraph service was maintained with points outside the disturbed area even though there was considerable damage to the lines. At Brawley gas service was discontinued but damage to mains was found to be practically negligible. Elevated water tanks at Holtville and Imperial collapsed.

Ground water.—In December 1937, a geyser appeared along U. S. Highway 395 about 40 miles north of Bishop. It threw steam and water continuously to a height of 100 feet until the day following the main shock, when it began intermittently to decrease, stopping completely after a slight earthquake at 2 a. m. on May 26.

Craterlets appeared in the bed of New River about a mile west of Brawley. The mud pots at Salton Sea were reported to have shown increased activity and a marked increase in the temperature of the water ejected.

Aftershocks.—Between 8:37 and 10:34 p. m. about 10 aftershocks were felt. The shock at 9:50 was reported as being responsible for the major damage at Brawley. On the 23d a destructive shock was again reported from Brawley. From the 19th to the end of the month about 20 aftershocks were reported from various points in the valley.

Strong-motion seismograph records.—The accelerograph operated by the Coast and Geodetic Survey at El Centro, with the cooperation of the Southern Sierra Power Co., recorded the main shock at 8:37 p. m. and a number of aftershocks. Weak records were also obtained in San Diego, Los Angeles, Hollywood, and San Bernardino. The results obtained are described in detail in the section entitled "Strong-Motion Seismograph Results."

In the following summary of earthquake effects in the various towns it is impossible to distinguish between the effects of the main shock and those due to aftershocks. This is especially so in the case of Brawley. The net results are therefore given for the entire series.

Intensity IX:

Imperial.—About 80 percent of the buildings were damaged to some degree. In the business district almost all buildings were damaged, many so seriously that they were condemned. Older residences suffered appreciable damage; new ones, very little. The city's 100,000 gallon water tank collapsed. Apparently there was no great damage to the water mains and the sewage system. The city hall was unroofed and one wall was knocked out. Four persons were killed in the total collapse of a grocery store.

Brawley.—First shock VII, aftershock IX. In the business district all buildings were damaged, and it was estimated that 50 percent of them had to be condemned. All stores were closed on Main Street pending a survey of structural damage. Perhaps 25 percent of all residences were damaged. Some of the walls of the city hall, a one-story adobe structure, fell and others were badly cracked. There were a large number of breaks in the water mains, and water was shut off in hundreds of homes because of broken plumbing.

Intensity VII to VIII:

Holtville.—In the business section only a few walls were thrown down. In the residential section damage was mostly to chimneys which were thrown down. The city water tank collapsed.

El Centro.—A number of old brick buildings were so badly damaged that they were condemned. Damage was chiefly to old brick construction, to walls that were not reinforced or tied to the structures, and to balconies projecting over sidewalks. There were a few breaks in the water mains, but practically no damage to the water plant nor to sewer lines.

Intensity VII:

Calexico.—One building was damaged appreciably and a number of others showed cracks, fallen plaster, and some broken columns. Many windows were broken; chimneys were twisted and cracked. Dishes were broken; stock fell from store shelves. Rumbling sounds were heard with the arrival of the earthquake.

Heber.—Some chimneys fell; others were twisted. Walls and windows were cracked, but the damage was slight. Liquids were spilled from outdoor containers.

Mexicali.—Direct damage was not large, but a short circuit caused by the

earthquake set fire to a large hotel which was destroyed. Clefts in sand dunes below Mexicali were clearly visible from the air along the fault.

San Luis, Ariz.—Twisting and fall of chimneys reported. Dishes, windows, and furniture were broken.

Yuma, Ariz.—Some damage to poorly constructed buildings. Visible swaying of buildings and trees. Twisting and fall of columns and monuments. Dishes broken. Panic in theaters. Bumping and rumbling sounds heard. In the lower Yuma Valley cracks opened up in fields and water and sand gushed up; wells spouted 15 feet into the air.

Intensity VI:

Calipatria.—Plaster cracked and dishes broken. Water spilled from tanks. Trees and bushes shaken moderately.

Hipass.—Vases overturned.

Jacumba.—Small objects overturned. Rocks dislocated.

Ogilby.—Small objects overturned.

Palo Verde.—Plaster fell; windows and dishes broken; small objects overturned; damage slight. Concrete wall reported cracked.

Pine Valley.—Vases, small objects, and furniture reported overturned.

Plaster City.—Plaster cracked; dishes broken. Damage slight.

Petrero.—Small objects overturned.

Ranchero Santa Fe.—Small objects overturned.

Seeley.—Plaster cracked; small objects overturned; pictures fell.

Liberty, Ariz.—Small objects overturned.

Tonopah, Ariz.—One chimney cracked.

Wellton, Ariz.—Plaster cracked; dishes broken; water spilled from indoor and outdoor containers.

Intensity V:

Alpine.—Small objects moved.

Banning.—Visible swaying of buildings and trees.

Barret Dam.—Visible swaying of buildings and trees. Beds and pictures swayed.

Beaumont.—Objects disturbed; hanging objects swung.

Blythe.—Hanging objects and trees swayed.

Bonita.—Plaster reported cracked. Hanging objects swung.

Borego.—Slight damage to irrigation pipe line. Trees and bushes shaken.

Cabazon.—Hanging objects, trees, and bushes disturbed. All residents awakened.

Cathedral City.—Hanging objects disturbed. Slight damage to concrete.

Descanso.—Small objects moved. Hanging objects, trees, and bushes disturbed.

Jamul.—Hanging objects swung.

Laguna Beach.—Hanging objects, trees, and bushes disturbed.

Mesa Grande.—Water spilled from containers; clocks stopped; small objects moved.

Moreno Dam.—All awakened.

National City.—Hanging objects swung. Clocks stopped.

Ocean Beach.—Hanging objects swung.

Ramona.—Small objects and furnishings moved.

San Diego.—Hanging objects, trees, and bushes disturbed. Some clocks stopped.

Sante.—Small objects moved.

Sunnyside.—Hanging objects, trees, and bushes disturbed.

Tecate.—Plaster reported cracked. Trees and bushes shaken.

Valley Center.—Plaster reported cracked. No damage.

Vidal.—Pictures fell. Hanging objects, trees, and bushes shaken.

Warner Springs.—Buildings, pictures, and trees swayed. Objects disturbed.

Intensity V in Arizona:

Ajo.—Hanging objects swung.

Aztec.—Clocks stopped. Furnishings moved.

Dome.—Hanging objects, trees, and bushes disturbed.

Palo Verde.—Plaster reported cracked. Oil and water spilled from containers. Small objects moved.

Phoenix.—Window pane reported broken. Hanging objects swung.

San Simon.—Plaster reported cracked. Water spilled from containers.
Tacna.—Bottles overturned and broken.
Wenden.—Small objects and furnishings moved.

INTENSITY IV:

Aguanga, Avalon, Bellflower, Campo, Chula Vista, Corona, Coronado, Crucero, Cuyamaca Peak Lookout, Del Mar, Earp, Elsinore, El Toro, Encanto, Escondido, Fawnskin, Forest Home, Gardena, Grossmont, Hodges Dam, Huntington Park, Idyllwild, Indio, Julian, La Jolla, Lakeside, La Mesa, Lemon Grove, Leucadia, Mecca, Mentone, Miramar, Mount Laguna, Murrieta, Nestor, Palm City, Parker Dam, Redlands, Rice, Ripley, Riverside, San Bernardino, San Clemente, San Jacinto Mountain, San Juan Capistrano, Santa Ysabel, San Ysidro, Seven Oaks, Spring Valley, Summit, Temecula, Thermal, Vista, Westmorland, and Yucaipa.

INTENSITY IV IN ARIZONA:

Agua Caliente, Arlington, Avondale, Bouse, Congress, Gila Bend, Glendale, Kirkland, Maricopa, Mesa, Mohawk, Parker, Prescott, Quartzsite, Salome, San Miguel, Sentinel, Tempe, Topock, Wickenburg, and Wittman.

INTENSITY I TO III:

Arrowhead Springs, Barstow, Compton, Encinitas, Etiwanda, Fall Brook, Fullerton, Highland, Inglewood, Lucerne Valley, Maywood, Newport Beach, Needles, Pasadena, Romoland, Santa Ana, Twentynine Palms, Valyermo, Westend, and Anza.

INTENSITY I TO III IN ARIZONA:

Aguila, Avondale, Chino Valley, Kingman, Peoria, Seligman, Tucson, Valentine, Wagoner, and Wikieup.

INTENSITY I TO III IN NEVADA:

Las Vegas.

Not felt at Acton, Atolia, Big Bear City, Burbank, Camp Baldy, Cajon, Cima, Death Valley, El Segundo, Essex, Fillmore, Fontana, Glendora, Gorman, Grapevine, Helendale, Ivanpah, Kelso, Keen Camp, La Canada, Lake Arrowhead, Lancaster, Llano, Ludlow, Long Beach, Mojave, Monolith, Monrovia, Mount Wilson, Nipton, Newbury Park, Ontario, Palmdale, Pasadena, Phelan, Pomona, Randsburg, Redondo Beach, Rosamond, Saltdale, San Dignito Dam (Rancho Santa Fe), San Fernando, Santa Monica, Stanton, Saugus, Silverado, Shoshone, Tecopa, Venice, Ventura, and Yosemite National Park.

Not felt in Nevada at Boulder City, Dry Lake, Jean, Las Vegas, Searchlight, and Sloan.

Not felt in Arizona at Ajo, Amando, Ash Fork, Castle Hot Springs, Chloride, Estrella, Florence, Hillside, Laveen, Mammoth, Oracle, Payson, Peach Springs, Pine, Redrock, Rillito, Sacaton, Sedona, Superior, Tonto Basin, Vail, and Winkleman.

Aftershocks.—Many aftershocks were reported from the affected area. At the Pasadena Seismological Laboratory about 50 aftershocks of magnitude 3 and over were recorded in the 8 hours following the main shock. The most outstanding occurred at the following times: May 18 at 10:48, 20:55, 21:04, 21:44, 21:51, 21:52, 21:57, 22:18, 22:33, 22:36, 23:02; May 19 at 0:55, 1:18, 4:09, 5:07, 5:41, 7:31, 7:52, 22:27, 23:06; May 20 at 3:13, 4:42, 6:01, 13:31; May 22 at 2:59, 10:35, 12:56, 16:12, 19:18. At Brawley the greatest damage was inflicted by a destructive aftershock at about 21:50, 1 hour 13 minutes after the main shock. The maximum intensity was IX, but reports are too confusing to distinguish the effects and extent of it from the main shock.

Aftershocks were reported at various times from the following places: Brawley (destructive at 21:15 and 21:40), Banning, Calipatria, Cuyamaca Peak Lookout, Colton, Descanso, El Cajon, El Centro (considerable damage at 21:51), Essex, Fenner, Garnet, Indio, Moreno, Oceanside, Ogilby, Pala, Palm Springs, Perris, San Diego, San Luis Rey, San Marcos, Seeley (slight damage at 10:05), Santa Ysabel, Thousand Palms, Winchester, and Winterhaven (slight damage at 9:15). Aftershocks were also reported from Las Vegas, Nev., and Mobile, Tacna, and Wintersburg, Ariz.

May 18: 21:50. Imperial Valley. Destructive aftershock near Brawley. For details see description of main shock at 20:37.

May 21: 2:05.* San Luis Obispo County. Epicenter 35°17′ north, 120°29′ west, P. Felt strongest at Morro Bay, Cambrai, and San Luis Obispo. At Morro Bay groceries were shaken from shelves, vases overturned, and pictures and some plaster fell. At Cambrai dishes, windows, and some furniture were broken, but damage was slight. At San Luis Obispo one window was broken. Also felt at Cayucgos, Pismo Beach, Avila, Paso Robles, and Atascadero.

May 22: 22:40.* Epicenter about 33°50′ north, 117°24′ west, the Gavilan district, P. Felt at Riverside.

May 23: 3:00. Brawley. Strong aftershock broke dishes and cracked plaster.

May 23: 5:31.* Epicenter about 33°50′ north, 117°24′ west, P. Felt slightly at San Bernardino.

May 23: 9:30 and 10:45. Brawley. Strong aftershock caused some structural damage. Chimneys and plaster were cracked, and vases overturned. Also felt at El Centro.

May 31: 21:26. Riverside County. Slight shock felt at Idyllwild and Thermal.

June 3: 17:15. San Jose. Slight shock felt by eastside residents.

June 4: 2:35.* San Diego County. Epicenter 33°07′ north, 116°25′ west, near Verruga, P. Eighteen aftershocks recorded at Pasadena up to June 15. Felt strongest at Borego, Cuyamaca Peak Lookout, Mt. Laguna, Potrero, San Diego, and Santa Ysabel. At most of these places hanging objects swung. Water was spilled from containers at the Lookout, and overturning of small objects was reported from Potrero. Felt also at Alpine, Descanso, El Centro, Encanto, Etiwanda, Hemet, Hodges Dam, Jacumba, Julian, Jamul, Lakeside, Moreno Dam, Nuevo, Riverside, Romoland, Santee, Spring Valley, and Thermal.

June 4: 5:05. Imperial Valley. Canal bank damaged near Brawley. Also felt at Calipatria.

June 5: 0:27.* Riverside County. Epicenter 33°50′ north, 117°24′ west. Near Riverside, P. Felt at Fontana, Riverside, and San Bernardino.

June 5: 18:27.* Epicenter 33°57′ north, 117°33′ west, near Riverside, P. Felt at Etiwanda and Fontana.

June 6: 15:21.* San Diego County. Epicenter 33°16′ north, 116°24′ west, near Clark Lake, P. Felt at Borego, Cuyamaca Peak Lookout, and Santa Ysabel. Hanging objects swung at Santa Ysabel.

June 7: 16:30.* Los Angeles region. Epicenter 33°59′ north, 118°18′ west, southwest Los Angeles, P. At Inglewood residents reported dishes broken, lamps overturned, and pictures knocked from walls. Damage slight. Also felt at Hawthorne and Maywood.

June 16: 1:25.* Off Point Arguello. Epicenter about 34°33′ north, 120°47′ west, P. Rumbling noise heard at Guadalupe. Also felt at Los Alamos.

June 23: 21:30.* San Pedro Channel. Epicenter about 33°33′ north, 118°21′ west, P. Felt slightly at San Pedro and Seal Beach.

June 25: 21:00. Imperial Valley. At Brawley an aftershock caused part of theater audience to hasten into the street. Felt very slightly at Imperial and El Centro.

June 25: 21:21. Humboldt County. Light shock felt at Ferndale, Scotia, Fortuna, and Dyerville.

June 27: 16:46.* Santa Rosa Mountains. Epicenter probably near 33°28′ north, 116°35′ west (Terwilliger Valley), P. Felt at Aguanga and in the lookout tower at Palomar Mountain.

July 6: 17:51.* Near Riverside. Epicenter 34°06′ north, 117°20′ west, P. Felt by many in San Bernardino.

July 7: 10:43.* Near head of Gulf of California. Epicenter about 31°40′ north, 115°05′ west, P. Felt at Lakeside.

July 8: 2:05.* Near Mina, Nev. Epicenter about 38°35′ north, 117°50′ west, P. Felt at Benton.

July 8: 2:58.* Near Mammoth Lakes. Epicenter about 37°27′ north, 119°00′ west, Sierra, south of Mammoth, P. Felt at Benton, Bishop, Hot Creek, Huntington Lake, Lakeshore, and Yosemite Valley (Yosemite Lodge).

July 14: 18:36.* Imperial Valley. Epicenter about 32°44′ north, 115°27′ west, P. Felt at El Centro and Brawley.

July 19: 20:01.* Near Long Beach. Epicenter 33°42′ north, 118°04′ west, off Bolsa Chica, P. Felt at Long Beach, Naples, and Belmont. Disturbed objects were reported from Long Beach.

July 20: 10:08.* Near Long Beach. Epicenter 33°42′ north, 118°04′ west, off Bolsa Chica, P. Hanging objects swung at Long Beach.

July 21: 0:36.* San Jacinto fault. Epicenter 33°05′ north, 115°59′ west, San Jacinto fault at Carrizo Creek, P. Felt at Black Mountain Lookout (Aguanga).

July 21: 6:15.* Near Mammoth Lakes. Epicenter about 37°27′ north, 119°00′ west, Sierra, south of Mammoth, P. Felt at Benton and Hot Creek.

July 21: 14:16.* Near Mammoth Lakes. Epicenter about 37°27, north, 119°00′ west, Sierra, south of Mammoth, P. Felt at Benton.

July 21: 19:22.* Near Santa Ana. Epicenter 33°46′ north, 117°55′ west, P. Felt at Placentia and Yorba Linda.

July 21: 22:24.* Los Angeles region. Epicenter 33°59′ north, 118°23′ west, southwest Los Angeles, P. Felt in Los Angeles, Santa Monica, Hollywood, Inglewood, Beverly Hills, Mar Vista, Venice, and Catalina Island. Hanging objects swung at Beverly Hills.

July 22: 0:24.* Los Angeles region. Slight aftershock felt in Los Angeles.

July 22: 15:01.* Near Mammoth Lakes. Epicenter 38°38′ north, 118°52′ west, P. Felt at Big Creek, Benton, and Hot Creek. Trees and bushes were shaken slightly at Hot Creek.

August 7: 13:52.* Near Palomar. Epicenter about 33°22′ north, 116°55′ west, P. Felt at Oak Grove Ranger Station (Aguanga), and Palomar Mountain. Steel girders of tower rattled as though something had crashed into the tower.

August 19: 10:24.* Los Angeles region. Epicenter 34°02′ north, 117°41′ west, near Chino, P. Felt at Upland.

August 26: 22:40.* Los Angeles region. Epicenter about 33°59′ north, 118°18′ west, P. Felt in Culver City, West Adams district of Los Angeles, North Long Beach, Gardena, and Baldwin Hills.

August 27: 20:54.* Tulare County. Epicenter 36°02′ north, 118°30′ west, upper Kern River, P. Felt at Blue Ridge Lookout (Sequoia National Forest), California Hot Springs, Frog Meadow Guard Station (Sequoia National Forest), Glendale, Haley Meadows (near Pansy), Kern River Plant No. 3, Mule Peak Lookout (Porterville), Needles Lookout (Springville), Poso Guard Station, Sequoia National Park (sec. 21, T. 18, R. 33 E.), Tobias Lookout, and Quaking Aspen. Near Needles Lookout rocks were dislodged, and small objects and furnishings were moved. At several stations rumbling sounds were heard.

September 7: 5:02.* Monterey County. Epicenter about 36.5° north, 121.5° west, P. Felt at Salinas and Carmel.

September 17: 20:23.* Off Redondo Beach. Epicenter 33°49′ north, 118°27′ west, P. Felt at Redondo Beach where chandeliers swayed, Hermosa, Torrance, and Manhattan Beach.

September 17: 0:21.* Central California. Epicenter about 38° north, 121° west, P. Felt at Isleton, Byron, and Stockton. At Byron dishes were shaken off shelves.

September 20: 10:59.* Central California. Epicenter about 38° north, 121° west, P. Aftershock felt at Byron. Residents reported dishes and other household articles broken.

September 21: 23:31.* Los Angeles region. Epicenter about 34.0° north, 118.3° west, southwest Los Angeles City, P. Felt in south and west Los Angeles.

September 27: 9:03.* Cape Mendocino region. Epicenter 40° north, 124° west, P. Felt over a land area of approximately 2,000 square miles. Maximum intensity did not exceed V. Felt at Eureka, Arcata, Blue Lake, Briceland, Bridgeville, Carlotta, Dyerville, Ettersburg, Ferndale, Garberville, Kneeland, Miranda, Orick, Pepperwood, Petrolia, Rockport, Scotia, Trinidad, and Upper Mattole. Hanging objects swung at Arcata, Blue Lake, Eureka, and Ferndale. Trees and bushes were shaken at Eureka, Rockport, and Upper Mattole.

Not felt at Crescent City, Forest Glen, Garberville, Laytonville, Richardson Grove, Silverdale, Westport, and Zenia.

October 4: 2:54.* Los Angeles region. Epicenter 33°54′ north, 118°19′ west, southwest Los Angeles, P. Felt at San Fernando, Van Nuys, Wilshire District, Beverly Hills, Eagle Rock, Hermosa Beach, and in parts of Los Angeles.

October 6: 12:54 (about). Humboldt County. Felt at Scotia and Upper Mattole. Trees and bushes were shaken at the latter place. Two aftershocks were reported the next day at Scotia.

October 6: 13:27.* Near Long Beach. Epicenter 33°46′ north, 118°06′ west, P. Very light shock felt in Long Beach.

October 10: 9:08. Imperial Valley. Epicenter about 32°44′ north, 115°27′ west, P. Hanging objects swung at Brawley. Shock preceded by a prolonged rumble.

October 10: 21:57.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt over a land area of approximately 7,000 square miles. Maximum in-

tensity VI with minor damage at a few places. Strongest at Keystone. Several strong motion seismograph records were obtained in the Los Angeles region.

INTENSITY VI:

Gardena.—Small objects overturned; trees and bushes shaken.

Keystone.—Plaster walls and chimneys reported cracked; dishes broken. Damage to brick work about $200. Tall vase overturned. Water spilled from containers.

Long Beach.—Some plaster cracked. Doors and chandeliers moved.

Redondo Beach.—Small objects overturned. Damage reported slight.

INTENSITY V:

Bell.—Small objects and furnishings moved.

Beverly Hills.—Pendulum clocks stopped and small furnishings moved.

Compton.—Hanging objects swung.

Lomita.—Hanging objects swung.

Los Angeles.—Some plaster cracked, damage very slight. Small objects disturbed. Trees and bushes shaken slightly.

Manhattan Beach.—Slight damage to plaster walls.

Maywood.—Plaster walls slightly cracked. Theaters emptied.

Port Hueneme.—Small furnishings moved.

Seal Beach.—All awakened. Direction of motion northwest-southeast.

Venice.—Small objects moved.

INTENSITY IV:

Acton, Aguanga, Alberhill, Balboa, Bellflower, Claremont, Culver City, El Segundo, El Toro, Glendale, Hemet, Hollywood, Huntington Beach, Huntington Park, Iglewood, La Crescenta, Laguna Beach, Mar Vista, Moreno, Oxnard, Palmdale, Pasadena, San Bernardino, San Pedro, Santa Paula, Topanga, Torrance, Van Nuys, Venice, Ventura, Whittier, and Wilmington.

INTENSITY I TO III:

Alhambra, Altadena, Anza, Arrowhead Springs, Big Bear Lake, Brea, Burbank, Cabazon, Cornell, Fullerton, La Canada, Monrovia, Moorpark, Newport Beach, Olive View, Riverside, Sandberg, San Diego, San Fernando, Santa Ana, Santa Barbara, Santa Monica, and Spring Valley.

Not felt at Alpine, Alta Loma, Arlington, Baldwin Park, Beaumont, Bloomington, Cajon, Camp Baldy, Corona, Crestline, Garnet, Glendora, Glenn Ranch, Escondido, Fall Brook, Fawnskin, Fillmore, Fontana, Indio, Jamul, Keen Camp, La Jolla, Mentone, Mount Wilson, National City, Newport Beach, Ontario, Pala, Palm Springs, Perris, Phelan, Pomona, Romoland, Rosamond, Roscoe, Sage, Saugus, Seven Oaks, Sunland, Temecula, Twentynine Palms, Victorville, Vista, Wheeler Springs, and Yucaipa.

October 10: 23:50.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Very light shock felt at El Segundo.

October 11: 16:24.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt in Balboa, Big Bear Lake, El Segundo, Gardena, Huntington Park, Long Beach, Manhattan Beach, Maywood, Redondo Beach, San Pedro, Torrance, Venice, Firestone Park, Hawthorne, Inglewood, and Santa Monica. At Redondo Beach some plaster was cracked, and bottles and cans fell from shelves.

Not felt at Alta Loma, Cornell, El Toro, Huntington Beach, Keen Camp, National City, Newport Beach, Seven Oaks, and Spring Valley.

October 11: 19:19.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt at Balboa, Fawnskin, Gardena, Huntington Park, Maywood, and Venice. Liquids were spilled from containers at Huntington Park; small objects and furnishings moved at Venice. Not felt in 12 other towns canvassed.

October 13: 3:55.* Vallecito Mountains. Epicenter about 32°56′ north, 116°25′ west, P. Felt at Descanso.

October 14: 12:51.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt at Gardena, Lomita, Maywood, and San Pedro. Hanging objects swung on fifth floor of City Hall at San Pedro. Not felt at Big Bear Lake and Newport Beach.

October 17: 2:18.* Imperial Valley. Epicenter about 32°44′ north, 115°27′ west, P. Hanging objects swung and small objects and furnishings moved near Imperial. Also felt at El Centro.

October 20: 11:00. San Francisco Bay region. Light shock reported at Lafayette and Walnut Creek.

October 20: 22:50.* San Jacinto Mountains. Epicenter 33°07′ north, 116°25′ west, Agua Caliente fault, near Aguanga, P. Felt at Alpine, Calexico, Descanso, Hemet, Lakeside, Palm Springs, San Diego, and Santa Ysabel. Reported strongest at Descanso and Hemet.

October 20: 23:17.* San Jacinto Mountains. Epicenter about 33°07′ north, 116°25′ west, Agua Caliente fault, near Aguanga, P. Aftershock felt at Descanso.

October 22: 3:01. Humboldt County. Felt over a land area of approximately 2,000 square miles. Maximum intensity VI at Scotia where merchandise in grocery and drug stores was thrown from shelves; books were knocked from racks; windows and plaster walls were broken; and file boxes weighing 3 to 4 pounds were shaken from shelves. Many objects, including quart bottles of ink, overturned. Three underground pipes were broken. A number of aftershocks were reported from Scotia. Small objects and hanging objects were disturbed at Bridgeville, Ferndale, and Fortuna. It was felt rather strongly at Alton, Upper Mattole, and Weott. Other places reporting it were Arcata, Blue Lake, Briceland, Ettersburg. Eureka, Garberville, Loleta, Miranda, Pepperwood, Petrolia, and Yager. Subterranean sounds were reported from Yager.

Not felt at Cape Mendocino Light Station, Crescent City, Hayfork, Orick, Trinidad, and Rockport. Three aftershocks were reported from Scotia the same day.

Strong motion seismograph records were obtained at Eureka and Ferndale.

October 23: 2:30 (about). Humboldt County. Strong aftershock felt at Alton, Bridgeville, Fields Landing, Fortuna, Scotia, Upper Mattole, and Yager. At Scotia plaster was cracked and knickknacks fell. Trees and bushes were shaken slightly. Hanging objects swung at Fields Landing. Another aftershock was recorded at 6:50.

October 30: 0:35. Sonoma County. Two short shocks felt at Santa Rosa. Police and newspaper offices flooded with calls. Felt in downtown and residential districts. Possibly an explosion. Not felt at 36 other places canvassed.

October 31: 23:25.* Los Angeles region. Epicenter 33°47′ north, 118°25′ west, Santa Monica Bay, P. Felt over a land area of about 1,200 square miles. Intensity V or over was reached at several places. At Huntington Park there was slight damage to wood, knickknacks fell, water spilled from indoor containers, and clocks stopped. At Keystone water spilled from outdoor containers, a china cabinet moved on its casters, and slight damage was reported. In Los Angeles there were some reports of small objects falling from shelves and swinging of chandeliers. One observer reported a small bed moved. At Redoudo Beach some patrons left the theaters. It was felt rather strongly at Acton, Lomita, and Maywood. Other places reporting the disturbance were Alhambra, Avalon, Inglewood, Long Beach, Mar Vista, Seal Beach, Torrance, Venice, and Wilmington.

The strong-motion seismographs in the Los Angeles Chamber of Commerce Buildings were set in operation.

November 1: 5:20.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt at Redondo Beach.

November 1: 12:01.* San Pedro Bay. Epicenter 33°38′ north 118°12′ west, P. Felt at Huntington Beach, Long Beach, Lytle Creek Ranger Station (San Bernardino), San Pedro, and Seal Beach. Hanging objects swung at San Pedro.

November 1: 18:58.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt at Inglewood, Keystone, Lomita, Long Beach, Los Angeles, Mar Vista, Maywood, Redondo Beach, San Pedro, Seal Beach, and Wilmington. The shock was strongest at Keystone where about 10 windows were broken. Derailing machine reported thrown out of adjustment. Hanging objects swung in Los Angeles and San Pedro.

November 2: 11:15. Humboldt County. Felt at Alton and Scotia. Hanging objects swung in Scotia.

November 3: 18:01.* San Bernardino Mountains. Epicenter about 34°20′ north, 117°00′ west, P. Felt at East Highlands.

November 4: 22:05.* Los Angeles region. Epicenter 33°57′ north, 118°08′ west, Norwalk fault, near Downey, P. Light shock felt in Los Angeles, Beverly Hills, East Los Angeles, and Monterey Park.

November 6: 12:44.* Santa Monica Bay. Epicenter 33°47′ north, 118°25′ west, P. Felt at Redondo Beach, Hermosa Beach, Manhattan Beach, and Torrance.

November 8: 22:57.* San Bernardino Mountains. Epicenter 34°20′ north, 117°00′ west, P. Felt at Fawnskin.

November 10: 2:25.* Santa Barbara Channel. Epicenter about 34°21′ north, 119°46′ west, P. Felt at Galeta, Paradise Camp, and Santa Barbara.

November 16: 23:24. Humboldt and Mendocino Counties. Felt over a land area of approximately 2,500 square miles. Maximum intensity did not exceed V. A strong-motion record was obtained from the accelerograph at Ferndale. At Eureka hanging objects swung, trees and bushes were shaken slightly. Hanging objects swung at Ferndale and Fortuna. It was strongly felt at Fields Landing.

Intensity IV at Carlotta, Klamath, Rockport, Upper Mattole, and Westport.

Also felt at Alderpoint, Arcata, Briceland, Bridgeville, Ettersburg, Petrolia, and Scotia.

Not felt at Blue Lake, Dyerville, Garberville, Hayfork, and Orick.

November 17: 12:06.* Los Angeles region. Epicenter about 33°55′ north, 118°13′ west, southwest Los Angeles, P. Felt at Huntington Park, Inglewood, Los Angeles, Maywood, Gardena and Watts. At Maywood a telephone switchboard was momentarily thrown out of commission. Hanging objects swung at Huntington Park.

November 19: 10:34. Humboldt, Mendocino, and Trinity Counties. Felt over a land area of approximately 8,000 square miles. Epicenter probably offshore.

INTENSITY VI:

Briceland.—Canned goods thrown off refrigerator; trees and bushes shaken strongly.

Bridgeville.—Bottles fell from shelves; small objects moved; clocks stopped.

Field Landing.—Small objects and furniture overturned; knickknacks fell; trees and bushes shaken slightly.

Garberville.—Plaster cracked slightly; trees and bushes shaken slightly.

Honeydew.—Small objects overturned; some canned goods thrown from store shelves.

Upper Mattole.—Loose bricks thrown from chimney; small objects and furnishings moved.

Westport.—Chimneys cracked. Hanging objects swung.

INTENSITY V:

Capetown.—A few objects displaced; suspended objects swung.

Eureka.—Small objects moved. Hanging objects swung in circles.

Fortuna.—Hanging objects, trees, and bushes shaken.

INTENSITY IV:

Alderpoint, Arcata, Blue Lake, Carlotta, Cummings, Dos Rios, Dyerville, Elk, Ferndale, Forest Glen, Fort Seward, Harris, Hyampon, Island Mountain, Loleta, Miranda, Myers, Petrolia, Punta Gorda Light Station, Rockport, Salyer Ranger Station, Scotia, Trinidad, Weott, Willits, and Yager.

INTENSITY I TO III:

Albion, Bell Springs, Branscomb, Fort Bragg, Kneeland, and San Juan Creek.

Not felt at Boonville, Cape Mendocino Light Station, Casper, Covelo, Crescent City, Elk Creek, Hearst, Hoopa, Lake Mountain, Navarro, Orick, Paskenta, Philo, Point Arena, Potter Valley, Red Bluff, Redding, Redwood Valley, Requa, Ukiah, Weaverville, Willow Creek, and Zenia.

November 24: 5:05.* Imperial Valley. Epicenter about 32°44′ north, 115°27′ west, P. Moderate shock felt at Brawley.

November 25: 22:27.* Los Angeles region. Epicenter 33°47′ north, 118°25′ west, off Palos Verdes, P. Felt slightly at Redondo Beach.

December 7: 14:16.* Near head of Gulf of California. Epicenter about 31°40′ north, 15°05′ west, P. Felt at Calexico, Dulzura (Barrett Dam), Heber, Jacumba, Lakeside, San Diego, and Spring Valley. In San Diego chandeliers and other suspended objects swung and many objects were disturbed. One clock stopped.

December 9: 0:20.* Near San Bernardino Mountains. Epicenter 33°56′ north, 116°45′ west, near Cabazon, P. Felt at Banning, Beaumont, Cabazon, Palm Springs, and San Gorgonia Pass.

December 20: 15:41. Northern California. Epicenter probably off Cape Mendocino. Felt over a land area of about 9,000 square miles. Maximum intensity VI. Strong motion seismograph records were obtained at Ferndale and Eureka.

INTENSITY VI:

Benbow.—Plaster cracked; a few small objects overturned; water spilled from containers.

Briceland.—Small objects overturned; clocks stopped.

Ettersburg.—Vases and small objects overturned; water spilled from containers.

Ferndale.—Small objects overturned.

Fort Bragg.—Dishes broken; books fell over; liquids spilled from indoor containers. One building swayed visibly.

Garberville.—Vases overturned; small objects moved.

Rockport.—Vases overturned; knickknacks fell.

INTENSITY V:

Fields Landing.—Small objects moved; water spilled from containers.

Forest Glen.—Small objects moved; liquids spilled from containers.

Harris.—Small objects moved; trees and bushes shaken.

Petrolia.—Small objects moved: liquids spilled from containers.

Punta Gorda Light Station.—Clocks stopped. Small amount of quicksilver spilled out of base of light.

Upper Lake.—Small objects moved; trees and bushes shaken.

Upper Mattole.—Small objects moved.

Weott.—Small objects moved; liquids spilled from containers.

Willits.—Clocks stopped.

INTENSITY IV:

Albion, Alderpoint, Arcata, Blocksburg, Blue Lake, Branscomb, Cape Mendocino, Carlotta, Covelo, Comptche, Dyerville, Eureka, Island Mountain, Littleriver, Potter Valley, Scotia, Ukiah, Weaverville, Westport, and Yager.

INTENSITY I TO III:

Casper, Cummings, Dos Rios, Hayfork, Lake Mountain, Kneeland, Philo, and San Francisco.

Not felt at Big Bar, Boonville, Cazadero, Cloverdale, Crescent City, Geyserville, Hoopa, Hopland, Klamath, Lakeport, Lodoga, Orick, Orleans, Paskenta, Platina, Point Arena, Red Bluff, Redding, Sawyers Bar, Stewarts Point, Trinidad, Wilbur Springs, Willows, and Yreka.

Not felt in Oregon at Grants Pass, Klamath Falls, Brookings, Gold Beach, and Medford.

WASHINGTON AND OREGON

[120TH MERIDIAN OR PACIFIC STANDARD TIME]

NOTE.—More details will be found in Abstracts of Earthquake Reports for the Pacific Coast and Western Mountain Region.

January 5: 24:00 (about). Ephrata, Wash. Weak.

March 23: 15:30 (about). Puyallup, Wash. Moderate shock disturbed objects and swung chandeliers.

March 23: 19:04. Mount Rainier area, Washington. Rather widely felt shock did not exceed IV at any point. Strongest at Cle Elum, Enumclaw, Hyak, Longmire, North Bend, Palmer, and Sumner. Also felt at Buckley, Cashmere, Chelan, Elbe, National, Olympia, Omak, Packwood, Renton, Seattle, and Shelton.

Not felt at Ariel, Centralia, Ellensburg, Elma, Ephrata, Greenacres, Lucerne, Moses Lake, Okanogan, Orondo, Puyallup, Prosser, Quincy, Republic, Seattle, Skykomish, Sunnyside, Tacoma, Tonasket, Toppenish, Wapato, Waterville, Wenatchee, and Yale.

March 24: 10:00 (about). Hyak, Wash. Weak aftershock.

April 25: 10:02 and 10:11. Seattle, Wash. Two light shocks.

May 25: 8:02. Oregon west coast (Lincoln County). At Waldport small objects and furnishings were moved. Also felt at Toledo, De Poe Bay, and Nashville.

October 27: 14:30 (about). Puget Sound region, Washington. Intensity V earthquake felt over a land area of about 12,000 square miles in the area draining into Puget Sound. The maximum intensity was reported from various places extending from Bellingham south to Seattle. No structural damage was reported.

The questionnaire coverage was made jointly by the Seismological Field Survey and Dr. Harold E. Culver, head of the department of geology, Washington State College, collaborator in seismology for the State of Washington. The shock appeared to be strongest in the Port Angeles-Port Townsend-Everett area.

All places listed below are in Washington unless otherwise stated.

INTENSITY V:

Bellingham.—Small objects moved.

Big Four.—Visible swaying of flagpole, trees, and buildings. Small objects disturbed. Small landslide reported in Big Four Mountains.

Brinnon.—Small objects moved; hanging objects swung.

Edgecomb.—Small objects moved; trees and bushes shaken.

Everett.—Many objects disturbed. Coffee slopped from cup. Rain gage recorder registered disturbance.

Greenwater.—Visible swaying of buildings. Dishes and other objects displaced.

Mount Vernon.—Small objects moved, some overturned; hanging objects disturbed. Trees and bushes shaken.

North Bend Ranger Station.—Small objects moved.

Port Angeles.—Chandeliers swung, bed moved, pictures disarranged; observer left building. Many telephone inquiries at police station.

Port Townsend.—Many small objects disturbed; lighting fixtures swayed; stove rattled. Piling in harbor reported moving to and fro. Bumping sounds.

Seattle.—Many small objects and some furniture moved. Suspended objects. trees, and bushes disturbed. Slight swaying of buildings. Faint bumping sounds.

Stampede.—Several objects disturbed; mirrors and pictures swayed. Faint bumping sounds.

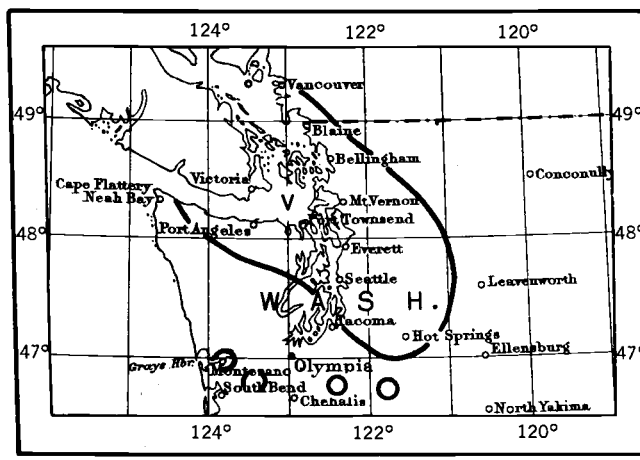

FIGURE 7.—Area affected by the Puget Sound earthquake of October 27, 1940.

INTENSITY IV:

Alder, Anacortes, Blaine, Bothell, Clinton, Camano Island, Concrete, Coupeville, Darrington, East Sound, Everson, Friday Harbor, Hartford, Kent, Keyport, Monroe, Port Ludlow, Port Orchard, Preston, Scenic, Sedro-Woolley, Skykomish, Skykomish Salmon Hatchery, Snohomish, Snoqualmie, Stanwood, and Sultan.

INTENSITY I TO III:

Baldi, Brooklyn, Clallam Bay, Enumclaw, Mazama, Palmer, Potlatch, Puyallup, Quilcene, and Sequim.

Not felt at Ashford, Buckley, Castle Rock, Cathlamet, Centralia, Chehalis, Cle Elum, Diablo, Forks, Gig Harbor, Glacier, Grapeview, Hyak, Joyce, Kalama, Kelso, Kosmos, Lakebay, Lester, Lucerne, Mineral, Moclips, Monroe, Naselle.

Neah Bay, North Head, Oakville, Point Angeles, Point Roberts, Pysht, Quinault, Randle, Rockport, Sandsburg, Shelton, Spirit Lake, South Bend, Tacoma, Tatoosh Island, Vashon, Washougal, Wenatchee, Winton, Yacolt, and Yelm.

The shock was felt slightly in Vancouver, British Columbia.

November 13: 22:30. Tacoma-Olympia area in Washington. Epicenter 47.7° north, 121.5° west, according to Jesuit Seismological Association. Light shocks accompanied by subterranean sounds reported by many residents of Tacoma, Olympia, and nearby points. Felt at Brown's Point, Dash Point, Fox Island, La Grande, and Lakebay. Reported not felt in some sections of Tacoma, Seattle, Port Angeles, Tatoosh Island, and Neah Bay.

November 18: 23:00 (about). Tacoma, Wash. Slight.

November 25: 3:00, 4:47, and 11:00 (about). Tacoma, Wash. Feeble shocks reported by residents at various times.

ALASKA

[150TH MERIDIAN TIME]

January 2: 23:57. Fairbanks. Light shock felt by many.

January 5: 23:30. Fairbanks. Felt by few.

January 6: 2:56. Big Delta and Fairbanks. Everyone awakened at Big Delta. Felt by many in Fairbanks.

January 6: 21:25. Fairbanks. Light shock felt by many.

January 26: 16:27. Fairbanks. Felt by several. Second shock at 17:05 lighter than first.

February 12: 0:22. False Pass and Port Moller. Awakened all. Hanging objects swung.

March 5: 12:37, 13:01, 13:55. McKinley Park and Healy. Moderate shocks of explosive type about the same at both places. Third shock rather violent, stopping clocks and moving small objects. McKinley Park reported additional shocks at 15:15, 15:32, 16:35, 19:52, 20:33, and 21:43. The 19:52 shock stopped clocks. Fairbanks reported light shocks at 13:01 and 13:55 and somewhat stronger ones at 19:53 and 20:28. Broad Pass felt the shocks slightly. Nenana reported only the two strongest felt.

March 6: 22:19. Fairbanks. Slight.

March 8: 19:05. Fairbanks. Slight.

March 22: 17:59. Fairbanks. Slight.

April 12: 10:22. Fairbanks. Slight.

May 4: 10:14. Anchorage. Slight.

May 23: 18:17. Fairbanks. Felt by most of population.

June 12: 13:05. Big Delta. Slight.

June 13: 9:19. Fairbanks. Felt by many.

July 19: 6:30. Anchorage, VI. Walls cracked, damage slight. Small objects moved; hanging objects swung. Many residents awakened.

August 21: 16:27.* Epicenter 51.9° north, 164.9° west, about 250 km. S. 27° E. of Dutch Harbor. Recorded widely on seismographs. Felt at Dutch Harbor. At Unalaska buildings rocked and dishes rattled.

August 29: 21:32. Fairbanks. Felt by large part of population. Some light objects displaced.

September 12: 21:51. Fairbanks. Felt by many.

September 22: 11:40. Fairbanks. Felt by several.

October 10: 21:56. Anchorage. Felt by many. Suspended objects swung.

November 2: 11:08. Juneau. Felt by few.

HAWAIIAN ISLANDS

[157½ MERIDIAN (WEST) TIME]

NOTE.—In the case of these islands with their many earthquakes of volcanic origin, only the stronger ones are listed. Reports of the Hawaiian Volcano Observatory under the jurisdiction of the National Park Service give all details. "HVO" indicates that the epicenter was determined by the Hawaiian Volcano Observatory.

January 19: 14:24 Hookena, Hawaii. Weak tremor accompanied by sounds reported by one observer.

June 16: 23:57.* Strong submarine shock north and east of Hawaiian Islands reported felt on all islands. Epicenter, as determined with the cooperation of the Hawaiian Volcano Observatory, 21.0° north, 155.3° west. The observatory reported 19 aftershock epicenters in the same general area through June 28.

Aftershocks were felt on Hawaii, Maui, and Oahu at 7:47 and 12:39 on the 17th. Many residents of the islands were awakened by the main shock but damage was insignificant.

The earthquake was reported felt at sea by the American Steamer *Monterey* in latitude 22°27'00" north, longitude 155°45'00" west. The ship experienced a very heavy vibration.

At Hilo, on the island of Hawaii, all residents were awakened, and small objects moved. At Kaunakakai vases overturned, glass was cracked, and water spilled from containers, Maui experienced sharp shocks, all residents being awakened, many jumping from their beds. Some medicine bottles were broken and clocks were reported stopped. On Molokai dishes were displaced and, as on the island of Lanai, all residents were awakened. On Oahu and Kauai the earthquake was generally felt and many residents were awakened. In Honolulu the intensity seemed about as great as on the islands closer to the epicenter.

July 15: 21:13.* Light shock reported felt in parts of Hawaii and Maui.

July 15: 16:48.* Strong aftershock of earthquake of June 16 felt in all of the islands except Kaui, 20°54' north, 155°08' west, HVO.

July 19: 7:42.* Light offshore shock felt at Kohala, T. H.

August 5: 3:27.* Northeast rim of Kilauea Crater near National Park Headquarters, 19°25.7' north, 155°15.5' west, HVO. Many persons in immediate vicinity of epicenter awakened.

August 5: 7:31.* Northeast rim of Kilauea Crater, 19°25.5' north, 155°15.5' west, HVO. Felt in Hawaii National Park.

September 1: 22:15.* Aftershock of June 16 earthquake felt generally on island of Hawaii, 21°00.0' north, 155°16.0' west, HVO.

October 26: 19:57. Felt sharply by many at Pahala; also felt in Hawaii National Park. Epicenter, east slope of Mauna Loa, 19°31.0' north, 155°26.5' west, HVO.

October 28: 21:27. Felt by a few at Hilo. Epicenter, between Puu Ohale and Keahou Landing, 19°20.0' north, 155°16.0' west, HVO.

November 27: 22:12. Reported felt at Paauhau. Recorded instrumentally on Hawaii.

December 9: 6:51. Reported felt at Hookena. Recorded instrumentally on Hawaii.

PHILIPPINE ISLANDS

[120TH MERIDIAN (EAST) TIME]

NOTE.—In the case of these islands with their many minor earthquakes only the stronger ones are listed. Reports of the Weather Bureau of the Philippine Islands give all details. Instrumental times given below are arrival times of the first preliminary tremors recorded at Manila unless otherwise stated. The intensities are according to the Rossi-Forel scale. Information in this report is taken from reports of the Weather Bureau of the Philippine Islands, that for the last 6 months being taken from the instrumental bulletins only.

January 23: 19:30.* Luzon. Epicenter in Lamon Bay. Felt with intensity IV.

February 22: 21:32.* Northern Luzon. Epicenter in Babuyan Islands. Felt with intensity V.

March 2: 14:35.* Samar and Leyte. Felt with intensity IV.

March 13: 6:20.* Northern Luzon. Felt with intensity IV.

March 28: 23:49.* Luzon and Mindoro. Felt with intensity IV–V in Manila. Radius of microseismic area about 400 km.

April 8: 10:50.* Southeastern Luzon and Samar. Epicenter in Philippine Deep. Felt with intensity V.

April 14: 22:36.* Northeastern Mindanao. Epicenter in Philippine Deep. Felt with intensity IV.

June 1: 6:36.* Southeastern Visayas and Northern Mindanao. Epicenter in Bohal Strait. Felt with intensity IV.

July 19: 4:24.* IV at Dapa.

July 23: 17:21.* IV at Dapa.

September 1: 16:16.* Near 9°45' north, 126°35' east. Felt in northeastern Mindanao and eastern Leyte.

September 8: 3:26.* Near 9° north, 126°50' east. Felt in eastern Mindanao.

September 14: 15:05.* Felt in Catbalogan, Borongan, Tacloban, Cebu, and Iloilo.

October 16: 6:39.* About 9°50' north, 126°20' east. Felt at Surigao and Butuan.

October 20: 18:56.* 14°35' north, 122°50' east. Felt in southern Luzon.

PUERTO RICO

No earthquakes reported felt in 1940.

PANAMA CANAL ZONE

[75TH MERIDIAN TIME]

NOTE.—Instrumental times given below are the arrival times of the first recorded phases on the seismograph at Balboa Heights unless otherwise stated.

May 16: 21 : 00.* Epicenter about 120 miles from Balboa Heights. Felt locally by many people, some of whom were frightened. Intensity II.

July 13: 11 : 48.* Epicenter about 125 miles from Balboa Heights. Generally felt. Intensity II.

MISCELLANEOUS ACTIVITIES

During 1940 no geodetic operations for studying earthquake movements were carried on by the Coast and Geodetic Survey. No tidal disturbances of seismic origin were noted on the gages of the Survey, nor were any earthquakes reported by vessels of the Bureau.

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 Survey.

Instrumental results are published for the following observatories:

Balboa Heights, C. Z. (the Panama Canal).
Bermuda (Meteorological Station, St. George's, and International Union of Geodesy and Geophysics).
Boulder City, Nev. (Bureau of Reclamation, National Park Service).
Bozeman, Mont. (Montana State College).
Burlington, Vt. (University of Vermont).
Butte, Mont. (Montana School of Mines).
Chicago, Ill. (University of Chicago and United States Weather Bureau).
College, Alaska (University of Alaska).
Columbia, S. C. (University of South Carolina).
Des Moines, Iowa (Private station, M. M. Seeburger, director).
East Machias, Maine (Massachusetts Institute of Technology).
Honolulu, T. H. (University of Hawaii).
Huancayo, Peru (Carnegie Institution of Washington).
Ivigtut, Greenland (Geodaetisk Institut, Copenhagen, Denmark).
Lincoln, Nebr. (Nebraska Wesleyan University).
Logan, Utah (Utah State Agricultural College).
Montezuma, Chile (Smithsonian Institution).
Philadelphia, Pa. (Franklin Institute).
Salt Lake City, Utah (University of Utah).
San Juan, P. R.
Seattle, Wash (University of Washington).
Scoresby-Sund, Greenland (Geodaetisk Institut, Copenhagen, Denmark).
Sitka, Alaska.
Tucson, Ariz.
Ukiah, Calif. (International Latitude Observatory).

San Juan, Sitka, Tucson, and Ukiah are Coast and Geodetic Survey stations; Bermuda, Bozeman, Butte, Chicago, College, Columbia, Honolulu, Lincoln, and Salt Lake City are cooperative stations; Balboa Heights, Burlington, Des Moines, East Machias, Huancayo, Logan, Montezuma, Philadelphia, and Seattle are independent stations. Through arrangements made by the International Union of Geodesy and Geopyhsics the Coast and Geodetic Survey is temporarily aiding in the maintenance of the Danish stations at Scoresby-Sund and Ivigtut in Greenland. All readings are made or revised at the Washington office except those for Balboa.

The tabular summary of instrumental results for 1940 was not ready when this publication went to press.

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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 obtain data needed in the design of earthquake-resisting structures. Notes pertinent to the development of this program will be found in the seven preceding issues of this series, Serials 579, 593, 600, 610, 619, 629, and 637, and in Special Publication 201, "Earthquake Investigations in California, 1934–35." Material in the "United States Earthquakes" series is restricted to the analysis is strong-motion seismograph records. Special Publication 201 is much broader in scope, containing data on structural and ground vibrations and detailed descriptions of the various activities which comprise the seismological program as a whole. The reader is also referred to Special Publication 206, "Selection, Installation, and Operation of Seismographs," for descriptive material on strong-motion instruments and vibration meters in addition to similar information on teleseismic instruments.

Interpretation of records.—The following analyses are based on the assumption of simple harmonic motion. This refers especially to the computation of displacement from accelerograph records. As most accelerograph records are of irregular character, and the character of the longer-period waves is often obscured by the superposing of shorter-period waves of relatively large amplitude, the estimates of displacement must be considered as only approximate. One must refer to the illustrations of the curves themselves to evaluate the probable accuracy of the estimated displacements.

For the more important records—those involving destructive ground motions—the use of integration methods in computing velocity and displacement curves has become established practice. The accuracy of such work, as well as an appraisal of instrumental performance, has been definitely established through accelerometer shaking table tests made at, and with the cooperation of, the Massachusetts Institute of Technology. In the displacement results the errors of mensuration, computation, and adjustment can be kept within a range of 1 cm. Errors due to minute shiftings of the zero positions of the pendulums on pivot accelerometers increase this range of error to about 2 or 3 cm. In both cases the errors apply only to displacements of a slow drifting type, somewhat similar to waves of about 10 seconds period and over. But they represent motions that are necessarily associated with extremely small accelerations and are therefore of no significance in engineering studies.

For 1940 the only record thus processed was the El Centro accelerograph record of the Imperial Valley earthquake of May 18. This record represents the most violent seismic motion yet satisfactorily recorded. As far as can be ascertained, the accelerations were as great or possibly greater than those recorded at Long Beach in 1933. Unfortunately, a large part of the most active portion of the

latter record is illegible. During the current year a recomputation of displacement was made in the case of the Helena record of October 31, 1935, as some of the questions raised in Serial 600 were definitely answered by the shaking table tests previously mentioned.

Units used.—Quantitative results are expressed in c. g. s. units; centimeters or millimeters for displacement; centimenters 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 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 centimenters for a constant acceleration of 100 cm./sec.^{2} This means that the seismometer pendulum is tilted sideways until the effective component of the earth's gravitational field is equal to 100 cm./sec.^{2}, or practically 0.1 g.

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.=10 mm.
1 cm./sec.=0.03281 ft./sec.	0.1 g.=98 cm./sec.^{2}=3.215 ft./sec.^{2}.
1 cm./sec.^{2}=0.03281 ft./sec.^{2}.	1 (statute) mile=1.609 km.

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

Seismogram illustrations.—Reproductions of seismograms are usually tracings of the original records and must not be accepted as genuine copies. They are intended to show the nature of the data rather than furnish a means through which the reader can make his own measurements. Those who desire true copies for critical study should address the Director of the Coast and Geodetic Survey for further particulars.

The tabulated instrumental constants refer to the original records. The tracings in this publication are reduced so that the same scales do not apply. The reductions are approximately in the ratio of 1.7 to 1. (See table 1 on p. 38 for list of records obtained in 1940.)

NOTES ON STRONG-MQTION SEISMOGRAPH RECORDS

The practice of attempting to describe the seismograms in detail in the text is believed to be rather superfluous because the outstanding periods are listed in tables, such as table 2 in this issue, and the illustrations provide a far better picture of the records than can be obtained in any other way. The following notes will therefore contain only such information on the earthquakes and the records which may not be evident from table 2 or from the illustrations. For convenience certain fundamental informtaion on the earthquakes will be repeated from the noninstrumental part of the publication.

It is well to repeat here that, as the measurement of periods on records of this nature is dependent largely on the judgment of the person reading them, considerable latitude must be allowed in appraising their accuracy. The aim of such analyses is primarily to give a fair picture of the magnitudes of the various elements involved, and the figures tabulated should therefore not be used for important studies

without first referring to the illustrations for some idea of the nature of the original records.

TABLE 1.—*List of shocks recorded and records obtained on strong-motion seismographs in 1940*

Date, epicenter, and recording station	Records		
	Accelerograph	Displacement meter	Weed strong-motion seismograph
Jan. 12: Los Angeles region: Vernon	1		
May 18: Imperial Valley: [1]			
El Centro	1		
San Diego	1		
San Bernardino			1
Los Angeles Subway Terminal	2	1	
Los Angeles Chamber of Commerce	2		
Hollywood	3		
May 19: Imperial Valley: [2] El Centro	1		
Sept. 27: northern California: Ferndale	1		
Oct. 10: Santa Monica Bay:			
Vernon	1		
Los Angeles Chamber of Commerce	2		
Hollywood	3		
Oct. 22: Cape Mendocino: Ferndale	1		
Oct. 31: Santa Monica Bay: Los Angeles Chamber of Commerce	2		
Nov. 16: Cape Mendocino: Ferndale	1		
Nov. 19: Cape Mendocino: Ferndale	1		
Dec. 20: Cape Mendocino:			
Ferndale	1		
Eureka	1	1	
Dec. 23: Montana: Helena	1		
Totals	26	2	1

[1] A number of weak aftershocks of this quake were recorded at El Centro. Some of them were recorded at the Los Angeles Chamber of Commerce Station and at Hollywood.
[2] Aftershock of the foregoing.

EARTHQUAKE OF JANUARY 12 NEAR LOS ANGELES

Epicenter near Long Beach. Intensity about V.

Vernon.—Figure 8. About 15 miles N. 14° W. of epicenter. Intensity about III. Weak record; maximum acceleration about 2 cm./sec.^{2}

IMPERIAL VALLEY EARTHQUAKE OF MAY 18

Maximum intensity X. See special report on page 58. Epicenter in the Imperial Valley about 6 miles northeast of Calexico. Earthquake was featured by a 40-mile fault with maximum horizontal slippage nearly 15 feet, close to the border. Felt over a land area of about 60,000 square miles.

El Centro.—Figures 8, 9, and 18. Station about 7 miles N. 52° W. of the instrumental epicenter, and about 13 miles N. 49° W. from the point of maximum slippage on the fault. Intensity VII to VIII. A valuable accelerogram was obtained, containing also records of a number of weak aftershocks. The maximum acceleration on the vertical component was about 220 cm./sec.^{2} associated with a period of 0.102 sec. On the horizontals the maximum resultant acceleration was about 350 cm./sec.^{2} associated with a period of about 0.4 sec. The maximum acceleration reached in the aftershocks on May 18 was about 80 cm./sec.^{2}

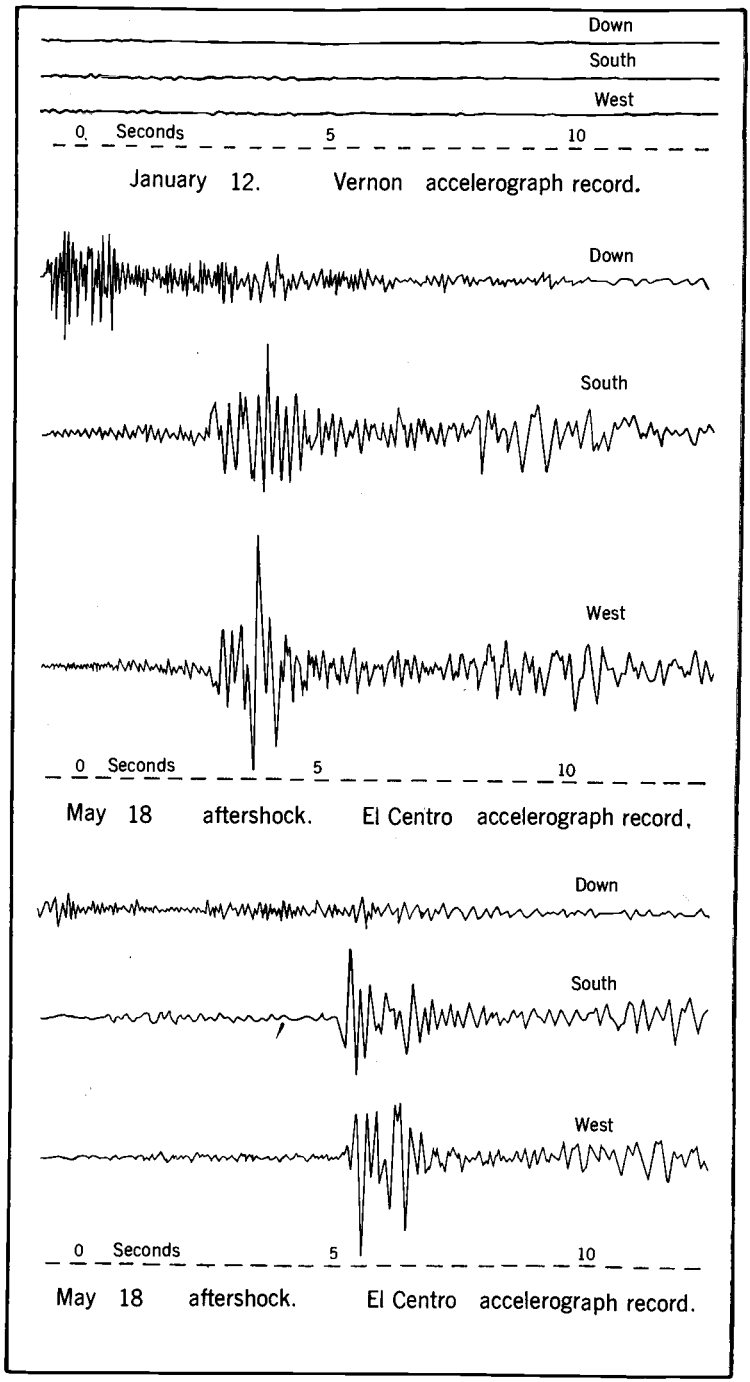

FIGURE 8.—Tracings of Vernon accelerograph record of January 12, 1940, and El Centro accelerograph records of two aftershocks on May 18, 1940.

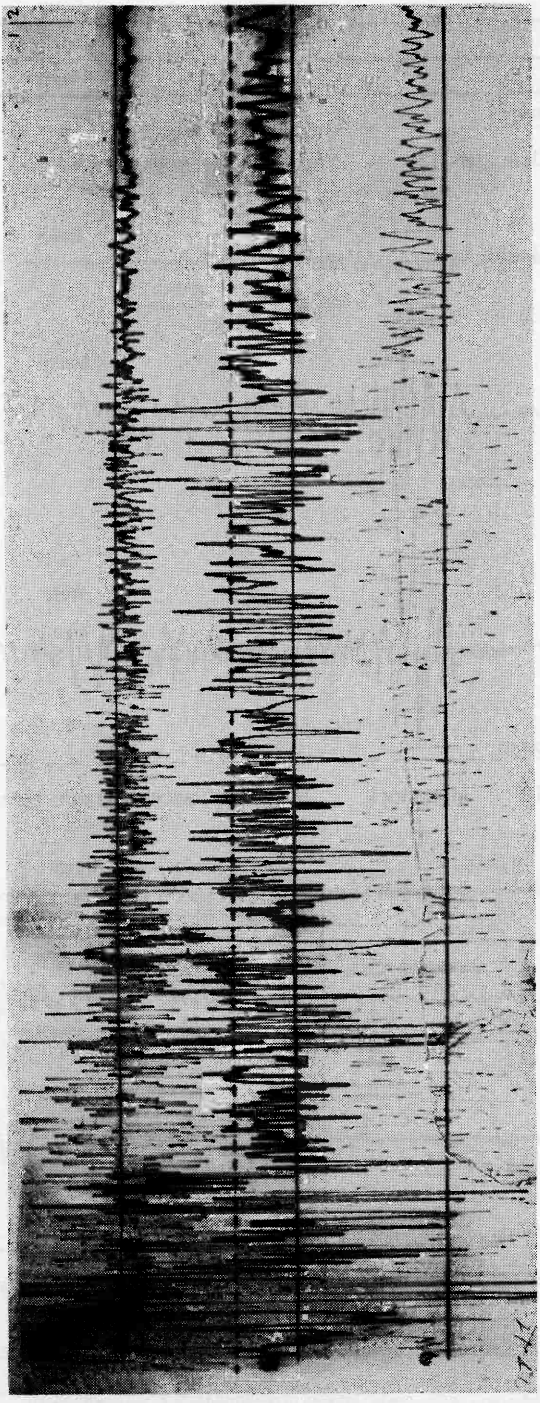

FIGURE 9.—Original El Centro accelerograph record of Imperial Valley earthquake of May 18, 1940. See Fig. 18 for tracings of the curves after separation.

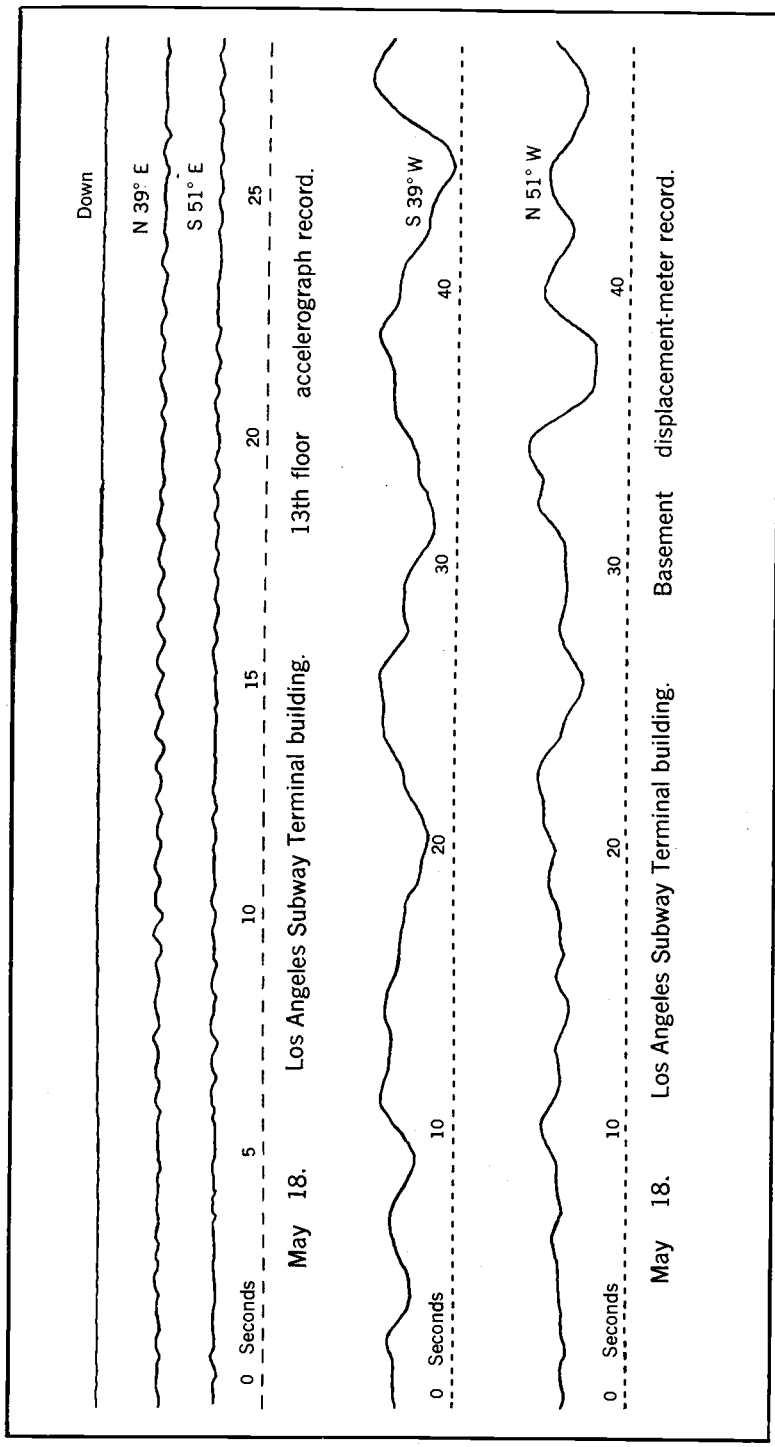

FIGURE 10.—Tracings of strong-motion records obtained in Los Angeles Subway Terminal building on May 18, 1940.

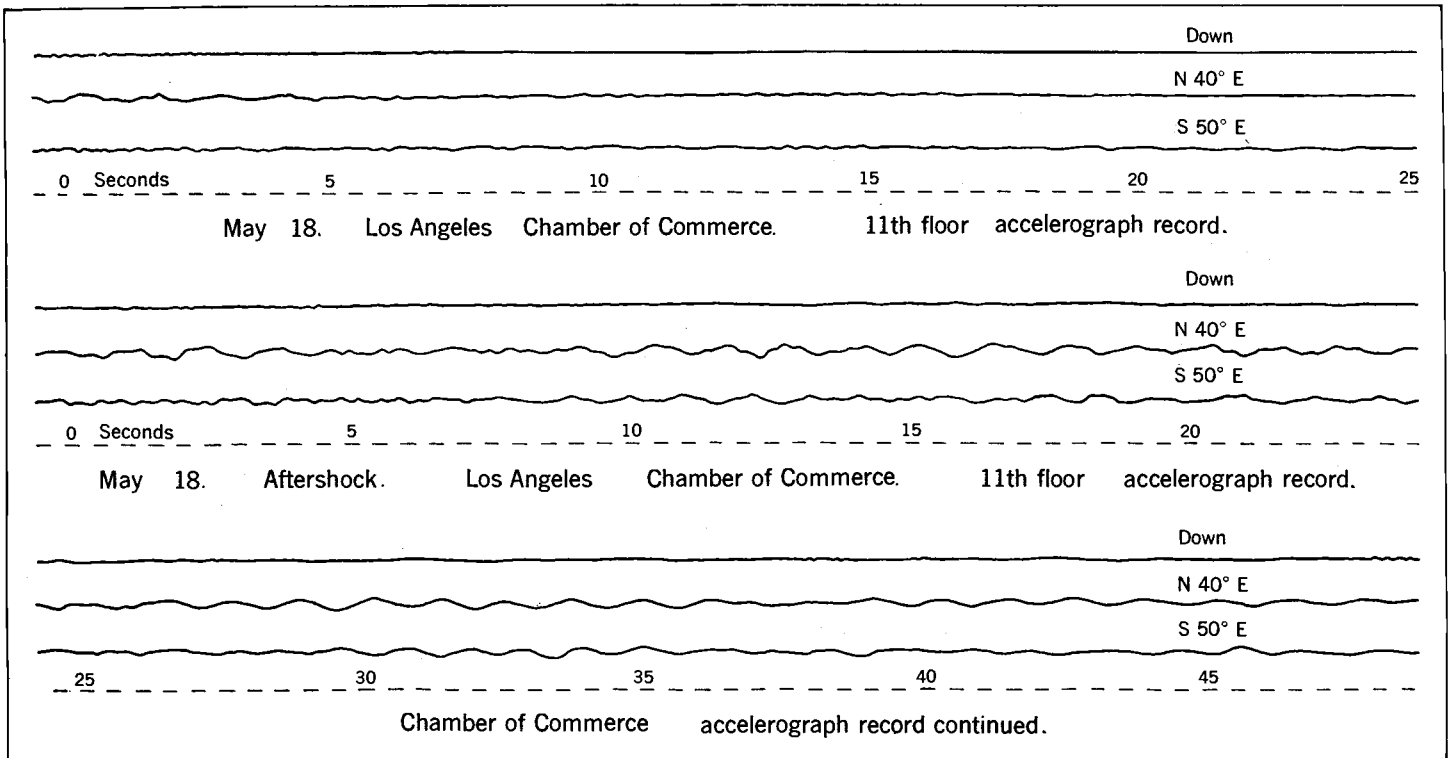

FIGURE 11.—Tracings of accelerograph records obtained in Los Angeles Chamber of Commerce building on May 18, 1940.

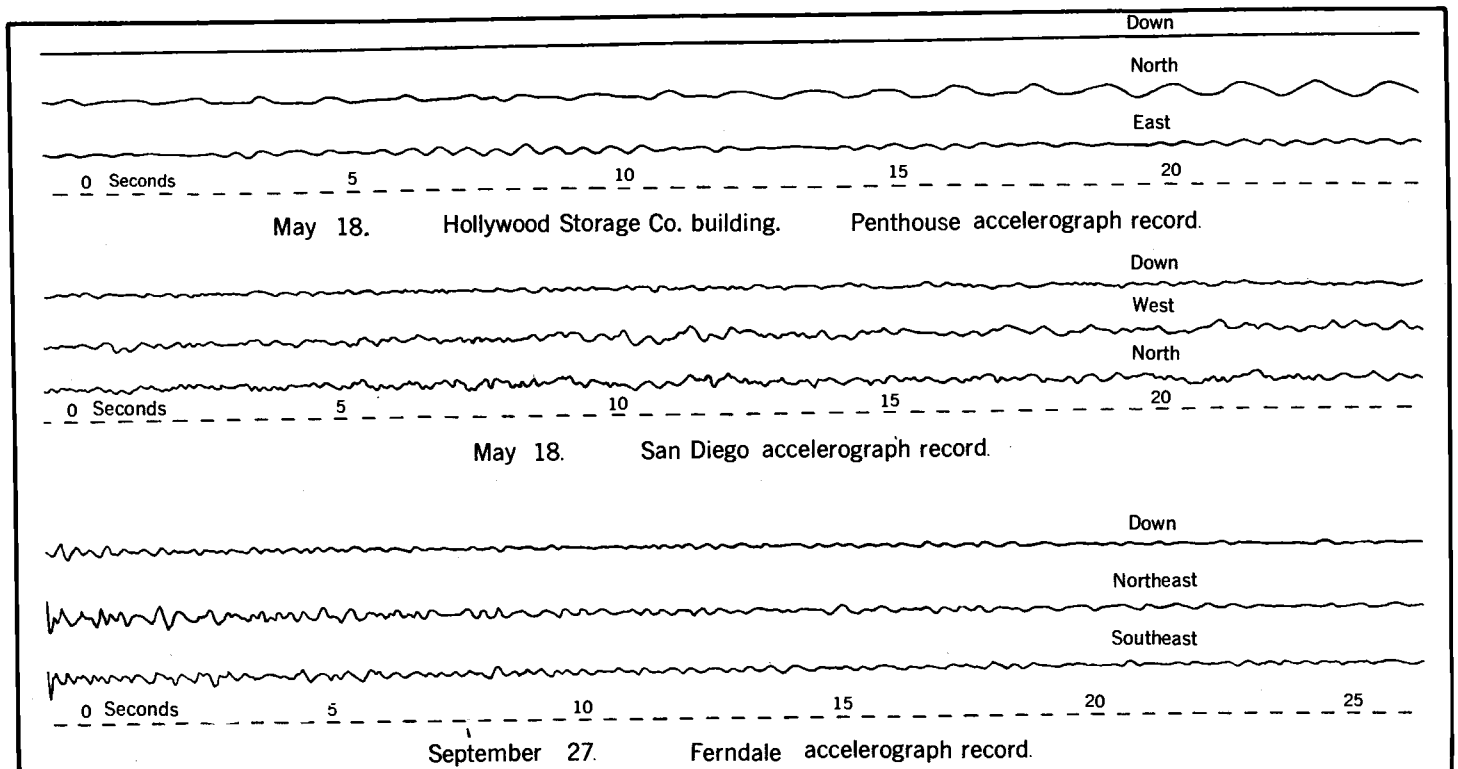

FIGURE 12.—Tracings of accelerograph records obtained at Hollywood and San Diego on May 18, 1940, and at Ferndale on September 27, 1940.

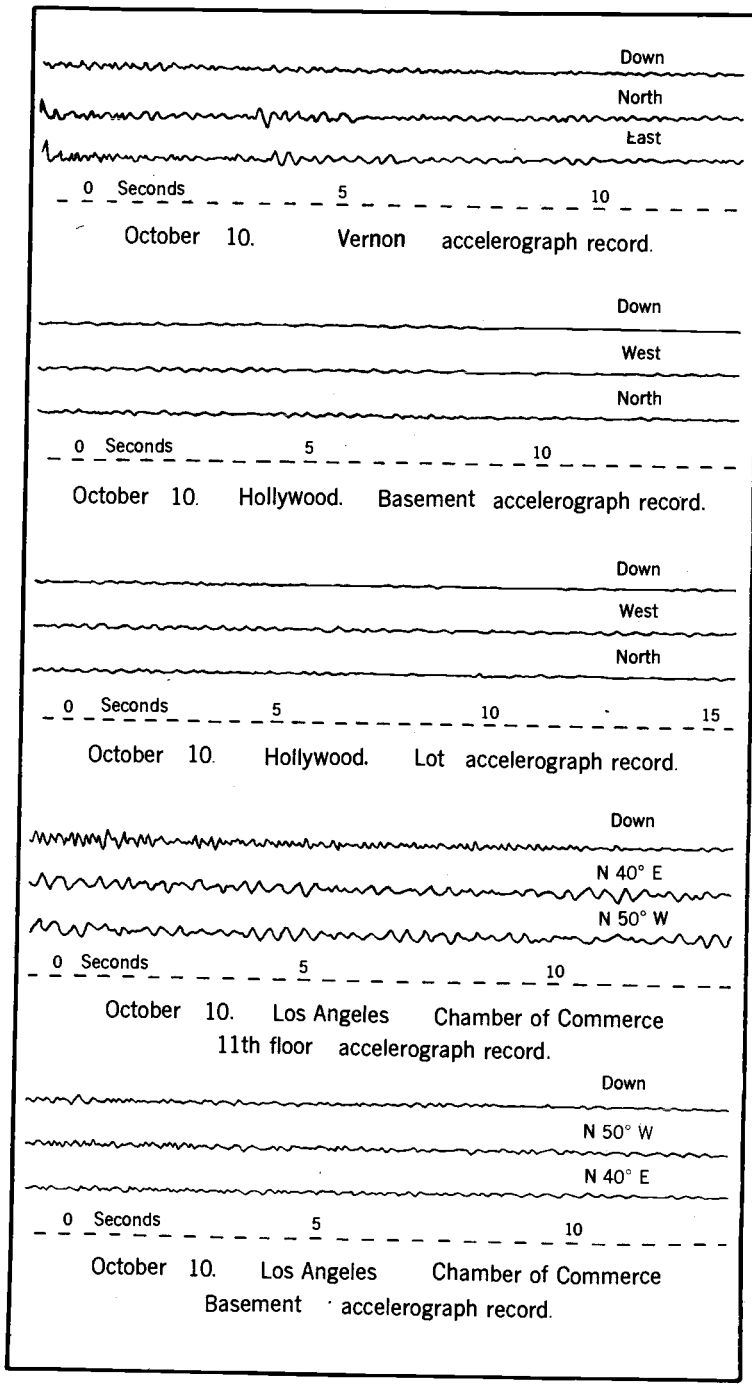

FIGURE 13.—Tracings of accelerograph records obtained at Vernon and Hollywood, and in the Los Angeles Chamber of Commerce building on October 10, 1940.

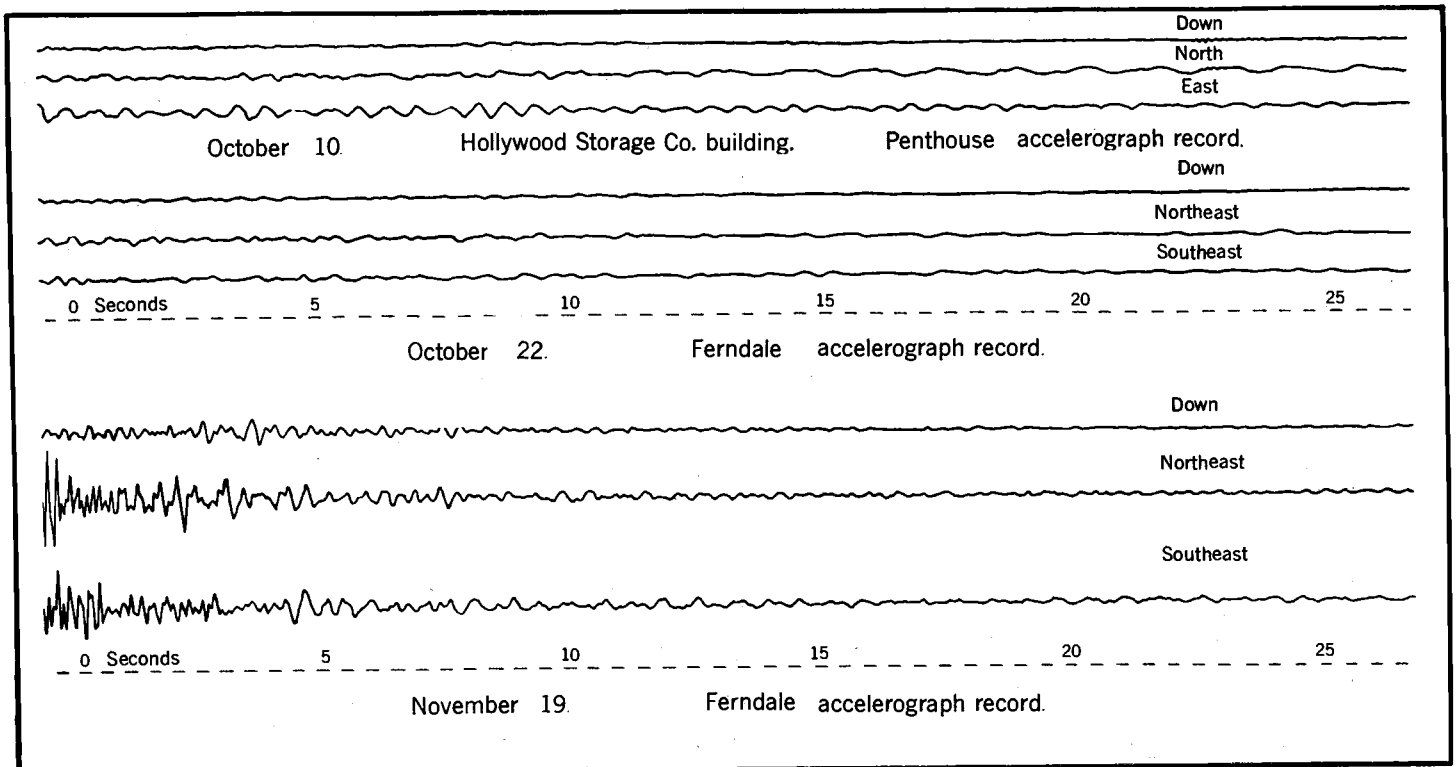

FIGURE 14.—Tracings of accelerograph records obtained at Hollywood on October 10, 1940, and at Ferndale on October 22 and November 19, 1940.

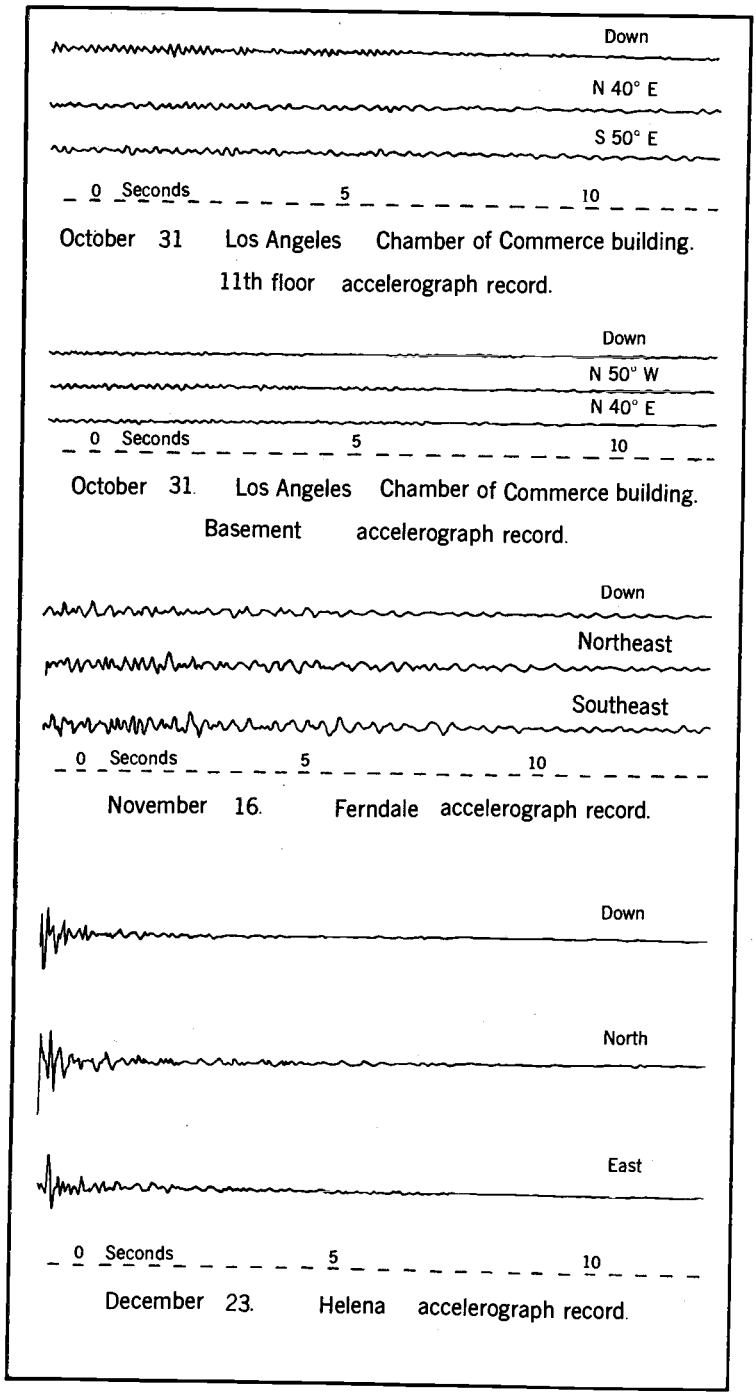

FIGURE 15.—Tracings of accelerograph records obtained in Los Angeles Chamber of Commerce building on October 31, 1940, at Ferndale on November 16, 1940, and at Helena, Mont., on December 23, 1940.

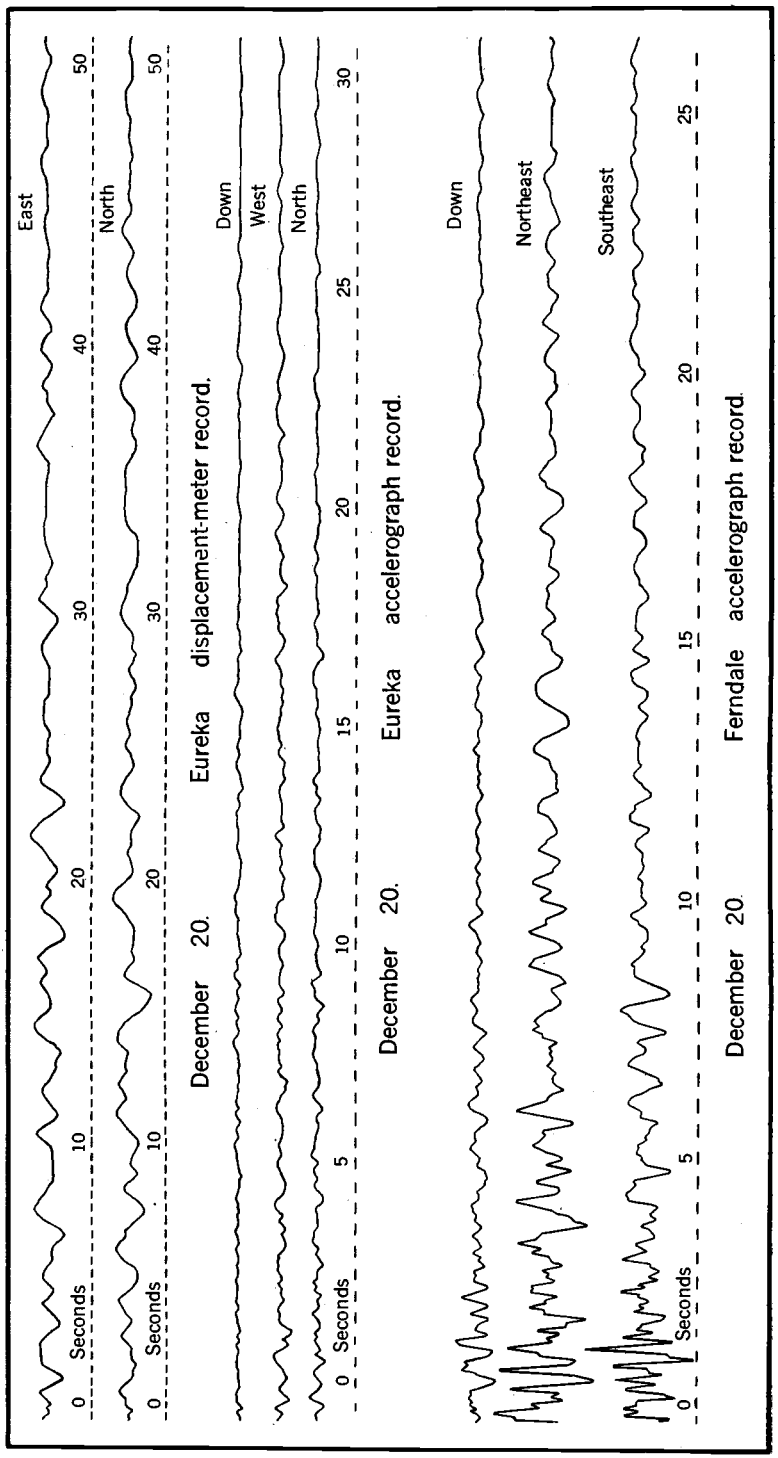

FIGURE 16.—Tracings of strong-motion seismograph records obtained at Eureka and Ferndale on December 20, 1940.

See page 58 for a comprehensive analysis of the El Centro accelerogram.

San Diego.—Figure 12. Station about 99 miles S. 89° W. of the instrumental epicenter. Intensity IV to V. Maximum acceleration 4 cm./sec.^{2}

San Bernardino.—Station about 142 miles N. 48° W. of epicenter. Intensity IV. Maximum acceleration about 1 cm./sec.^{2} Very weak record, on smoked glass, not reproduced.

Los Angeles Subway Terminal Building.—Figure 10. Station about 186 miles N. 61° W. of epicenter. Maximum acceleration 1 cm./sec.^{2} in the basement; 5 cm./sec.^{2} on the thirteenth floor. The displacement-meter in the basement shows long-period motion (period about 12.6 sec.) of about 0.73 cm. amplitude. The basement accelerograph record is not shown.

Los Angeles Chamber of Commerce Building.—Figure 11. Station about 186 miles N. 61° W. of epicenter. The motion was less than 1 cm./sec.^{2} in the basement, and 4 cm./sec.^{2} on the eleventh floor. The basement record is not shown.

Hollywood Storage Co. Building.—Figure 12. Station about 192 miles N. 61° W. of epicenter. The maximum accelerations on the adjoining lot, in the basement, and in the penthouse were 1, 2, and 8 cm./sec.^{2}, respectively. The ground records are not shown.

IMPERIAL VALLEY AFTERSHOCK OF MAY 19

Epicenter in the Imperial Valley a short distance north of the Mexican border. Aftershock of the foregoing earthquake.

El Centro.—Station about 7 miles N. 52° W. of epicenter. Instensity about III. Maximum acceleration 7 cm./sec.^{2} Record not shown.

NORTHERN CALIFORNIA EARTHQUAKE OF SEPTEMBER 27

Epicenter at sea off Cape Mendocino. Maximum intensity on land V—.

Ferndale.—Figure 12. Distance and bearing from the epicenter unknown. Intensity about IV. Maximum acceleration about 17 cm./sec.^{2}

SANTA MONICA BAY EARTHQUAKE OF OCTOBER 10

Maximum intensity about VI. Slight damage.

Vernon.—Figure 13. Station about 19 miles N. 40° E. of epicenter. Intensity about V. Maximum acceleration about 15 cm./sec.^{2}

Los Angeles Chamber of Commerce Building.—Figure 13. Station about 20 miles N. 25° E. of epicenter. Intensity about V. Maximum acceleration about 2 cm./sec.^{2} in the basement, and 7 cm./sec.^{2} on the eleventh floor.

Hollywood Storage Co. Building.—Figures 13 and 14. Station about 22 miles N. 10° E. of epicenter. Intensity about IV. Maximum acceleration 3, 2, and 3 cm./sec.^{2} on the adjoining lot, in basement, and in penthouse, respectively.

NORTHERN CALIFORNIA EARTHQUAKE OF OCTOBER 22

Epicenter probably near Cape Mendocino. Maximum intensity about VI.

Ferndale.—Figure 14. Distance and bearing from epicenter not known. Intensity about IV. Maximum acceleration 2 cm./sec.^{2}

SANTA MONICA BAY EARTHQUAKE OF OCTOBER 31

Maximum intensity V to VI. No structural damage.

Los Angeles Chamber of Commerce Building.—Figure 15. Station about 20 miles N. 25° E. of epicenter. Intensity IV to V. Maximum acceleration about 2 cm./sec.^{2} in the basement, and about 5 cm./sec.^{2} on the eleventh floor.

CAPE MENDOCINO EARTHQUAKE OF NOVEMBER 16

Maximum intensity about V. No damage.

Ferndale.—Figure 15. Distance and bearing from epicenter not known. Intensity V−. Maximum acceleration about 16 cm./sec.^{2}

CAPE MENDOCINO EARTHQUAKE OF NOVEMBER 19

Maximum intensity about VI. Some cracked plaster and chimneys.

Ferndale.—Figure 14. Distance and bearing from epicenter not known. Intensity IV. Maximum acceleration about 37 cm./sec.^{2}

CAPE MENDOCINO EARTHQUAKE OF DECEMBER 20

Maximum intensity about VI. Slight damage.

Ferndale.—Figure 16. Distance and bearing from epicenter not known. Intensity VI; slight damage. Maximum acceleration 34 cm./sec.^{2}

Eureka.—Figure 16. Distance and bearing from epicenter not known. Intensity IV. Maximum acceleration 4 cm./sec.^{2}; maximum displacement 0.27 cm.

The acceleration record was used to test the accuracy of the displacement obtained by double integrating the acceleration curves. It is expected that the detailed results will appear in a 1942 or 1943 number of the Bulletin of the Seismological Society of America. A certain amount of drift, between 1 and 2 cm., was found in the computed displacement, when compared with the displacement-meter record, even though the ground motions were not severe. This is attributed mostly to minute shifting of the zero position of the accelerometer pendulum and to inaccuracies in scaling the acceleration curve.

MONTANA EARTHQUAKE OF DECEMBER 23

Epicenter near Helena. Maximum intensity about V. Some plaster cracked and pictures knocked from walls.

Helena.—Figure 15. Bearing from epicenter not known; distance very few miles. Maximum intensity V; slight damage. Maximum acceleration 64 cm./sec.^{2}

TABLE 2.—***Summary of strong-motion seismograph data for the year 1940***

[See the text preceding this table for additional details. Simple harmonic motion is assumed when computing displacement from an accelerogram and when computing acceleration from a displacement-meter record]

EARTHQUAKE OF JAN. 12, NEAR LONG BEACH

Station and component	Earth-wave period	Maximum acceleration	Maximum displace-ment	Remarks
	Seconds	*Cm./sec.²*	*Cm.*	
Vernon accelerograph:				
Vertical	0.30	1	0.002	Poorly defined waves.
	0.1	1—	0.001—	Do.
N. 8° E.-S. 8° W.	0.20	2	0.002	
N. 82° W.-S. 82° E.	0.20	2	0.002	

IMPERIAL VALLEY EARTHQUAKE OF MAY 18

El Centro accelerograph:				The tabulated readings were made on the original accelerogram. For further analysis see special article on page 58 abstracted from Coast and Geodetic Survey report MSS-9, Analysis of the El Centro Accelerograph Record of the Imperial Valley Earthquake of May 18, 1940. (*) indicates periods which are also outstanding in several strong aftershocks.
Vertical	0.41	18	0.077	
	0.34	17	0.050	
	0.25	22	0.035	
	0.193	38	0.036	
	0.130	66	0.028	
	0.123*	108	0.041	
	0.106*	259	0.074	Off sheet. Amplitude estimated.
	0.092*	153	0.033	
	0.079*	102	0.016	
North-south	2.93	7	1.6	
	1.07	80	2.3	
	0.73	116	1.6	
	0.42	50	0.22	
	0.25*	113	0.179	
	0.19*	119	0.109	
	0.181*	314	0.260	Do.
	0.161	166	0.109	Superposed on longer period waves.
East-west	4.00	7	3.0	
	1.33	7	0.33	
	1.06	67	1.9	
	0.53	110	0.78	
	0.48	53	0.31	Off sheet. Amplitude estimated.
	0.26*	166	0.284	
	0.193*	169	0.159	Do.
	0.174*	148	0.114	
	0.137	120	0.057	Off sheet. Superposed on longer period waves.
San Diego accelerograph:				
Vertical	0.13	1	0.001—	
	Irregular	2		
North-south	0.41	2	0.011	
	0.16	1	0.001	
	Irregular	4		
East-west	0.40	3	0.011	Superposed on longer period waves.
	Irregular	5		
San Bernardino, Weed seismograph:				
Northeast-southwest	2.2	1	0.14	
Northwest-southeast	Irregular	1+		
Los Angeles Subway Terminal, basement accelerograph:				
Vertical	Irregular	1—		
N. 39° E.-S. 39° W.	Irregular	1		
N. 51° W.-S. 51° E.	Irregular	1		
Los Angeles Subway Terminal, basement displacement—meter:				
N. 39° E.-S. 39° W.	12.5	1—	0.73	
	7.0	1—	0.46	
	4.0	1—	0.29	
N. 51° W.-S. 51° E.	12.8	1—	0.30	
	5.5	1—	0.49	

TABLE 2.—*Summary of strong-motion seismograph data for the year 1940*—Con.

IMPERIAL VALLEY EARTHQUAKE OF MAY 18—Continued

Station and component	Earth-wave period	Maximum acceleration	Maximum displacement	Remarks
	Seconds	*Cm./sec.²*	*Cm.*	
Los Angeles Subway Terminal, 13th floor accelerograph:				
N. 39° E.-S. 39° W.	0.79	2	0.04	Train of regular waves.
	0.70	5	0.06	Do.
N. 51° W.-S. 51° E.	0.78	2	0.03	Rather irregular.
	0.58	2	0.02	Do.
Los Angeles Chamber of Commerce Bldg., basement accelerograph:				
N. 40° E.-S. 40° W.	Irregular	1—	----------	
N. 50° W.-S. 50° E.	Irregular	1—	----------	
Los Angeles Chamber of Commerce Bldg., eleventh floor accelerograph:				
Vertical	0.19	1—	0.001—	
	0.15	1—	0.001—	
N. 40° E.-S. 40° W.	1.23	4	0.15	Long train.
	1.08	1—	0.02	
	0.35	1—	0.02	
N. 50° W.-S. 50° E.	1.28	2	0.07	
	1.02	1	0.03	
Hollywood Storage Co. Bldg., adjoining lot accelerograph:				
Vertical	Irregular	1—	----------	
North-south	1.28	1—	0.029	
	0.40	1	0.004	
East-west	1.57	1—	0.06	Irregular.
	Irregular	1—	----------	
Hollywood Storage Co. Bldg., basement accelerograph:				
Vertical	0.54	1—	0.004	
North-south	0.40	1	0.004	
	0.38	1	0.004	
	Irregular	2—	----------	
East-west	1.98	2—	0.15	
	0.44	1	0.005	
Hollywood Storage Co. Bldg., penthouse accelerograph.	----------	----------	----------	Vertical record lost.
North-south	1.35	8	0.35	Train of regular waves.
East-west	0.53	5	0.036	Do.

IMPERIAL VALLEY AFTERSHOCK OF MAY 19

El Centro accelerograph:	----------	----------	----------	Two more aftershocks on this accelerogram. Insignificant on all components.
Vertical	0.064	3	0.001	
North-south	0.18	1	0.001	
	0.16	2	0.001	Rather long wave train.
	0.092	2	0.001—	
East-west	0.18	2	0.002	
	0.17	2	0.002	
	0.17	1	0.001	

NORTHERN CALIFORNIA EARTHQUAKE OF SEPT. 27

Ferndale accelerograph:				
Vertical	0.31	6	0.015	
	0.26	2	0.003	
Northeast-southwest	0.44	7	0.036	
	0.31	3	0.008	
	0.20	6	0.006	
	Irregular	15	----------	Maximum at start of record.
Northwest-southeast	0.45	3	0.017	
	0.44	3	0.016	
	0.29	3	0.007	
	Irregular	17	----------	Maximum at start of record.

TABLE 2.—*Summary of strong-motion seismograph data for the year 1940*—Con.

SANTA MONICA BAY EARTHQUAKE OF OCT. 10

Station and component	Earth-wave period	Maximum acceleration	Maximum displace-ment	Remarks
	Seconds	*Cm./sec.²*	*Cm.*	
Hollywood Storage Co. Bldg., adjoining lot accelerograph:				
Vertical	Irregular	1	----------	
North-south	0.27	2	0.003	
	0.122	3	0.001	In aftershock.
East-west	0.45	1	0.007	
	0.37	1	0.005	
	0.26	1	0.002	
	0.107	2	0.001	In aftershock, fully recorded. S−P=0.4 sec.
Hollywood Storage Co. Bldg., basement accelerograph:	Irregular	2	----------	
Vertical	0.40	1−	0.002	
North-south	0.43	1−	0.002	
	0.28	1	0.003	
	0.28	1−	0.002	
	0.122	1−	0.001−	Aftershock.
East-west	0.20	1	0.002	
	0.28	2	0.004	At start of record; possibly preceded by stronger motion.
Hollywood Storage Co. Bldg., penthouse accelerograph:	0.104	1	0.001−	In aftershock.
Vertical	0.47	1	0.008	
	0.120	1	0.001−	In aftershock. At beginning of the record.
	Irregular	2	----------	
North-south	1.24	30	0.12	A long train of waves.
	0.54	3	0.021	At beginning of the record.
	0.112	2	0.001−	In aftershock. Superposed on the motion of period 1.24 sec.
	Irregular	4	----------	Irregular train of waves of variable amplitude and period.
East-west	0.51	6	0.040	
	0.49	8	0.049	At beginning of the record.
	0.48	3	0.018	
	0.128	4	0.002	In aftershock.
Los Angeles Chamber of Commerce Bldg., basement accelerograph:				
Vertical	0.30	3	0.007	
S. 50° E.-N. 50° W	0.31	1	0.003	
	0.083	1−	0.001−	
S. 40° W.-N. 40° E	0.34	1	0.003	
	Irregular	2	----------	
Los Angeles Chamber of Commerce Bldg., eleventh floor accelerograph:	----------	----------	----------	Weak aftershock also recorded.
Vertical	0.160	4	0.002	
	0.156	4	0.002	At beginning of the record.
	Irregular	7	----------	
S. 40° W.-N. 40° E	1.12	2	0.060	
	0.39	3	0.011	
	0.37	6	0.021	
	0.35	6	0.017	
	0.34	6	0.016	
N. 50° W.-S. 50° E	0.95	1	0.025	
	0.34	5	0.015	
	0.33	5	0.013	Do.
Vernon accelerograph:				
Vertical	0.26	4	0.006	
	Irregular	2	----------	At beginning of the record; possibly preceded by stronger motion.
N. 8° E.-S. 8° W	0.24	7	0.009	
	Irregular	15	----------	At beginning of the record.
N. 82° W.-S. 82° E	0.31	2	0.005	
	0.29	2	0.005	
	0.27	6	0.010	
	0.111	4	0.001	
	Irregular	14	----------	Do.

TABLE 2.—*Summary of strong-motion seismograph data for the year 1940*—Con.

EARTHQUAKE OF OCT. 22, NEAR CAPE MENDOCINO

Station and component	Earth-wave period	Maximum acceleration	Maximum displace-ment	Remarks
	Seconds	*Cm./sec.²*	*Cm.*	
Ferndale accelerograph:				
Vertical	Irregular	2		At beginning of the record; possibly preceded by stronger motion.
Northeast-southwest	0.69	2	0.024	Shorter period motion superposed.
	0.27	2	0.004	Superposed on longer period motion.
Northwest-southeast	0.74	2	0.028	
	0.33	2	0.006	

SANTA MONICA BAY EARTHQUAKE OF OCT. 31

Los Angeles Chamber of Commerce Bldg. basement accelerograph:				
Vertical	Irregular	1		
	0.17	1—	0.001—	
S. 50° E.-N. 50° W	Irregular	2		
	0.14	2	0.001	
S. 40° W.-N. 40° E	Irregular	1		
	0.13	1	0.001—	
	0.16	1	0.001	
Los Angeles Chamber of Commerce Bldg. eleventh floor accelerograph:				
Vertical	0.15	5	0.003	At beginning of the record. Possibly preceded by stronger motion. A train of smooth waves.
S. 40° W.-N. 40° E	Irregular	3		
N. 50° W.-S. 50° E	Irregular	3		
	0.20	3	0.003	

EARTHQUAKE OF NOV. 16 NEAR CAPE MENDOCINO

Ferndale accelerograph:				
Vertical	0.43	3	0.015	
	0.40	2	0.008	
	0.33	4	0.011	Shorter period motion superposed on these waves.
Northeast-southwest	0.55	2	0.017	
	0.45	2	0.009	
	0.33	4	0.011	
	0.18	5	0.004	
	0.17	4	0.003	
	0.14	4	0.002	
		9		At beginning of the record. Possibly preceded by stronger motion. Period indeterminate.
Northwest-southeast	0.39	5	0.018	
	0.34	5	0.014	
	0.16	7	0.004	
		16		At beginning of the record. Period indeterminate.

EARTHQUAKE OF NOV. 19 NEAR CAPE MENDOCINO

Ferndale accelerograph:				
Vertical	0.24	4	0.005	
	Irregular	11		
Northeast-southwest	0.38	8	0.029	
	0.36	13	0.043	
		37		At beginning of the record. Possibly preceded by stronger motion. Period indeterminate.
Northwest-southeast	0.69	2	0.023	
	0.66	3	0.036	
	0.42	12	0.054	
	0.23	8	0.011	
	0.17	16	0.011	
	0.134	7	0.003	

TABLE 2.—*Summary of strong-motion seismograph data for the year 1940*—Con.

EARTHQUAKE OF DEC. 20, NEAR CAPE MENDOCINO

Station and component	Earthwave period	Maximum acceleration	Maximum displacement	Remarks
	Seconds	*Cm./sec.²*	*Cm.*	
Ferndale accelerograph:				
Vertical	1.37	2	0.11	Poorly defined waves.
	0.52	13	0.090	
	0.31	10	0.024	
Northeast-southwest	0.92±	13	0.27	
	0.82	20	0.34	Only 1 wave.
	0.43	34	0.16	At beginning of the record.
Northwest-southeast	0.89	16	0.32	
	0.87	5	0.098	
	0.26±	34	0.058	
Eureka accelerograph:				
Vertical	0.34	2	0.005	
	Irregular	3	----------	
	Irregular	2	----------	
North-south	0.93	2	0.039	
	0.49	4	0.023	Do.
East-west	1.12	4	0.14	
	1.08	2	0.053	
	Irregular	5	----------	
Eureka displacement-meter:				
North-south	4.51	1—	0.15	
	2.54	1	0.19	Shorter period motion superposed.
	1.89	1	0.10	
East-west	2.40	2	0.22	
	2.03	1—	0.07	
	1.78	1	0.11	
	Irregular	----------	0.27	
	Irregular	----------	0.21	

MONTANA EARTHQUAKE OF DEC. 23

Helena accelerograph (Carroll College):				
Vertical	0.29	2	0.004	
	0.150	44	0.025	
North-south	0.35	8	0.025	
	0.191	30	0.028	
	0.154	64	0.038	At beginning of the record.
East-west	0.36	3	0.011	Poorly defined waves.
	0.132	23	0.010	
	Irregular	53	----------	

TABLE 3.—***Instrumental constants of strong-motion seismographs in 1940***

EARTHQUAKE OF JAN. 12 IN THE LOS ANGELES REGION

Station, instrument, and paper speed	Orientation of instrument [1]	Pendulum period	Static magnification	Sensitivity [2]	Damping ratio	Instrument number
		Sec.		*Cm.*		
Vernon; accelerograph No. 1; 0.886 cm./sec.	Up-down	0.100	106	2.63	8	V-66
	S. 8° W.-N. 8° E	0.100	107	2.55	6	L-64
	N. 82° W.-S. 82° E	0.097	107	2.60	7	T-65

IMPERIAL VALLEY EARTHQUAKE OF MAY 18

El Centro; accelerograph No. 4; 1.068 cm./sec.	Up-down	0.095	109	2.48	9	V-55
	N.-S	0.099	110	2.74	8	L-56
	E.-W	0.100	106	2.69	7	T-57
San Diego; accelerograph No. 5; 1.153 cm./sec.	Up-down	0.096	103	2.40	8	V-70
	E.-W	0.100	106	2.68	9	L-71
	S.-N	0.100	108	2.74	8	T-72
San Bernardino; Weed strong-motion seismograph No. 10; 0.217 cm./sec.	NE.-SW	0.19	7.66	0.70	2.1	R
	NW.-SE	0.19	7.79	0.71	2.1	L

TABLE 3.—*Instrumental constants of strong-motion seismographs in 1940*—Con.

IMPERAL VALLEY EARTHQUAKE OF MAY 18—Continued

Station, instrument, and paper speed	Orientation of instrument [1]	Pendulum period	Static magnification	Sensitivity [2]	Damping ratio	Instrument number
		Sec.		*Cm.*		
Los Angeles Subway Terminal Bldg.: [3]						
Basement accelerograph No. 38; 1.155 cm./sec.	Up-down	0.098	77	1.86	9	V-111
	S. 51° E.-N. 51° W.	0.096	79	1.85	10	L-91
	S. 39° W.-N. 39° E.	0.098	76	1.85	10	T-101
Basement displacement meter No. 15; 1.68 cm./sec.	N. 39° E.-S. 39° W.	9.8	1.14	----------	9	R
	S. 51° E.-N. 51° W.	9.8	1.14	----------	10	L
Thirteenth floor accelerograph No. 39; 1.016 cm./sec.	Up-down	0.100	81	2.06	11	V-112
	S. 39° W.-N. 39° E.	0.100	81	2.04	10	L-92
	N. 51° W.-S. 51° E.	0.100	80	2.03	11	T-102
Los Angeles Chamber of Commerce Bldg.: [3]						
Basement accelerograph No. 21; 1.179 cm./sec.	Up-down	0.098	108	2.63	10	V-28
	S. 50° E.-N. 50° W.	0.100	105	2.67	10	L-9
	S. 40° W.-N. 40° E.	0.097	104	2.48	12	T-26
Eleventh floor accelerograph No. 22; 1.182 cm./sec.	Up-down	0.099	107	2.66	12	V-25
	S. 40° W.-N. 40° E.	0.098	105	2.55	10	L-3
	N. 50° W.-S. 50° E.	0.100	107	2.71	9	T-18
Hollywood Storage Co. Bldg.: [3]						
Adjoining lot accelerograph No. 41; 0.965 cm./sec.	Up-down	0.101	77	2.00	9	V-114
	E.-W	0.103	83	2.22	10	L-94
	S.-N	0.100	77	1.95	10	T-104
Basement accelerograph No. 42; 0.926 cm./sec.	Up-down	0.099	81	2.02	9	V-115
	E.-W	0.095	82	1.87	10	L-95
	S.-N	0.100	81	2.06	10	T-105
Penthouse accelerograph No. 40; 1.144 cm./sec.	Up-down	0.101	82	2.12	10	V-113
	S.-N	0.104	77	2.11	8	L-93
	W.-E	0.099	80	1.99	8	T-103
IMPERIAL VALLEY EARTHQUAKE OF MAY 19						
El Centro; accelerograph No. 4; 1.086 cm./sec.	Up-down	0.095	109	2.51	9	V-55
	N.-S	0.100	110	2.79	10	L-56
	E.-W	0.100	106	2.69	10	T-57
NORTHERN CALIFORNIA EARTHQUAKE OF SEPT. 27						
Ferndale; accelerograph No. 28; 1.071 cm./sec.	Up-down	0.097	102	2.43	9.5	V-10
	SW.-NE	0.096	114	2.66	8.5	L-4
	NW.-SE	0.099	108	2.68	10	T-15
SANTA MONICA BAY EARTHQUAKE OF OCT. 10						
Vernon; accelerograph No. 1; 1.175 cm./sec.	Up-down	0.100	107	2.71	8	V-66
	S. 8° W.-N. 8° E.	0.101	104	2.69	6	L-64
	N. 82° W.-S. 82° E.	0.097	110	2.61	9	T-65
Los Angeles Chamber of Commerce: [3]						
Basement accelerograph No. 21; 1.166 cm./sec.	Up-down	0.099	109	2.70	10	V-28
	S. 50° E.-N. 50° W.	0.100	106	2.70	10	L-9
	S. 40° W.-N. 40° E.	0.098	104	2.54	10	T-26
Eleventh floor accelerograph No. 22; 1.141 cm./sec.	Up-down	0.100	108	2.74	10	V-25
	S. 40° W.-N. 40° E.	0.099	105	2.61	10	L-3
	N. 50° W.-S. 50° E.	0.100	108	2.74	8	T-18
Hollywood Storage Co. Bldg.: [3]						
Adjoining lot accelerograph No. 41; 0.985 cm/sec.	Up-down	0.102	77	2.03	8	V-114
	E.-W	0.103	81	2.17	9	L-94
	S.-N	0.100	77	1.96	10	T-104
Basement accelerograph No. 42; 1.067 cm./sec.	Up-down	0.100	81	2.05	8	V-115
	E.-W	0.096	82	1.90	10	L-95
	S.-N	0.100	80	2.03	10	T-105
Penthouse accelerograph No. 40; 1.229 cm./sec.	Up-down	0.098	81	1.97	9	V-113
	S.-N	0.102	77	2.03	8	L-93
	W.-E	0.097	81	1.93	8	T-103

TABLE 3.—*Instrumental constants of strong-motion seismographs in 1940*—Con.

CAPE MENDOCINO EARTHQUAKE OF OCT. 22

Station, instrument, and paper speed	Orientation of instrument [1]	Pendulum period	Static magnification	Sensitivity [2]	Damping ratio	Instrument number
		Sec.		*Cm.*		
Ferndale; accelerograph No. 28; 1.075 cm./sec.	Up-down	0.097	102	2.43	10	V-10
	SW.-NE	0.099	114	2.82	9	L-4
	NW.-SE	0.098	108	2.63	10	T-15

SANTA MONICA BAY EARTHQUAKE OF OCT. 31

Los Angeles Chamber of Commerce: [3]						
Basement accelerograph No. 21; 1.198 cm./sec.	Up-down	0.099	109	2.70	10	V-28
	S. 50° E.-N. 50° W.	0.100	106	2.70	10	L-9
	S. 40° W.-N. 40° E.	0.098	104	2.54	10	T-26
Eleventh floor accelerograph No. 22; 1.138 cm./sec.	Up-down	0.099	108	2.68	10	V-25
	S. 40° W.-N. 40° E.	0.097	105	2.51	10	L-3
	N. 50° W.-S. 50° E.	0.100	108	2.74	8	T-18

CAPE MENDOCINO EARTHQUAKES OF NOV. 16 and 19

Ferndale; accelerograph No. 28; 1.062 cm./sec. Nov. 16; 1.407 cm./sec. Nov. 19.	Up-down	0.097	102	2.43	11	V-10
	SW.-NE	0.098	114	2.76	9	L-4
	NW.-SE	0.099	108	2.68	10	T-15

CAPE MENDOCINO EARTHQUAKE OF DEC. 20

Ferndale; accelerograph No. 28; 1.079 cm./sec.	Up-down	0.098	102	2.48	11	V-10
	SW.-NE	0.098	113	2.76	10	L-4
	NW.-SE	0.098	110	2.68	11.5	T-15
Eureka: [3]						
Accelerograph No. 30; 0.923 cm./sec.	Up-down	0.099	102	2.53	10	V-29
	E.-W	0.099	110	2.72	11	L-13
	S.-N	0.099	111	2.76	9	T-8
Displacement meter No. 13; 0.547 cm./sec.	S.-N	9.90	1.14		9.5	R-13
	W.-E	9.87	1.14		9.4	L-13

MONTANA EARTHQUAKE OF DEC. 23

Helena; accelerograph No. 48; 1.172 cm./sec.	Up-down	0.099	76	1.89	9	V-135
	S.-N	0.099	81	2.01	11.5	L-133
	W.-E	0.102	81	2.13	9.5	T-134

[1] The direction on the left ("Up" 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] The sensitivity is the number of centimeters on the seismogram that corresponds to 100 cm./sec.^{2} of acceleration. The deflection corresponding to 1/10 gravity may be obtained by multiplying the sensitivity tabulated by 0.98. (See p. 37.)

[3] Instruments at this station are wired to start simultaneously.

STRONG-MOTION SEISMOGRAPH STATIONS, 1940

The following changes should be made in the list of strong-motion seismograph stations, table 6, in Serial 637, United States Earthquakes, 1939, to cover the year 1940:

The Weed strong-motion seismograph was removed from the Golden Gate Park station in November 1939 and placed in operation in the Courthouse at Hollister in June 1940. Coordinates of Courthouse: Latitude, 36°51.14′ north, longitude, 121°24.21′ west.

A new 12-inch accelerograph with experimental displacement-meter was installed at the Golden Gate Park station in San Francisco in April 1940.

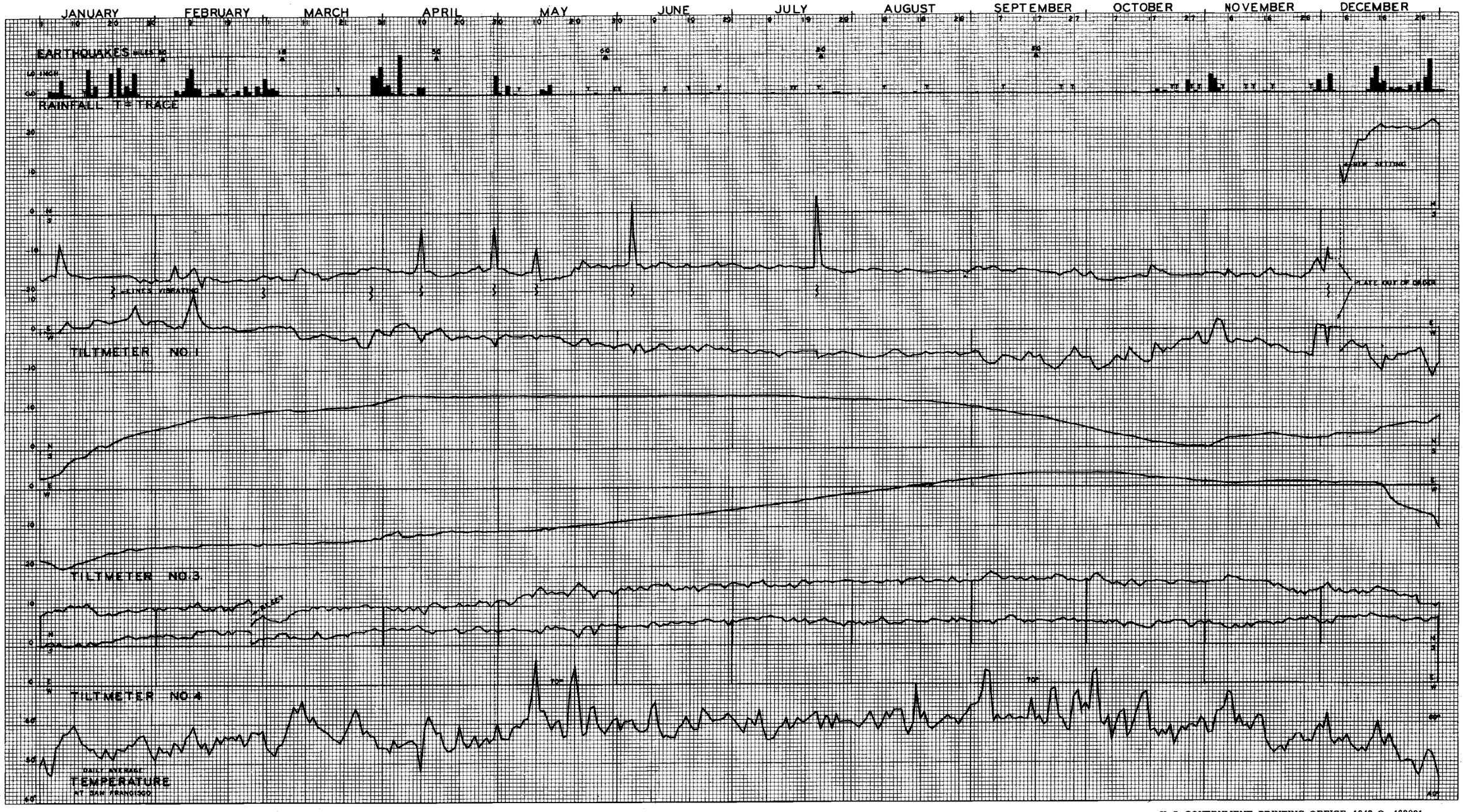

Figure 17.—Tilt curves for 1942.

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The station descriptions referred to in Serial 637 cover all of the places at which records were obtained in 1940.

TILT OBSERVATIONS

Three Merritt tiltmeters, described in Special Publication 201, Earthquake Investigations in California, 1934–1935, were kept in continuous operation at Berkeley with the cooperation of the University of California. Figure 17 summarizes the observational data in graphical form. Six earthquakes were felt at Berkeley during the year but no unusual changes in tilt were recorded before or after the shocks.

ANALYSIS OF THE EL CENTRO ACCELEROGRAPH RECORD OF THE IMPERIAL VALLEY EARTHQUAKE OF MAY 18, 1940

In addition to the analysis of the El Centro record given in table 2 the record was analysed by using methods of integration which produce the corresponding velocity and displacement curves. In view of results obtained in accelerometer shaking-table tests, and the nature of the adjustments necessary in the El Centro analysis, it is believed that the range of the computed displacement error does not exceed 2 or 3 centimeters. Such errors are of long period or undulating type and are associated with accelerations of extremely small magnitude. The details of the integration process and the difficulties encountered are explained in a special report, MSS–9, entitled "Analysis of the El Centro Accelerograph Record of the Imperial Valley Earthquake of May 18, 1940." Practically all of the material in this section, including illustrations, is taken from that report.

Fig. 18 shows the first 30 seconds of the three acceleration curves after separating them. Overlapping of the original curves was quite serious as will be seen in figure 9 and the separation was made with difficulty. The record therefore marks the maximum intensity which accelerographs with the present constants may be expected to record legibly. Steps are under way at this writing to test the feasability of reducing their sensitivity.

The computed velocity curves, obtained by one integration of the acceleration curves, are shown in figure 19. The curves have been corrected for wanderings due to accelerometer pendulum zero shifts which cause occasional abrupt changes in the direction of the axis of unadjusted velocity curves. Figure 20 shows the computed displacement curves obtained by integrating the velocity curves in figure 19. It is apparent from the computed curves that one of the greatest advantages in such work is the acquisition of data on the longer period waves which are almost totally obscured on acceleration records.

The analysis includes (1) a study of resultant horizontal motion diagrams, (2) study of longitudinal and transverse motions, (3) study of horizontal motion along polar coordinates—rotational motion, (4) a study of dominant periods, and (5) the construction of period-amplitude diagrams showing the envelopes for all three elements for periods from 0.1 to 10 seconds.

Resultant horizontal motion.—The *resultant acceleration* graph, figure 21, was plotted for the first 3 seconds only but it covers the period of maximum acceleration and it is assumed that it is characteristic of the accelerations which follow. The figures on the curve show the elapsed time from the start of the record in units very close to 0.1 second. It is rather noticeable that the first big loop has its major axis in the direction of the epicenter but in the next two circuits there is a shifting toward a north-south direction. This is an interesting

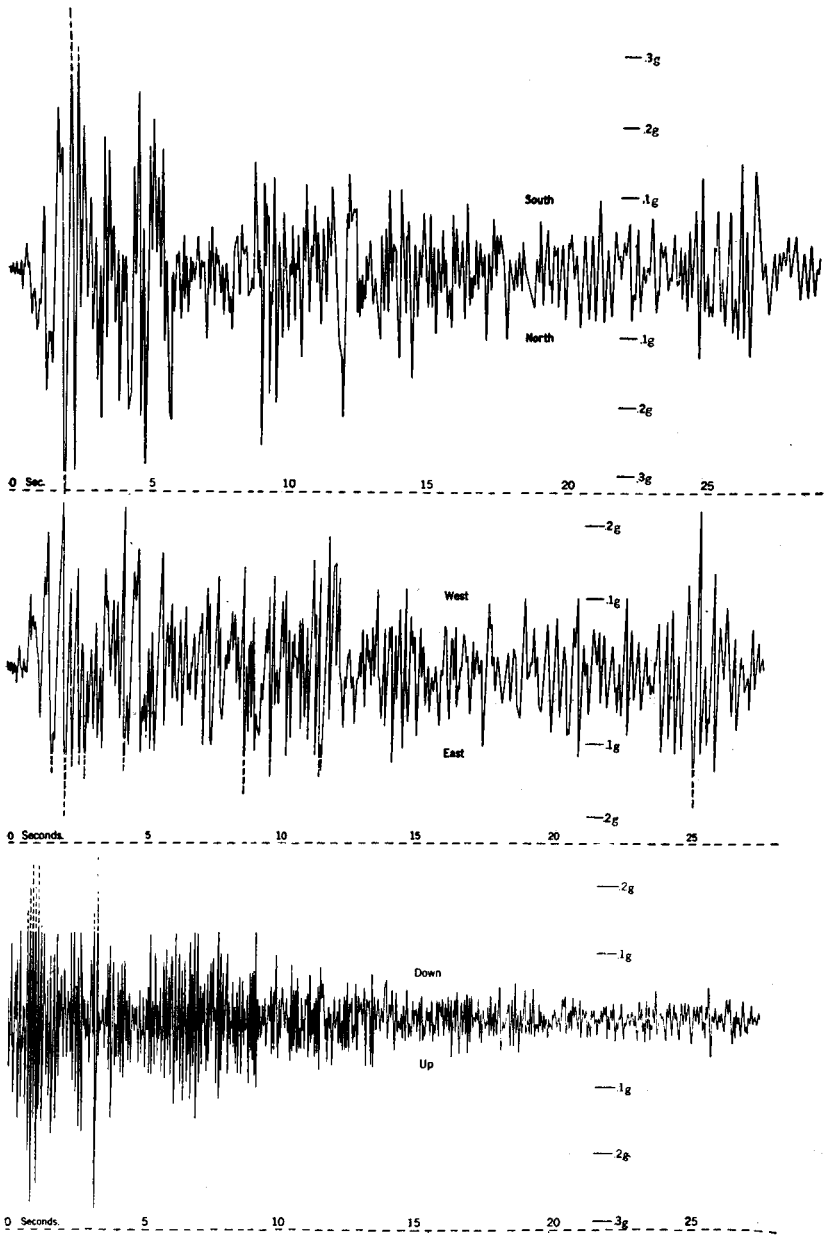

FIGURE 18.—Tracings of El Centro accelerograph record of the Imperial Valley earthquake of May 18, 1940.

phenomenon which may conceivably be due to a tendency of the vibrations to line up with the major axis of the Imperial Valley.

The maximum resultant acceleration is about 350 cm./sec.^{2} and is associated with a wave of about 0.4-second period between 19 and 23, figure 21. The motion in the opposite direction of this "loop" is only 250 cm./sec.^{2}, making the mean acceleration for this unsymmetrical cycle only about 300 cm./sec.^{2} A more symmetrical cycle with acceleration in both directions of 250 cm./sec.^{2} follows immediately. Its period is about 0.22 second. In the first of these loops the corresponding velocity and displacement (using the average acceleration) would

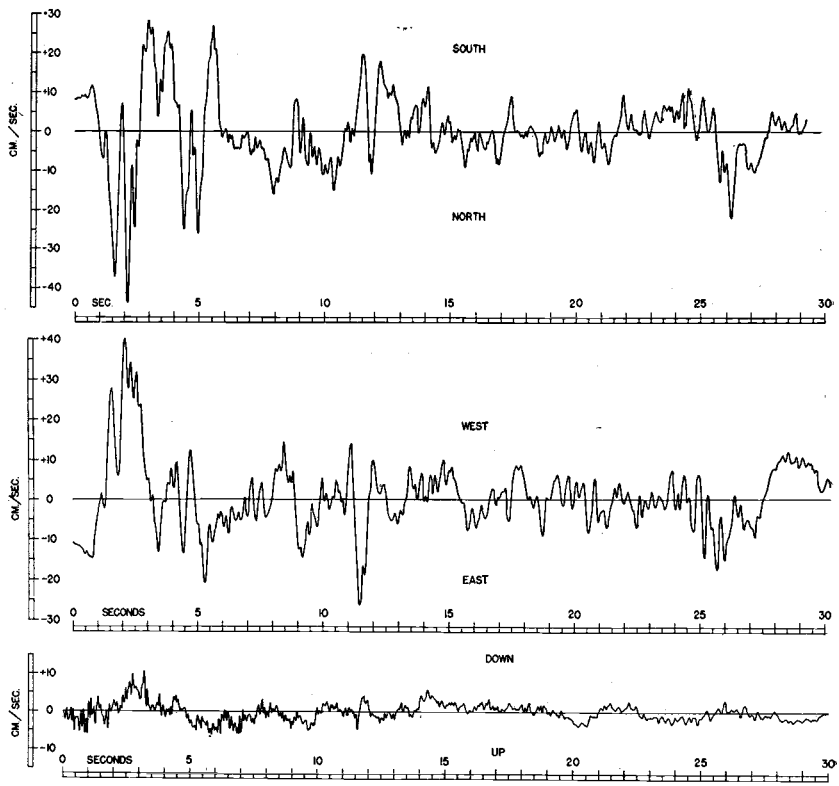

FIGURE 19.—Velocity curves computed from the El Centro acceleration record of the Imperial Valley earthquake of May 18, 1940.

be 19 cm./sec. and 1.3 cm. respectively; in the second loop, 9 cm./sec. and 0.3 cm., respectively.

The *resultant velocity* graph, figure 21, covers a period of 6 seconds, and each figure on the curve represents the interval in tenths of seconds, approximately, from the start. If we accept velocity magnitude as a function of the energy released, the graph would indicate that the greatest energy was being expended about 2.1 seconds after the start of the record in a generally northwest-southeast direction. The maximum velocity range, for any cycle appears to have occurred between 1.6 and 2.1 seconds after the start. This can be interpreted as indicating that the maximum energy was associated with a period

slightly over 0.5 second. This period also stands out clearly in the investigation of rotational characteristics later on.

The maximum resultant velocity is 59 cm./sec. but this high value is obviously the result of the superposing of two or more waves on each other. One of them is a wave of about 0.4-second period for which an average velocity of 24 cm./sec. may be measured if we consider that segment of the graph between 19 and 23 as a cycle. This

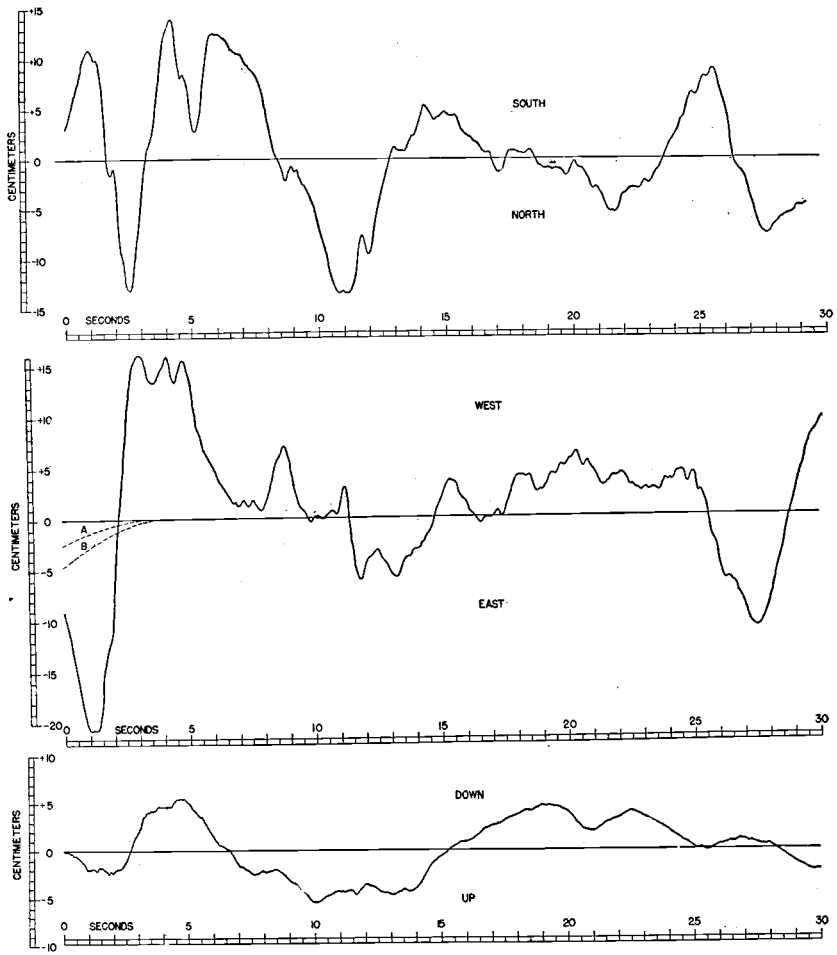

FIGURE 20.—Displacements curves computed from the El Centro acceleration record of the Imperial Valley earthquake of May 18, 1940.

quantity is variable depending upon just how it is measured. 19 cm./sec. was computed from the resultant acceleration graph for the same epoch. The nature of the motion on which this wave is superposed and which raises the resultant velocity to such high value is so complex that it is not posisble to assign any period to it on the strength of what appears on the graph. The longitudinal velocity wave (not reproduced here) reveals that it is a wave of about 2.5- or 3.0-seconds period with a maximum velocity of about 35 cm./sec. (This is also

a "rotation period" described under the section on rotational characteristics.) This velocity added to the 24 cm./sec. for the superposed wave would account for the resultant velocity of 59 cm./sec.

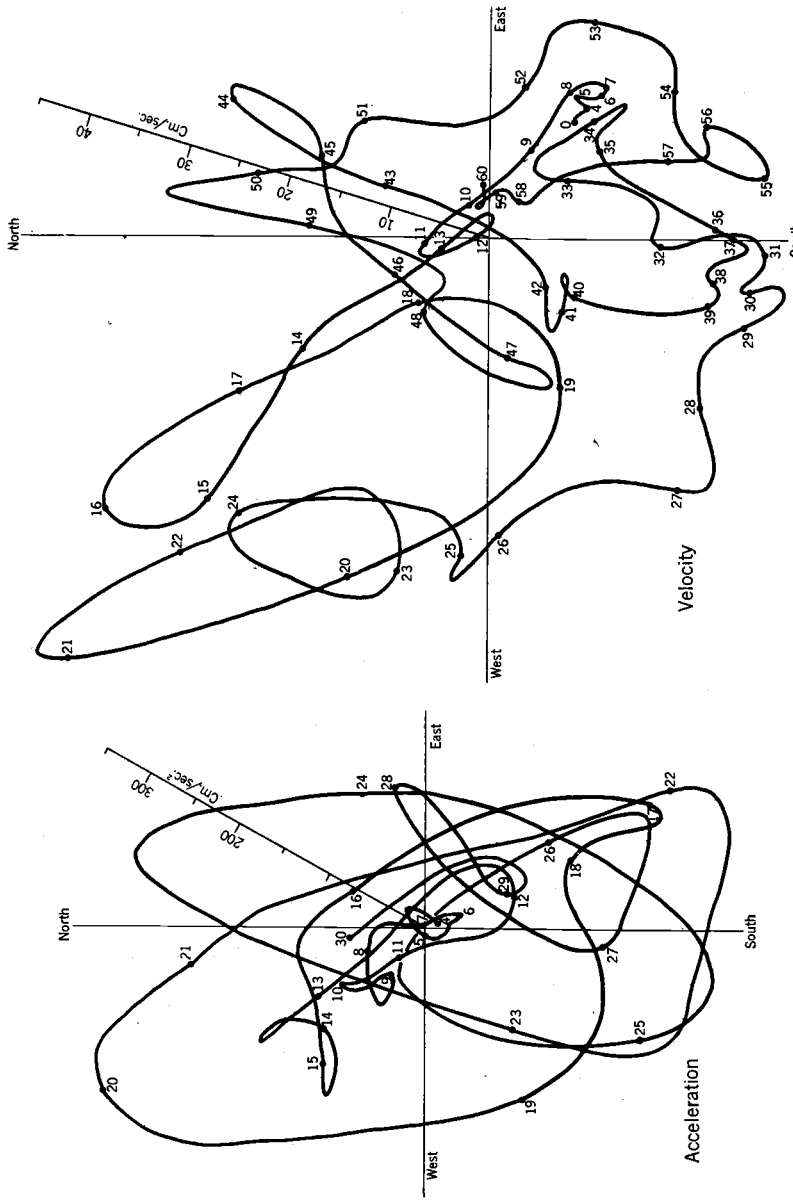

FIGURE 21.—Resultant horizontal motions, Imperial Valley earthquake of May 18, 1940. Acceleration and Velocity.

The *resultant displacement* graph is shown in figure 22 for a period of 29 seconds and is timed in the same manner as the two preceding graphs. A somewhat more precise version of this graph for the first 12 seconds is shown in the original report. Figure 22 shows the

nature of the major displacements rather than details needed to make comparison studies of the various graphs.

The maximum displacement is about 21 centimeters. The period is best shown on the longitudinal component and may be taken as 3.2 seconds. The corresponding velocity would be about 42 cm./sec. which ties in well with the general range of velocities at the start of the resultant velocity curve. The corresponding acceleration would be about 80 cm./sec.^{2} This is about one-fourth the amplitude of the superposed short-period accelerations, a ratio which is borne out by inspection of the acceleration curves.

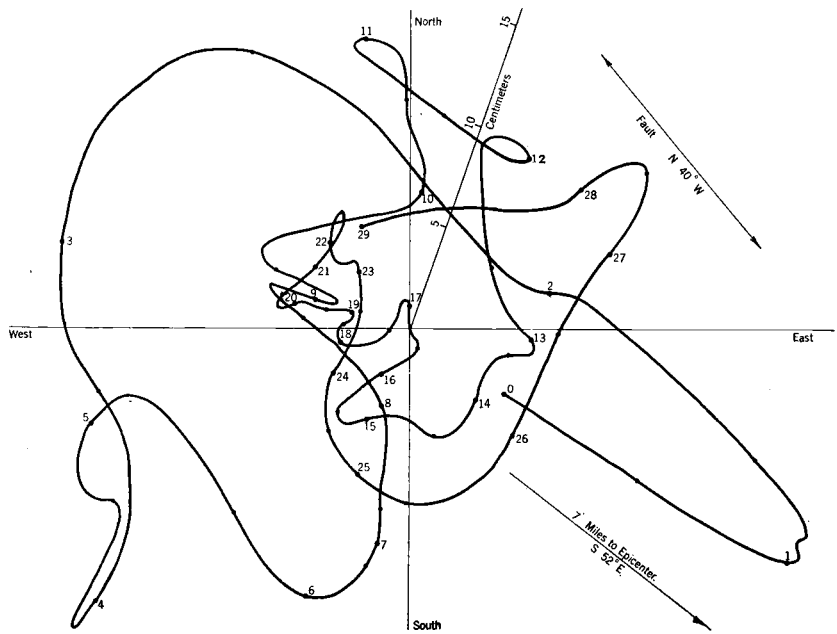

FIGURE 22.—Resultant horizontal displacement, Imperial Valley earthquake of May 18, 1940.

Vertical motion.—No attempt was made to combine the vertical motion with the horizontal to determine the nature of the vertical motion relative to the horizontal. An inspection of the acceleration record shows little tendency for the period to deviate widely from 0.10 second. In the early part of the record there are a number of turning points indicating periods as low as 0.03 second but they seem insignificant. The maximum vertical acceleration, 0.8 second after the start of the record is about 220 cm./sec.^{2}, and is associated with a period of 0.102 second. From the resultant horizontal acceleration graph it will be noted that this occurs while the horizontal accelera-

tions are only about one-fourth their maximum value. At this point it is difficult to associate the vertical with the horizontal motion because of the longer periods in the latter. This is also true when the horizontal acceleration reaches maxima between 1.8 and 2.5 seconds after the start. Here the vertical motion is of relatively small magnitude. Although waves of 0.11-second period are recorded on the horizontal acceleration records they are of generally small magnitude as compared with the vertical motion of the same approximate period, and no definite relation between them is readily evident.

With reference to the computed vertical velocity curve it is possible that further study may reveal some interesting relations between horizontal and vertical motion but as the vertical velocities are roughly only about one-fifth the magnitude of the horizontal, there would seem to be but little engineering significance in any relation which might be found. This is also true to a large extent of the vertical displacement. It is of interest to note that for the slow movements shown on the vertical displacement curve the high points appear when the displacement is in a northeasterly direction, and the low points when it is in a southwesterly direction. This, being associated with the longer periods, is of interest in the study of seismic wave theory. It is possible that a slow vertical motion along the fault is indicated.

Longitudinal and transverse motion.—With the aid of the resultant motion diagrams the motions were resolved along axes representing longitudinal and transverse motion with respect to the epicentral direction. This, according to theory, should simplify analysis of the motion by breaking it down into waves of purely longitudinal and transverse types. Unless seismograph pendulums are oriented end-on with respect to an epicenter the records contain some motion of each type. The curves, which cover the same period of time as the resultant motion curves, are not reproduced in this publication.

Periods of 0.11, 0.20, and 0.50 second were read from the longitudinal acceleration curve; 0.20, 0.30, and 0.50 second from the transverse.

Periods of 0.20 and 0.50 second were read from the longitudinal velocity curve, and 0.20, 0.30, 0.50, 0.70 (?), and 1.0 second from the transverse.

On the displacement curves periods of 0.7 (?), 1.0, 2.0, and 2.9 were read from the longitudinal component, and 0.7, 1.0, 2.0, 2.5 (?), 6.0, and 10.5 seconds from the transverse. All of these periods are later summarized for comparison with other readings.

This study of the El Centro records seems fruitful in showing that even when a station is as close as 7 miles to an epicenter, and still closer to a moving fault, the ground motion still preserves strong longitudinal and transverse characteristics and that fundamental ground periods can be measured best when these two components of motion are observed or computed.

Rotational motion.—Resultant horizontal motion graphs can be used not only to determine the motions along any system of rectangular coordinates, as previously stated, but they can also be used to study rotational motions by resolving the resultant motion along polar coordinates. This furnishes a means of showing independently the magnitude and direction of the motion at any instant for any element of motion. The symmetrical nature of the magnitude and direction

curves clearly indicates the existence of certain definite periods and it will be shown in the following paragraphs that these periods tie in almost identically with the dominant periods obtained previously from the longitudinal and transverse components.

In the case of rotational motion we must distinguish between the time required for the earth particle to make one complete rotation (rotation period) and the time required to complete a cycle (cycle period). It appears from the illustration that the earth particle may make several revolutions in one direction and then reverse itself, in the manner of a torsion pendulum. The rotation of the earth particle seems to be a natural consequence of the fact that the resultant motion is primarily a combination of oscillatory ground waves in which the earth particle motions are at right angles to each other.

Periods.—There seems to be no reason why the periods shown on the magnitude curves should not be true periods of ground waves, for similar waves would be obtained from the resultant horizontal motion graph of a simple longitudinal or transverse wave.

The acceleration magnitude curve shows dominant periods of 0.11 and 0.52 second. There is some evidence of a 0.15 second wave, but this is disregarded because of variations above and below that value. On the acceleration direction curve there is a rotation period of 0.5 second near a reversal of direction. At the highest rotational speed the rotation period is about 0.15 second. The cycle period, or interval between a reversal in the same direction, is about 2.6 seconds.

On the velocity magnitude curve dominant periods are 0.54 and 0.20 second. If we accept velocity amplitudes as a measure of wave energy, then the 0.54 second wave must be accepted as the most energetic of the group.

On the velocity direction curve the rotation period is between 2.5 and 3.0 seconds. A complete cycle is not indicated within the 6 seconds of the record worked up.

On the displacement magnitude curve, dominant periods of 1.0 and 2.0 seconds are present. The direction curve indicates a rotation period of 10 seconds and a cycle period of about 25 seconds.

None of the periods obtained in the study of rotation effects were used in the period graphs discussed later.

Dominant periods.—The following is a summary of all dominant periods previously stated as having been found on the longitudinal and transverse components, and on the magnitude and direction curves for limited periods of time. In all cases the maximum motions are included. In appraising the summary it should be remembered that minor errors are bound to creep into this type of work because of the limited number of points plotted for the various curves, and for other reasons, so that a tolerance of one, two or three digits in the last place for the tabulated periods must be allowed, the larger tolerances of course applying to the longer periods.

The following is a list of the dominant periods recorded, with the sources from which they were obtained:

Period	*Curves from which obtained*
0.11 second	Longitudinal acceleration, acceleration magnitude, and vertical acceleration; 3 sources.
0.20 second	Longitudinal and transverse acceleration, longitudinal and transverse velocity, and velocity magnitude; 5 sources.
0.30 second	Transverse acceleration and velocity; 2 sources.
0.53 second	Longitudinal and transverse acceleration, longitudinal and transverse velocity, acceleration magnitude and direction, and velocity magnitude; 7 sources.
0.7? second	Transverse displacement; weak on transverse velocity and longitudinal displacement; 3 sources.
1.0 second	Transverse velocity, longitudinal and transverse displacement, displacement magnitude; 4 sources.
2.0 seconds	Longitudinal and transverse displacement and displacement magnitude; 3 sources.
2.5 seconds	Transverse displacement, acceleration direction, velocity direction, acceleration "cycle period," velocity "rotation period"; 5 sources.
3.0 seconds	Longitudinal displacement; 1 source.
6.0 seconds	Transverse displacement; 1 source.
10.5 seconds	Transverse displacement, displacement "rotation period"; 2 sources.
25. seconds	Displacement "cycle period."

Period envelopes—relation between period and magnitude of motion.—The periods used in this investigation were measured largely from the original accelerograph record and the corresponding velocity and displacement curves. In the case of the acceleration data in the 0.1- to 1.0-second range, however, envelopes were drawn to cover measurements on the computed longitudinal and transverse curves. Although there was a definite grouping of periods for the longitudinal and transverse readings, the amplitude range did not differ materially from that obtained when readings were made on the original accelerograph record.

The period-amplitude envelopes are shown in figures 23 and 24. Some of the data are based on half periods where the lack of symmetry did not justify the measurement of the whole period or cycle. Judging by the uniformity of the data in the case of the 1- to 10-second curves, the measuring of half periods seems to be satisfactoriy where there is a lack of sufficient data to construct an envelope. Note that the acceleration envelope obtained from the acceleration data is practically the same as that obtained by computation from the velocity envelope based on measurements on the computed velocity curves.

In drawing the envelopes separate curves were drawn for the first large displacement. This may be considered abnormal with respect to the remaining motion, and perhaps with reference to ground

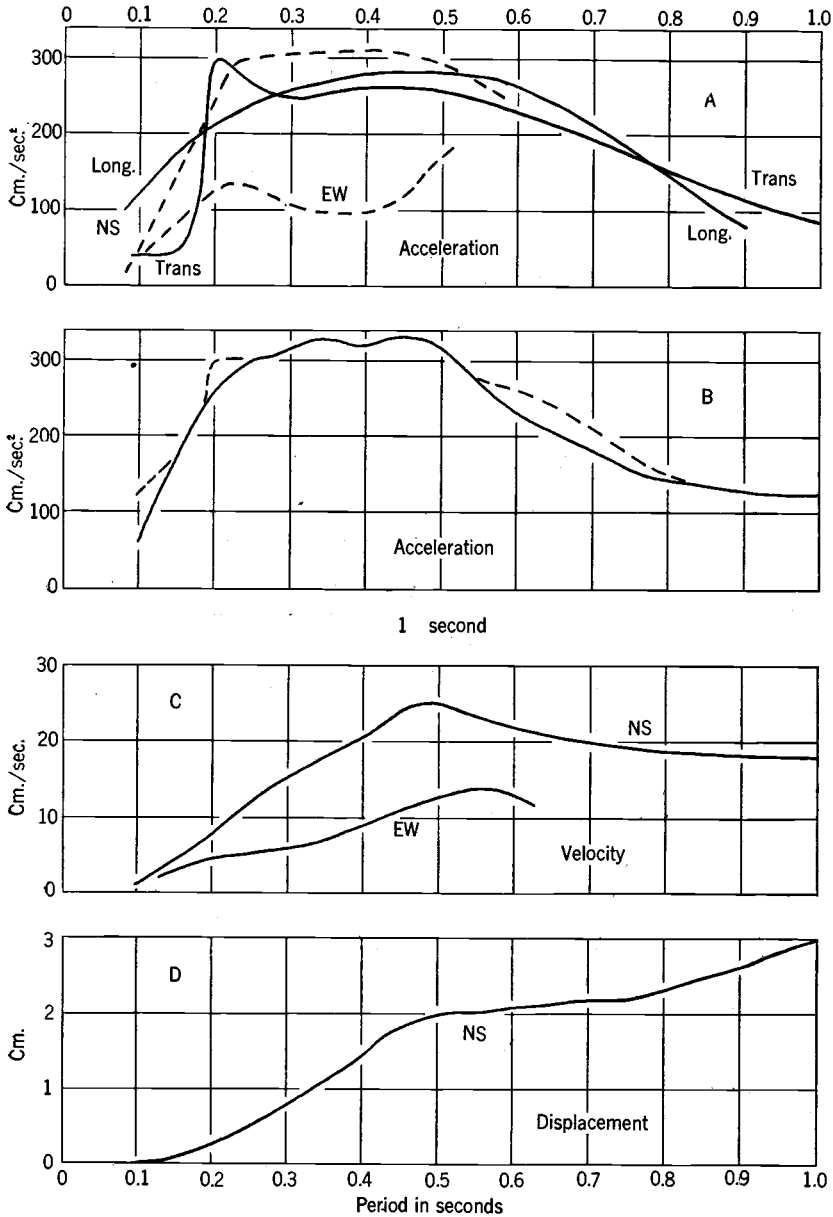

FIGURE 23.—Envelopes showing maximum values of all elements of motion for periods under 1.0 seconds. Imperial Valley earthquake of May 18, 1940.

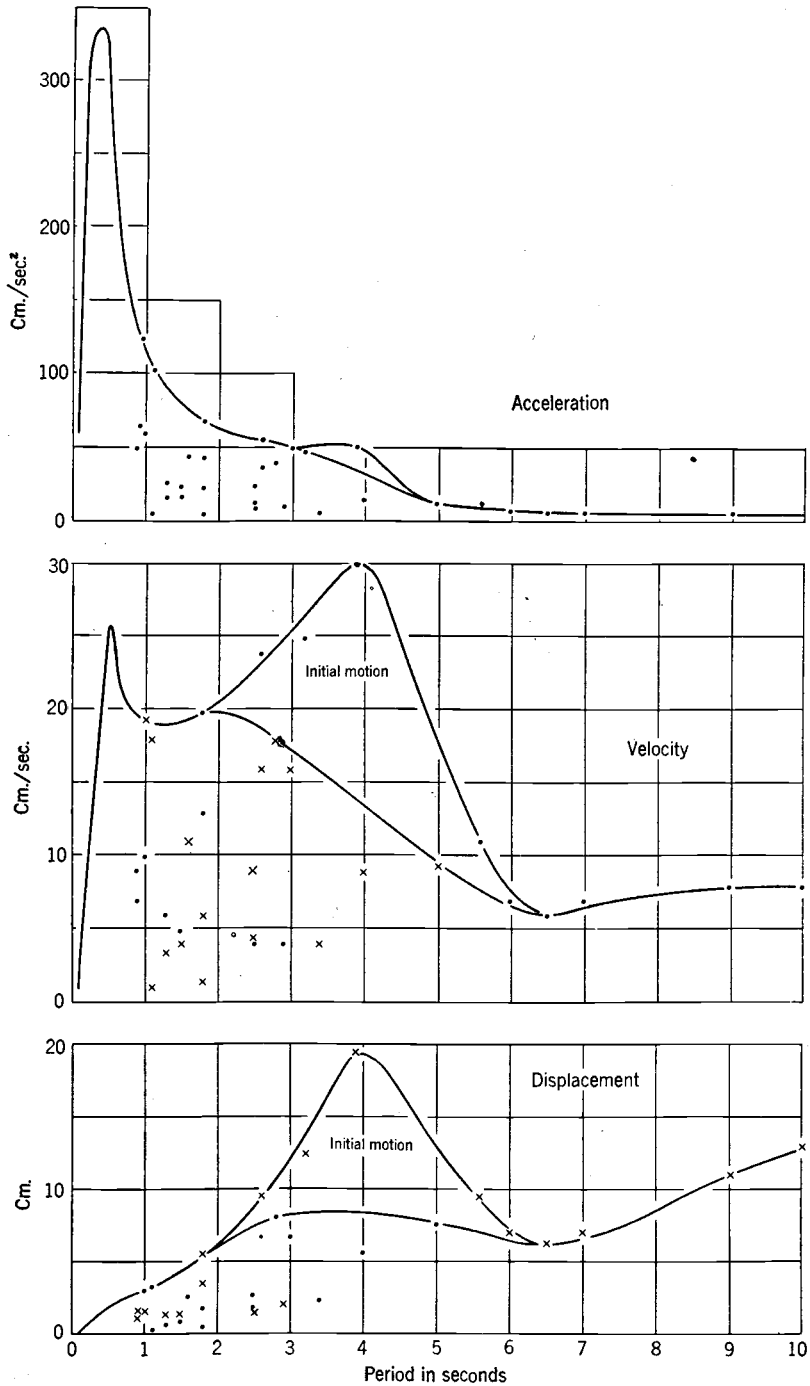

FIGURE 24.—Envelopes showing maximum values of all elements of motion for periods up to 10 seconds. Imperial Valley earthquake of May 18, 1940.

movements at points at greater distances than El Centro from the epicenter and fault. It is becoming more and more evident, however, that this outstanding displacement of relatively long period is typical of records obtained at short epicentral distances.

It will be noted that the maximum motions shown on the envelopes are always considerably less than the maximum movements shown on the resultant motion graphs. This is due to the fact that the resultant maxima are practically always a result of the superposing of two or more waves of different periods. In the section on horizontal motion graphs, it was shown quantitively how resultant maxima could be accounted for by combining waves of different periods.

The following table showing the maximum motions for the various period waves at El Centro, is based on the envelopes in Figs. 23 and 24:

Periods less than 1.0 second

Period (sec.)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Acceleration (cm./sec.^{2})	120	300	320	320	320	260	210	160	130	120
Velocity (cm./sec.)	2	10	15	20	25	25	23	20	18	20
Displacement (cm.)	0.03	0.3	0.8	1.3	2.0	2.4	2.6	2.7	2.7	3.0

Periods from 1.0 to 10.0 seconds

Period (sec.)	1	2	3	4	5	6	7	8	9	10
Acceleration (cm./sec.^{2})	120	65	50	50	11	8	6	5	4	2
Velocity (cm./sec.)	20	21	25	30	18	8	7	7	8	8
Displacement ,cm.)	3	6	12	19	13	7	7	9	11	13

A REVISED ANALYSIS OF THE HELENA, MONT., ACCELEROGRAM OF OCTOBER 31, 1935

In Serial 600, United States Earthquakes, 1935, the report on the analysis of the Helena accelerogram of October 31, 1935, included results obtained by double integration. The results were admittedly not satisfactory, and further investigation was promised. It has since been learned from shaking table tests made with the cooperation of the Massachusetts Institute of Technology that the major difficulty was the result of semipermanent shifts in the zero positions of the accelerometer pendulums, a condition suggested as a probable cause in the 1935 publication. It is now quite well established that errors in the displacement computation may be anywhere from 0 to 1 or 2 centimeters (single amplitude), seldom reaching the maximum value unless instrumental performance is below normal.

In reprocessing the Helena records only the first 17 seconds were used because that portion contains all of the motion of engineering significance. The original scalings, measured from an enlargement made with a lantern projector, were used in the revision. Although it was known from the Massachusetts Institute of Technology shaking table tests that a certain amount of heat distortion resulted from the use of the projector, it was felt that the original readings would be satisfactory because such distortion effects are largely eliminated when axis adjustments are as frequent as in the case of the Helena record of October 31. A time increment of 0.0565 second was used, the total number of increments being 300.

North-south component—Test with torsion pendulum analyzer.—The velocity curves in figure 25 show the final axes used in the computation of displacement. In the case of the north-south component the displacement was determined in 1936 with a torsion pendulum analyzer,[1] an experimental apparatus designed to mechanically compute the response of a simple oscillator to accelarations imposed on its support. The present revision afforded a means of comparing the two methods. Unforeseen circumstances somewhat vitiated the value of the comparison although the broader purpose was realized. The total range of displacement, for instance, was within the possible range of error expected in results obtained by double integration; and secondly, the instrumental performance was not up to standard because of an accident to the accelerometer in transit from the west coast and the emergency character of the installation. A number of velocity curve axis adjustments were accordingly necessary before a displacement curve was obtained which corresponded with some degree of fidelity to the torsion pendulum curve. The north-south displacement curve shown in figure 26 corresponds closer than any other to the

[1] A Mechanical Method of Analyzing Accelerograms, by Frank Neumann. Transactions American Geophysical Union, Part 1, 1936, pp. 111–115.

curve obtained with the torsion pendulum analyzer. The other curves, not reproduced here, come well within the expectable limit of error revealed in the Massachusetts Institute of Technology shaking table tests.

East-west component—permanent displacement.—Recomputation of the east-west component revealed a set of conditions which in all probability must be interpreted as permanent displacement. In the unadjusted east-west velocity curve, figure 25, the first condition to be satisfied in determining the true axis was that the axis in each segment of the curve must tentatively pass through the point representing the mean, centrally placed ordinate of the curve in that segment, and also connect with the axes of adjoining segments. This is found to be the only practicable basis on which to work even though the resulting displacement curve is distorted by forcing those points where axis shifts occur to roughly align themselves along an axis drawn through the starting point of the displacement curve. This alinement is due to the fact that the sums of the positive and negative areas in each velocity curve segment are approximately zero, thus making the displacement difference between the beginning and end of each segment also zero. After a curved axis is arbitrarily drawn through the distorted displacement curve (assuming oscillatory motion about a central axis) the relation of these critical points to the starting point of the curve is known, and final adjustment of the velocity curve axis is made to fit the new conditions. Although frequent zero shifts of the accelerometer pendulum tend to destroy the validity of displacement computations, it has been learned from shaking table tests and from experience that unusually large errors in displacement are associated with obvious abnormalities in the velocity curves and can therefore usually be detected. In other words, experience has shown that, within certain known limits of error, displacement curves representing oscillations about a central axis can be obtained by selecting velocity curve axes which produce a normal type of velocity curve, that is, a curve which in itself represents oscillations about a smooth central axis. But the Helena east-west component proved to be an exception to this rule.

Permanent displacement in the east-west component is indicated by an abnormal (unadjusted) velocity curve—abnormal because it is not possible to make a linear axis pass through or close to the mean, centrally placed ordinate of the first segment, and still satisfy end conditions reasonably well. But a reasonable axis can be drawn through the first segment provided the "mean" requirement is ignored. This indicates permanent displacement because there is a definite velocity in one direction which is not compensated. On the east-west component, figure 25, the mean ordinate of the first segment is indicated by the center of the small circle above the axis. The axis in this case was chosen to fit what were assumed to be the most probable beginning and end conditions in the first segment. A strong point in favor of the permanent displacement interpretation is that the excess velocity in one direction is coincident with the maximum velocity wave which represents the maximum energy of the ground motion. It is logical to expect that when a permanent displacement occurs it is associated with the maximum energy wave.

In considering whether the apparent presence or absence of permanent displacement may be due to frequent shiftings of accelerometer pendulum zero positions, it should be stated that permanent displacement does not call for a change in the average ordinate of the acceleration curve while the displacement is in progress. The presence of freak shifts in the acceleration curve which are of such nature that the positive and negative deviations will exactly balance within a definite time limit is extremely unlikely. This argument also holds true for errors of measurement.

The displacement curve, figure 26, shows the nature and magnitude of the permanent westerly displacement as based on the hypothesis just explained. It was obviously fortunate that the accelero-

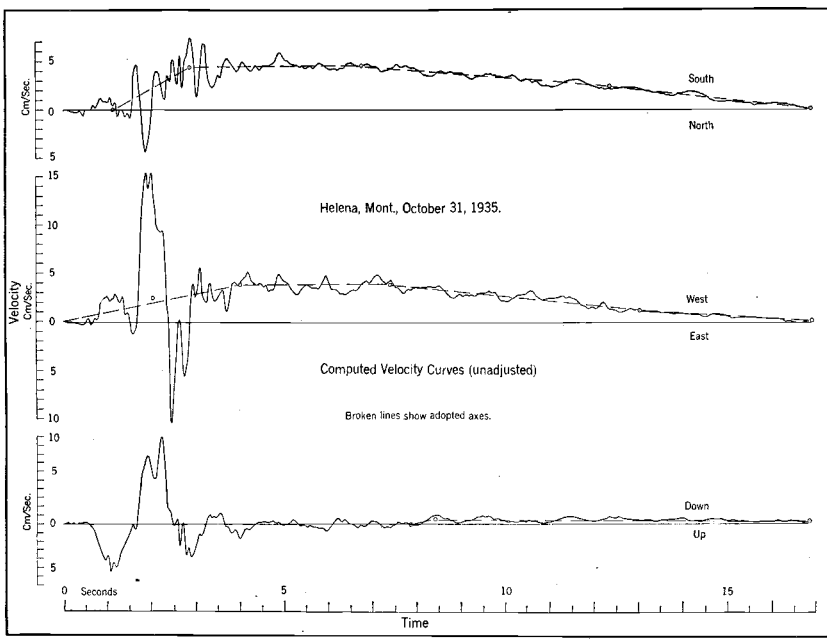

FIGURE 25.—Velocity (unadjusted) computed from the Helena, Mont., acceleration record of October 31, 1935.

graph operated so soon after the onset of the weak preliminary tremors; otherwise this part of the ground motion would have been lost. In most cases the early part of the ground motion is lost because it is necessary to adjust the starting pendulums to a low sensitivity in order that local artificial disturbances will not set the accelerographs in motion.

In the case of the vertical motion displacement curve, Figure 26, a drop of less than one centimeter is indicated if that part of the curve between 3 and 8 seconds is accepted as representing a new "zero" position. In view of the uncertainty attached to the slow drifting movement appearing in the curve at this time such a conclusion is plausible. Similarly a northward slip of about a half centimeter may be indicated on the north-south component.

Quantitative analyses.—The quantitative results previously represented in Serial 600 remain substantially unchanged. The value of this revision chiefly concerns the true form of the displacement curve. This is governed very largely by motions in which the accelerations are too minute to be of engineering significance or to influence the

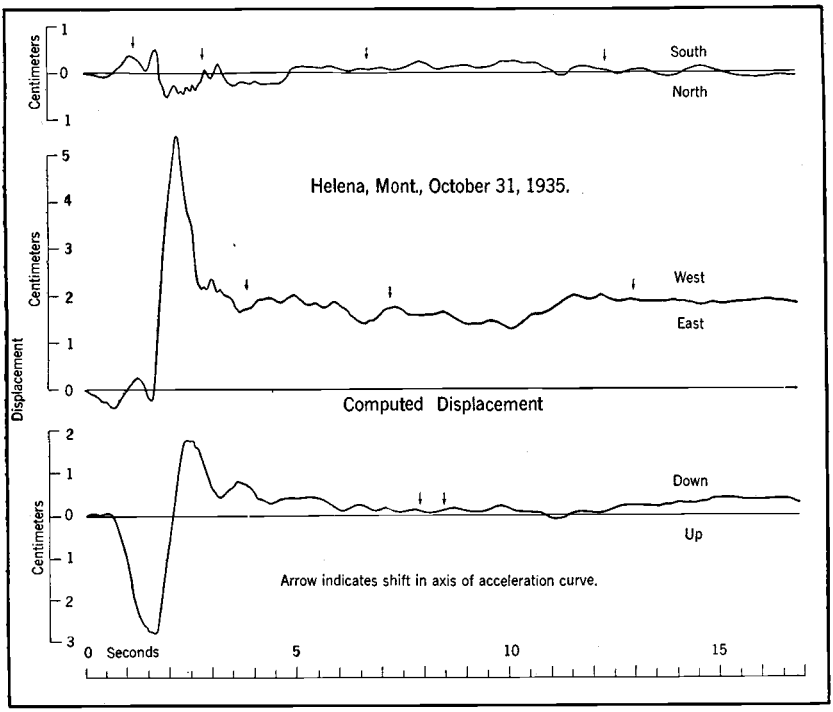

FIGURE 26.—Displacement computed from the Helena acceleration record of October 31, 1935.

form of waves of relatively short period. In view of the small amplitudes involved and the magnitude of probable displacement errors, there is danger that any further detailed analysis may lead to misleading conclusions.

1934: Correction to instrumental constant. In Serial 593, United States Earthquakes, 1934. At top of page 91 change orientation of the Santa Barbara accelerograph to read NE.-SW. and SE.-NW. instead of S.-N. and E.-W.

1934–39: Correction to instrumental constants. For the years 1934 to 1939, inclusive, change listed orientations of the Vernon pedulums to read "up," S. 8° W., and N. 82° W., for upward motions of the light spots, for the vertical, longitudinal, and transverse components, respectively.

1934, November 12: See The Earthquakes of 1934 and 1935 in Northwestern Illinois and Adjacent Parts of Iowa, by F. M. Fryxell, Bulletin of the Seismological Society of America, Vol. 30, No. 3, p. 213.

1935, January 5: See preceding reference.

1937, July 22: See The Alaskan Earthquake of July 22, 1937, by J. N. Adkins, Bulletin of the Seismological Society of America, Vol. 30, No. 4, p. 353.

1938, June 23: See The Chelmsford, Massachusetts, Earthquake of June 23, 1938, by Daniel Linehan, S. J., Bulletin of the Seismological Society of America, Vol. 30, No. 2, p. 99.

1939, January 11: 14:00.* Epicenter revision by Pasadena. Change 39.0° north, 119.2° west, to 38.6° north, 119.5° west.

1939, November 13: The Olympic Earthquake of November 13, 1939, by H. A. Coombs and J. D. Barksdale, Bulletin of the Seismological Society of America, Vol. 32, No. 1, p. 1.

1938, 1939, 1940: Earthquakes of the Northwestern United States and Eastern Canada, by D. Linehan, S. J., and L. D. Leet, Bulletin of the Seismological Society of America, Vol. 32, No. 1, p. 11.

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