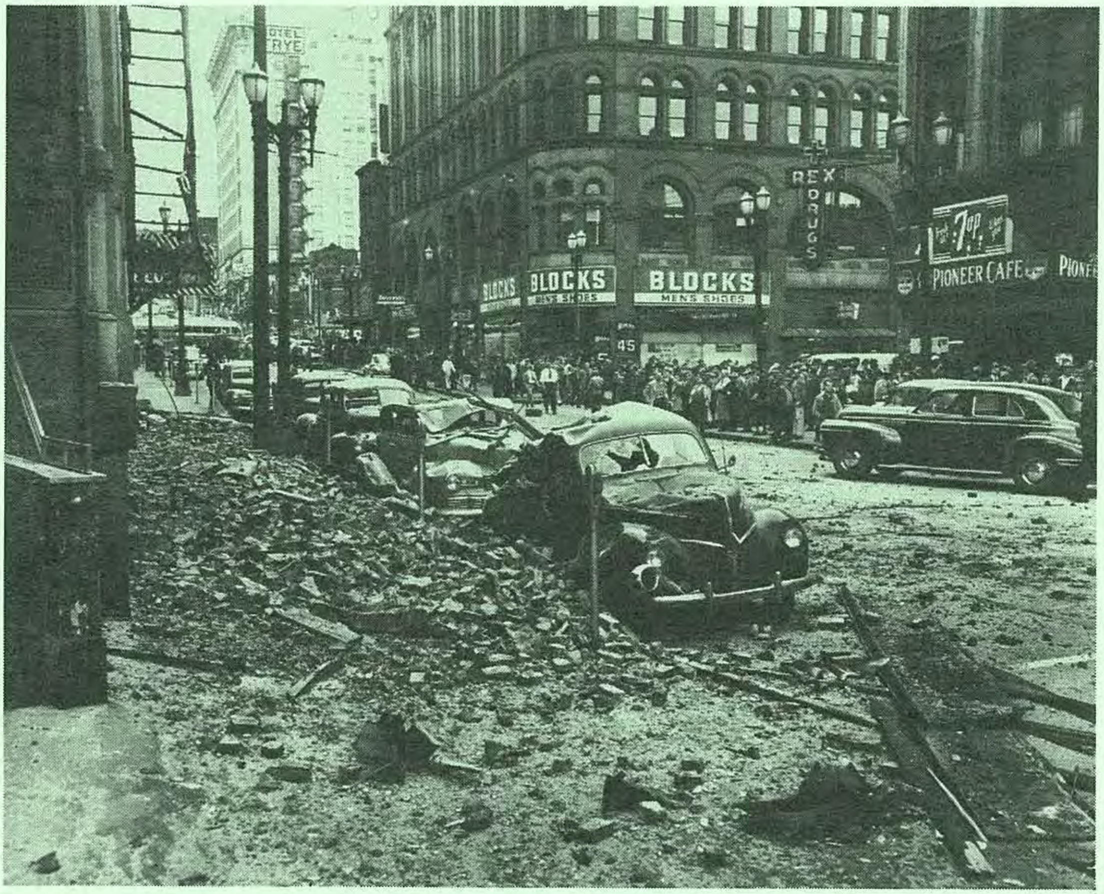
THE PUGET LOWLAND EARTHQUAKES OF 1949 AND 1965

REPRODUCTIONS OF SELECTED ARTICLES DESCRIBING DAMAGE

Compiled by
GERALD W. THORSEN



WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
INFORMATION CIRCULAR 81

1986

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Brian Boyle - Commissioner of Public Lands
Art Stearns - Supervisor

Front cover:

Falling parapets and ornamentation, rooftop water tanks, chimneys, and other heavy objects caused widespread damage during both the 1949 and 1965 events. Such falling debris commonly damaged or destroyed fire escapes, such as the one in the upper left. This Seattle Times photo shows Yesler Way on April 13, 1949. (Photo reproduced by permission of Seattle Times)

Back cover:

A. Earthquake-triggered landslides cut rail lines in both the 1949 and 1965 events. This slide occurred between Olympia and Tumwater. (1965 Daily Olympian photo by Greg Gilbert)

B. "Sand boils" were created by geysers of muddy water escaping from saturated sediments along Capitol Lake. Soil liquefaction, such as occurred here, was a common source of damage in low-lying areas of fill underlain by flood plain, tide flat, or delta deposits. Sidewalk slabs in this 1965 Division staff photo provide scale.

C. Suspended fluorescent light fixtures, such as this one in an Olympia school, commonly sustained damage during the 1965 quake. Three mail sorters were injured in the newly completed Olympia post office when similar fixtures fell. (Daily Olympian photo by Del Ogden)

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

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THE PUGET LOWLAND EARTHQUAKES OF 1949 AND 1965

Reproductions of selected articles describing damage

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INTRODUCTION

Since the Puget Sound region's most damaging recorded earthquake in 1949, the population of the Puget Lowland has more than doubled. Thus, the potential for damage and loss of life in future earthquakes has increased dramatically. Many of the reports of damage caused by that earthquake and more recent quakes were in publications of limited circulation, and many are out of print. Relatively few persons living in the area today were here during the 1949 event. This selection of reproduced information about the 1949 and 1965 earthquakes is intended to alert newcomers, as well as to remind the older residents, that the Puget Lowland is "earthquake country".

To help bring these earthquakes into current perspective, both monetary and population inflation should be considered. Using current U.S. Department of Commerce "price inflators", damage from the 1949 and 1965 earthquakes would approach $140 million and $40 million (in 1985 dollars), respectively. Human losses are more difficult to project because of the importance of the time at which a quake occurs. For example, Hopper and others (1975), assuming a 7.5-magnitude event in the southern Puget Lowland during business and school hours, estimate as many as 2,200 deaths, 8,700 serious injuries, and 23,500 temporarily homeless.

While examining the photographs of damage herein, one should keep in mind a fundamental shortcoming of our knowledge of seismic history: It is too short. The relative recency of settlement of the Pacific Northwest makes it difficult to project what is "normal". Major earthquakes, like volcanic eruptions, may not occur twice in an individual's lifetime. The 1949 quake may not have been representative of maximum shaking, duration of shaking, or depth of focus. Indeed, evidence is building that the Pacific Northwest could be subjected to an event of 8+ magnitude similar to the 1964 Alaska earthquake. Nevertheless, these accounts should remind us of some of the kinds of effects we can expect from the next damaging earthquake.

ACKNOWLEDGMENTS

We thank James E. Bihr, president of the International Conference of Building Officials, for permission to reprint the two articles from their "Building Standards" monthly periodical. Barbara Guptill, managing librarian in the Governmental Research Assistance Library of the Seattle Public Library, provided us with original articles for reproduction here.

Linda Johnson, of the Library of Congress, searched the records and confirmed that there had been no copyright renewal for the three articles from "Western Construction", a magazine that long ago ceased to be published. Don Duncan, Washington State Library, provided us with the original editions copied herein.

Jean Boucher, librarian for Shannon and Wilson in Seattle, was very helpful in loaning reports from their extensive collection. Gary Lundell, of the University of Washington Archives, made the Alfred Miller collection available for examination and arranged for copying of some of the photographs in this report.

Our special thanks to Connie Manson, librarian for the Division of Geology and Earth Resources, for her untiring effort in tracking down rare publications and clearing the way for their reprinting.

1st Installment: Complete Report of a 2-Year Committee Study on—

Lessons in Structural Safety Learned From the 1949 Northwest Earthquake

By HARLAN H. EDWARDS
Chairman, Earthquake Committee
Seattle Section, American Society of Civil Engineers

ABOUT NOON, Pacific Standard Time April 13, 1949, radio listeners were startled by excited announcements of a violent earthquake in western Washington and Oregon. By declarations of disaster which grew in size with each broadcast the impression was given that the cities of the area were a shambles, though it was far from the truth. However, frantic friends, relatives and others in distant areas who jammed communication lines for days in efforts to reach their loved ones could not know that this Pacific Northwest area was the world's luckiest place that day.

But the Northwest was favored!

Outstanding in natural beauty and moderate in weather, favored as a playground of the nation, the Northwest was unquestionably favored at 11:56 a. m. that April 13 by not only the earthquake but also by the fact that many of the schools were closed "on vacation."

Neither scenic beauty nor natural wealth would have availed anything had the shaking continued a little longer, or had there been the strong aftershocks that have characterized most of the severe earthquakes of recent time. Thousands of people who were on the streets at lunch time, that most-feared time for the occurrence of an earthquake, could have been buried under tons of parapet walls, ornamentation and broken building fronts. Thousands of children could have been filing out of the doors of their schools on their way to lunch or play only to be struck down by a hail of lethal masonry, could have been crushed in their rooms by collapsing buildings, or struck down on their playgrounds by falling walls and chimneys.

Yes, luck—if you want to call it that—was with us that day. Or could one call it the "handwriting on the wall?"

In the comparatively small proportion of buildings damaged, shocking conditions of building weakness were disclosed, conditions of inadequacy of design and of almost criminally cheap construction, duplicates of which exist in almost every city and state. Exposed to public gaze were the too-often-unrecognized results of penny-wise and pound-foolish policies which convicted owner, architect and builder alike of neglecting to consider in their structures the effect on human life of natural seismic forces which long since should have ceased to be "acts of God," which have occurred for ages and which may be expected to occur anywhere from time to time just as are heavy winds and floods.

An on-the-spot account of damage

Just before noon on that fateful though fortunate April 13, 1949, I was in a construction shack in Chehalis, Washington, checking over plans for a building being erected. Suddenly I sensed a vibration and heard a dull rumble that was foreign to the hustling and hammering of the job. It was more like a heavy truck approaching rapidly over a rough road.

"Something's not right," I thought, because vibrations of structures usually mean trouble to me. My work is that of a construction supervisor and structural engineer. From years of experience in the West I knew that such sounds and movements were not conducive to the health of structures, and particularly the health of the old brick buildings nearby.

The thought had scarcely flashed through my mind when the old frame shack weaved and shook, creaking in its every joint to the accompaniment of the unearthly rumble and muffled roar of an earthquake. My curiosity getting the better of my training to "stay put" during an earthquake, I dashed out of the door, saw the poles in the alley weave crazily and the taut wires swing in jerky circles like the jump rope of a pair of kids. I heard the rattle and dull roar of the brick walls of the garage across the street falling outward upon the cars parked closely in the lot adjacent. I saw the cloud of dust arise, then settle slowly upon the wreckage of cars that a moment before were the pride and joy of many families. I heard the shouts of excited people, then all was still like the lull after a storm. I wondered what was happening to the noonday crowds in Olympia, Tacoma, Puyallup and Seattle —whether the quake there had continued long enough to cast down upon them the tons of brick, terra cotta, glass and stone that are loosely attached to

How and Why the Seattle Section of ASCE Prepared This Report

ON APRIL 13, 1949, the people of western Washington and Oregon were shown that strong earthquakes could occur in their locality. Property damage as a result of the quake on that date totaled more than $15,000,000 and seven lives were lost. With the quake classified as VII and VIII on the Modified Mercalli scale, major damage resulted in the low, soft land areas extending from Seattle southward to Longview including the cities of Puyallup, Tacoma, Olympia, Centralia and Chehalis. Minor losses were suffered by other communities and outlying areas.

Competent observers in the area agree that had the violent phase of this temblor continued a few seconds longer, or had there been aftershocks of any consequence, the number of people meeting sudden death from buildings collapsing or masonry facings falling would have been appalling. Evidenced by fractures and sometimes-concealed incipient failures, tons of insecure masonry parapet walls, heavy cornices, ornamentation and whole faces of weak buildings would have cascaded down upon the streets giving few in the noon-hour crowds a chance to escape.

Considering the hazards thus made evident, and realizing that engineers are in duty bound as a public service to carefully analyze those conditions and make impartial corrective recommendations, the Pacific Northwest Conference of Earthquake Committees of the American Society of Civil Engineers was formed under the chairmanship of Prof. Alfred L. Miller of the University of Washington. Member committees were set up by actions of the local sections of the Society. Beginning on this page is the complete report of the Earthquake Committee of the Seattle Section, A.S.C.E., the committee being composed of Harlan H. Edwards, author-chairman; Cecil C. Arnold, vice chairman; S. Chas. Dearstyne, Elmer E. Gunnette, Homer M. Hadley, Wm. Enkeboll, Thos. Campbell and Holger Mittet.

Research was made and studies were conducted by the committee into many aspects of the subject earthquake. These included the following:

1. Examination of records of this earthquake and of other earthquakes back as far as recorded.

2. Examination of physical earthquake damage in the several areas and determination of extent and types of damage caused to structures, utilities, equipment and miscellaneous installations.

3. Collection of records, descriptions and photographs from all over the shaken area for study and comparison.

4. Conferences with representatives of bodies experienced with enforcement of measures to prevent earthquake damage, and study of laws and provisions designed to correct present structural inadequacies and to protect against such damage in new construction.

5. Discussion, sifting and weighing of all the information obtained, and developing the final conclusions and recommendations, as submitted in the report.

The complete report of the committee is being presented by *Western Construction* in three installments, beginning with this issue.

A BRIEF OUTLINE of the complete report prepared by the Earthquake Committee, Seattle Section, ASCE, as it will be published in this and the following two issues of *Western Construction* is as follows:

FIRST INSTALLMENT (this issue)—An on-the-spot account of the quake characteristics and damage to various types of structures as background for recommendations to be presented later; a discussion of the effects of this quake as compared to others.

SECOND INSTALLMENT (March issue)—Facts on how new structures can be built and old ones strengthened to become earthquake-resistant, based on analysis of damage by the Northwest quake.

THIRD INSTALLMENT (April issue)—Recommendations for a new approach to the design of structures in areas subject to earthquake hazards; legislation required to achieve the goal of structural safety in the Northwest and elsewhere.

the many buildings that line the streets. Heaven forbid such a disaster!

Mindful of the destructiveness of the aftershocks, if they came, I dashed to my car parked in front of the job, got it away from the old masonry buildings, grabbed my camera and started taking pictures. As usual, the ornate City Hall and Library entrances were blocked by fallen masonry. The structures were racked and broken. From a vantage point a few blocks up the hill I could see that the wood frame residences and similar structures visible from there had fared well so far. Only chimneys were down, but in that respect the damage was almost universal; 1,334 were later counted by the building inspector of that small city. Down the street the Methodist Church tower had broken, partly falling through the roof into the sanctuary and partly, as usual, over the front entrance stairs. Luckily, this was not a church day.

THIS FISSURE and others extended about 100 ft. in an old gravel pit near Centralia. At many locations, consolidation of alluvium by vibratory action of the earthquake freed water retained in spaces between soil particles, causing geysers of mud.

Public buildings damaged, as usual

A block further on, the children of the Junior High School were all out on the lawn. Their building did not seem damaged but on circling to the rear I saw the high brick chimney above the boiler room shattered, with a large chunk on the building side loosened ready to fall into the school. It was a good thing for the kids that the shake didn't last longer. Downtown, a similar chimney did fall from a building, coming to rest in the tangled debris of the display room of a store.

To the south of town several buildings at the State Training School for Boys were badly shattered and partly collapsed, reminding me of the wrecked schools of Long Beach, California, on March 10, 1933. At Castle Rock one of the High School students was struck down by falling brick from above the entrance as he left the school for lunch, while at Longview, on the alluvial plain of the Columbia River, heavy damage had occurred in places. At Centralia, damage similar to that of Chehalis had been suffered, killing one man downtown who was struck by the falling upper walls of a 2-story corner building.

SUBSIDENCE OF FILL brought this old piling to view through asphalt pavement in Olympia. In other areas, piles not driven to refusal dropped out of sight, while some freestanding piles rose.

By this time I had calmed down sufficiently to turn on the radio in the car. Hearing the reports of disaster broadcast, I realized that I had better start for home. As I neared the town of Tenino, north of Centralia, the broadcast told of its shattered buildings and of streets strewn with wreckage, but as I drove through, it was "business as usual." False Alarm! Although real damage had been done in many areas, the radio broadcasts were increasingly excited, exaggerated, and not dependable.

MORE THAN 10,000 unreinforced brick chimneys in the Northwest required repair after the quake. Many just turned on a mortar joint, as at this residence in Kelso, but far too many created hazards by toppling.

It soon became evident that the shock over the whole area had been of a rolling nature which, like the shaking of a bowl of jelly, amplified the movement of structures on the earth's surface, particularly on soft ground. Some damage was done to buildings on firm, compacted gravelly deposits also, but only sufficient to indicate that these areas, too, could be shaken strongly, given the right provocation.

Concealed weaknesses come to view

Outside Olympia at an old 1-story and basement wooden elementary school structure one complete chimney fell away from the building and spread its length over the playground. The top three feet of another chimney crashed through the roof and ceiling to the solid floor beside the blackboard of a classroom. No, there were no casualties, for the children were on vacation.

The School Board had apparently foreseen the need for a better building, because across the street was a new wood-frame-stucco school just ready for occupancy. It showed no damage, for according to qualified observers from California it was of the earthquake-resistant design closely approaching the concept of engineers and architects experienced in areas where earthquakes admittedly occur.

In Olympia another school was nearing completion. An unreinforced ma-

TOP—Poorly anchored brick veneer was knocked off Seattle structure. The obvious lesson here is that building facings must be designed to resist a reasonable amount of horizontal force.

BOTTOM—A man was killed in downtown Centralia by the falling upper walls of this 2-story corner building. Had such damage occurred during the rush noon-hour, more would have died.

sonry partition showed a very distinct crack about 8 ft. long, although green mortar generally concealed this weakness from public view. It was interesting to note that the reported cost for the new, substantially safe elementary school was $10 per sq. ft. of floor area while that of the other, uncertain but ornate school was approximately $15 per sq. ft.

Capitol buildings sitting ducks

Olympia was close to the epicenter of the earthquake and damage was noticeably greater in the larger structures. Buildings of the State Capitol group, typical of many stone-faced masonry structures built throughout the country without regard to seismic shock were materially damaged. The 80-ft. diameter stone-faced reinforced concrete dome of the capitol building erected in 1925 and rising 231 ft. above the entrance terrace showed little damage but that was not so concerning the stone lantern above it. As might be expected in a building of this type built without a continuous frame and having a heavy inverted pendulum forming the dome, large deformations were set up by the earthquake which caused the near-collapse of this lantern as well as typical shear cracks and minor movements in other parts of the structure. Many of the stones of the lantern were separated from the adjoining ones, a few had dropped out and others were hanging loose when the quake stopped.

Other buildings of the capitol group were broken, too. Parapets and cornices were down and many characteristic diagonal cracks were noted in interior partitions and walls. It was particularly evident that the large blocks of stone, wherever they were, had practically no mechanical anchors or ties to each other or to the backing, if any existed. They were just sitting there like ducks on a pond. It was noted and confirmed later, too, that in common with many similar structures of the same or greater age, little mortar existed in many vertical joints and not much more was seen in many of the bed joints.

In Olympia's business district substantial damage was suffered, too, while two tall brick chimneys on the tongue of the harbor alluvial fill were damaged. One broke and fell through the roof of its adjoining boiler plant and killed a man.

Substantiating the severity of the shock which caused all this and other damage in Olympia, authenticated accelerograph records were obtained on instruments of the Coast and Geodetic Survey, located near the State Highway Laboratory on the downtown tideflat fill. These records showed that the force exerted by this quake was more than 4 times the force normally used in designs for complete earthquake reinforcement as done in California where earthquake-resistant design is now standard practice.

Damage at Tacoma

At Tacoma, too, were occurrences of great interest, both on the lowlands and upon the hard gravel of the high land above the business district. To the westward the new Tacoma Narrows Bridge was under construction. A very heavy cast steel saddle which ultimately was to receive one of the great cables supporting the bridge was temporarily resting on wood blocking 3 ft. above the top of the high bridge tower, bolted tight to the tower top plate with four 1-in. vertical rods. During the quake, according to the testimony of men working on the tower, the top moved at least 6 ft. from its position of rest, then snapped back the same or greater distance the other way, breaking the bolts and throwing the casting off. It crashed through a work barge on the water 65 ft. to one side and 507 ft. below.

On the Tacoma lowlands as in Olympia, high factory chimneys broke off, parapet walls fell, and a 75-ft. high brick wall fractured 15 ft. from the top, moved out 5 in., but didn't collapse. On hard ground high above the business district the stone masonry tower of the 60-year-old county courthouse was badly racked by the shocks. It was so fractured in the uppor portion that collapse probably would have been certain had the earth movement continued, according to testimony of the building inspector and consulting structural engineers later on. In contrast, a local senior building group pooh-poohed the danger of collapse and pleaded "don't demolish it—only the cracks need be pointed up. It is a fine example of period architecture and it would be a shame to tear it down." They gave little thought to the fact that structures once cracked and broken remain in that state of suspended destruction until the next quake occurs, then anything could happen. They gave no consideration to the fact that the main structure far below was used by the public, or that it contained the county jail which housed many people against their will, all carrying definite responsibilities for maintaining protection. (Note: the dangerous portion of the tower was later removed.)

Strange things at Puyallup

In nearby Puyallup, strange things had happened. Located on natural alluvium having the ground water level 2 to 3 ft. below the surface, many of the brick buildings (which dated back many years) were damaged. Cornices and upper walls had collapsed. Low buildings bumped against higher ones having a different rate of motion in the earthquake, breaking the higher walls as they stopped short in their square dancing. Brick moved on brick as much as 3 in. outward at floor and roof levels of some large buildings, leaving the walls precariously near failure. Broken brick lined the wide cracks that were left when street faces of stores stopped on their weaving way to the sidewalk below, lacking the "pushover" of the usual aftershocks.

But this was not all. Throughout the town as least 200 chimneys were rotated up to 45 deg., generally in a clockwise direction with respect to the building, but few fell. Geysers of muddy water rose in many yards to heights as much as 3 ft., forming circular deposits of black, sandy clay while in some basements the surging earth pushed the floors up, crushing the furnaces and piping against the joists above.

Closed to public view and not under jurisdiction of the city building department and code, the unanchored roof and ceiling beams over the stage of the Puyallup High School auditorium slid off their supporting masonry walls and crashed down upon the floor below. Three students who were there when the quake started managed to be clear when the $100,000 crash came.

"Almost" at Seattle

Seattle, fortunately, was on the northerly border of the earthquake's strong rumbling and rubbling and except for buildings on soft ground, it suffered comparatively little from the shakeup. Not that the buildings were resistant to earthquakes, I hasten to add (for they were far from it) but because the shaking stopped too soon for damage to develop much beyond the cracking stage. Structures on hard ground were shaken, but not hard enough to hurt much. Masonry partitions were cracked and spalled, plaster fell, terra cotta facings loosened or sheared. On soft ground especially, many old building fronts and parapet walls broke their bonds to the rest of the structure but did not receive impetus enough to crash to the street. With a goodly part of their "earthquake life" gone, they now remain in their weakened condition ready to fall upon the people on the walks, come the next quake. Even without the seismic urge, three or more heavy chunks of masonry have fallen in downtown streets of Seattle in recent months, narrowly missing pedestrians.

Damage on the tide-flat

On the water-saturated, jelly-like tide-flat fill extending from west Seattle to the lower downtown section, however, substantial damage was done. Structures built on piles along the waterfront were whipped violently. A 50,000-gal. wood stave water tank resting on a reinforced concrete platform on 20-ft. high concrete columns above the building had suffered damage to the columns in the 1946 earthquake. Presumably adequately repaired at that time, but still fractured and weakened at the points of greatest stress, in this the succeeding quake it was precipitated to demolition. Its concrete platform crashed down through the concrete roof slab to the floor below breaking refrigeration lines, destroying the building's two elevators and putting the 7-story reinforced concrete refrigeration warehouse out of service for weeks. Cables supporting elevators in other buildings jumped out of their sheaves. A heavy track-mounted electric transformer moved up and off its supports at a substation and landed on the ground 17 in. away. Elsewhere in the area pre-1900 brick walls were collapsed, fractured or bulged and several old downtown buildings south of James Street were so dangerously damaged that they were later condemned and removed.

IN THE CAPITOL DOME at Olympia, erected in 1925, unanchored keystone dropped out and column caps broke away. It takes strong mortar, steel and concrete, besides stone, to make such structures earthquake-resistant.

MANY UNREINFORCED masonry chimneys were fractured and rotated far more than this one, which gave way at the flashing point above the roof. A competent designer could have avoided this weakness.

Earthquakes are all different

In clarifying public thinking on the subject of seismic action in relation to people and structures, certain facts stand out. An understanding and appreciation of them will remove the subject from the realm of mysticism to that of ordinary good sense.

1. Earthquakes in themselves are generally not hazardous. They are dangerous largely because we make them so by building structures that are weak in their resistance to seismic forces and hence can be easily shaken apart. They usually come without warning, and ordinarily, destruction occurs within a minute. The violent phase of the April 13 earthquake lasted less than 30 seconds. Longer duration or strong aftershocks would have transformed that moderate quake into a great disaster. Compared with tornadoes, cyclones or the like against which we now design our structures, ordinary earthquakes are mild.

2. No two quakes are alike. They differ in acceleration, rate and kind of motion, and in direction, duration and extent. One cannot know in advance what to expect. Earthquake motion is propagated through and reflected by many different strata from the point of origin miles below the earth's surface. Instead of arriving at the surface in

BRICK VENEER failed when improperly anchored to poorly braced frame structure. All structures built of unit material must be thoroughly tied together to move as a whole.

LEFT—Unanchored roof and ceiling beams over the stage of Puyallup high school auditorium slid off supporting masonry walls and crashed to floor, causing $100,000 damage.

RIGHT—At Castle Rock, a high school student was killed as unanchored gable masonry cascaded to the walk outside the entrance. There could have been more casualties.

waves like the ripples on a lake, they arrive as a complex variety of motions. Some impulses amplify others to create strong motion; others combine to weaken or nullify the shock. These opposing phenomena can occur in close proximity or far apart, depending upon the characteristics of the quake and of the strata through which the impulses pass. In soft ground areas strong motion earthquakes seem sometimes amplified by reflection from enclosing formations like waves are from a wharf or a rocky shore, or are built up over shallow areas like waves are over a reef in high seas.

3. After an earthquake it is surprising to see how many buildings remain unharmed in the midst of wreckage—buildings that are the counterparts of others that have been thoroughly wrecked. However, due to these amplifying and weakening combinations of earthquake forces it is folly for one to assume that one's building is adequately strong to resist earthquakes just because it comes through an earthquake unharmed. Only by careful examination of a building and by a thorough structural analysis of its frame by an engineer or architect skilled in such computation and design can this be determined and the need for strengthening be discovered.

This quake deep underground

Seismologists report that this earthquake originated at a point approximately 30 to 40 miles below the earth's surface and located somewhere within the triangle defined on the surface by the towns of Morton, Little Rock and Toledo, Washington, southeast of Olympia. Its intensity and effect at the surface varied decidedly. As water in a pan is strongly agitated and slopped over the edge by moving the pan with a slow, rocking motion, or is confined with relatively little surface effect by sharp, quick motions, so the soft ground areas were affected differently at different places. Generally speaking, structures on hard ground got off easier. The principal exception noted was along the faults affected by this quake where much more violent motion was seen or made evident by the results on land and buildings near-by.

A rocking and a rotation

Differing from quakes in other areas, this one was reported by many individuals to have a rocking motion; others reported a horizontal and vertical rotational characteristic. As a child moves a jump rope to make it swing in wide circles, so the utility poles in many areas seemed to introduce a vertical rotary movement to the wires held taut between them causing the wires to "wrap" with others nearby. This phenomenon seems to be unique with this quake.

Motion which induced the rotation of brick chimneys as much as 45 deg. on a mortar joint close above a building, (usually at a flashing) was particularly prevalent in areas having water-saturated alluvium soil such as at Puyallup, Harbor Island (Seattle), parts of Centralia, and Kelso, near Longview. The consolidation of the alluvium by the vibratory action of the earthquake freed water which previously had been retained in the spaces between the soil particles. The presence of this released water under the pressure of the surface soil or mat was evidenced by the geysers of water and mud which spurted from the ground reportedly as high as 3 ft., which flowed continuously for as long as 24 hours, and which filled basements in the Sears Roebuck area of 1st Ave. S. in Seattle with sand. During this temporary flotation of the surface areas the horizontal movements of the quake created compression zones in some areas. In parts of Puyallup they were so strong that basement floors were lifted like pistons in a pump as much as 16 in. so that furnaces and pipes were crushed against the joists above and did not recede, while stud or post supports were forced through floors to as much as 8 in. above. These compression areas and adjoining tension areas caused soil movements which pulled apart or broke underground piping or conduit systems.

Visible waves traveling over the earth's surface (often reported but pooh-poohed or disbelieved by seismologists at the times of other earthquakes) were seen here and in addition left their imprint on the sands and soils of the soft areas in several locations. On the Tacoma lowlands, definite, though slight parallel ridges about 12 ft. apart were left. In a freshly plowed, disked and leveled field near Kent definite waves with crests about 6 in. high and 30 ft. apart resulted, and on a black-topped road in Pierce County, according to the county engineer, troughs were evident afterward extending diagonally across the pavement for ¼ mile having a crest-to-trough height of 2 to 3 in. In Elma, west of Olympia, the originally-lined-up columns under a light grandstand were observed to "walk" or move up and down during the quake, deforming the structure. The importance of strong struts or solid slabs between footings to assure that the footings will maintain their relative positions in buildings on such material (as required by the earthquake-resistant code) is obvious.

Action like a huge vibrator

Earthquake impulses acted upon the water-saturated alluvium (whether natural or man made) and upon a number of high railroad and highway fills like a vibrator in concrete, causing settlement up to 8 inches in places near and under buildings. At one building in Seattle the ground settled and was washed from under a footing by escaping ground water. At other buildings, particularly back of bulkheads along and in waterfront structures, substantial settlement occurred, breaking water mains and sewers, pulling electric conduit apart as much as a foot, and causing similar damage to other underground structures. Where compaction by vibration of passing trains or trucks had occurred in fills, most of the settlement due to this quake occurred outside the line of influence of such equipment, to cause cracks and depressed areas to appear at the point of change.

Shocks severe near faults

Insofar as is presently known, practically no permanent horizontal displacement along a fault line occurred, though several opened fissures in soft soil were photographed and several accounts of strong motion near a fault were reported.

A fault known to exist near Chehalis is thought to be responsible for the exceptionally heavy damage to old masonry structures at the Washington State Training School for Boys, where three buildings were so badly shattered that further use or repair was impossible.

Three-part report to be continued next month and concluded in the April issue. **For a synopsis of the installments, see box on page 71.**

Reproduced from Western Construction, v. 26, no. 3, p. 85-88 (March 1951)

2nd Installment:

Lessons in Structural Safety Learned From the 1949 Northwest Earthquake

By HARLAN H. EDWARDS
Chairman, Earthquake Committee
Seattle Section, American Society of Civil Engineers

STRUCTURES react to earthquakes in the same way, whether they be in Seattle, Boston, Los Angeles or Tokyo. The principal difference is in the severity, duration and characteristics of the motion and in the type of construction that is predominant. Since earthquakes have occurred before, and unquestionably will occur again in the Pacific Northwest as well as elsewhere, it is well to know (1) how structures of the various kinds were damaged on April 13, 1949, and then (2) how they can be constructed or strengthened to resist being damaged.

Older and weaker are first

In all earthquakes the older, weak masonry structures failed first, and many of them completely. This is true of the quake under discussion in which the modern masonry structures as a group performed splendidly. But where typical earthquake-type fractures did occur and where one or more walls suffered partial destruction it was reemphasized that in addition to good workmanship and substantial materials, all structures built of unit materials must be thoroughly tied together so that they move or resist movement as a whole, and be so braced that no part can move beyond its limit of elasticity. In other words, all parts of the structure must have sufficient strength and stiffness or rigidity to transmit the forces acting upon them into other members able to receive them, without serious damage to finish materials.

One need only to see the shattered, pitifully weak masonry buildings after an earthquake to recognize how necessary good mortar is to a building. With mortar that combines strength, workability, adhesiveness, minimum bleeding, low expansion and contraction, and impermeability, the inherent qualities of good masonry will be realized.

A test for mortar

From exhaustive research at the Bureau of Standards in cooperation with industry, a measure of workability and quality has been developed in the "water retentivity test" which is included in Federal Specification SS-C-181b. It is based upon the fact that a good mortar is one that contains good materials in adequate amounts, and in addition will hold the most water within it for hydration of the cement contained. The use of this measure of quality is gradually being adopted by the trades and codes.

Exterior finish materials such as unanchored terra cotta, ceramic veneer, brick, stone, glass, sheet metal panels, etc., cracked, shattered, spalled or fell from the twisting and bending of their related buildings.

In some cases inadequately attached brick veneers fell clear of the structures, glass facings shattered and dropped to the ground, unanchored terra cotta or ceramic veneer broke and fell, and stone work shook apart. Heavy blocks of the various materials were cracked at their points of attachment but did not fall during this quake. In the year following, however, three heavy pieces of terra cotta fell on downtown Seattle sidewalks, narrowly missing pedestrians. How many more such deathtraps exist here and in other cities cannot be determined.

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A SMALL RESIDENCE on unconsolidated fill lost its foundation when settlement dropped the concrete wall and the horizontal movement added to the damage.

Los Angeles has recognized that there are definite life hazards in connection with building facings and overhanging objects and has passed an ordinance requiring that existing parapets or appendages attached to exterior walls either be removed or strengthened so that they will resist a reasonable degree of horizontal force without becoming dislodged with danger of falling into any public way. If, after inspection, the Building Inspector finds no immediate hazard, the owner is given five years in which to make the correction.

The cities of the Pacific Northwest have fully as great, if not greater hazard to the public than Los Angeles in this respect and should adopt similar legislation. Local history demonstrates that earthquakes are a normal, natural phenomenon of this region that will be anticipated by prudent persons. Therefore, since cities and towns are under a duty to the public to keep their public ways (including sidewalks) in a reasonably safe condition it normally should be expected that this duty should extend to keeping the same public ways free from hazard of falling bodies during or following earthquakes. While there is a dearth of judicial decisions of record relating to liability with reference to earthquakes there are a number of established legal rules that furnish analogies and guide lines on the subject, such as those set forth by the Bureau of Governmental Research and Services of the University of Washington in its memorandum entitled "Liability Resulting from Projections and Falling Objects Upon Public Ways with Special Reference to Earthquakes."

In addition to life hazards related to the exterior of buildings, there are many phases of the problem that are related to the structures themselves and things they support. In some cases these concern the hazards of partial or complete collapse with attendant losses.

LEFT—Unsupported by any adjoining building, the corner of this structure moved out from under the roof the distance indicated by the crack.

RIGHT—Heavily loaded floors resulted in the diagonal movement at the corner of this building which almost resulted in collapse. The wall bowed out 6 in.

Loading of floors

The effect of a heavy floor load on a structure must be considered if the building is to retain its good health. One 5-story warehouse structure on 1st Ave. S. in Seattle was partly occupied by a heavy hardware firm that carried a stock of metal that loaded the mid-story area thoroughly. After the quake the front wall was broken from the side wall, and the side wall was bulged out at its mid length about 5 to 7 in. at that mid-building story height. Further shaking would probably have brought complete collapse. Since this loading was on one side, also, of the large structure, torsional forces were doubtless involved.

The brick face of a 3-story downtown mill-constructed parking garage was fractured at numerous locations during the quake. Brick moved outward ¼ to ⅜ in. along many of these points of sheared mortar. Brick arches over small windows were broken and the keystone almost dropped out of two. These two were repaired and the structure face was given two coats of paint! It remains in a state of "suspended destruction" that will probably proceed to failure under a less intense shock than the one on April 13.

Buildings constructed without adequate space between them battered together creating clouds of dust, pulling away roof flashings, knocking trusses off their seats and fracturing fire walls. Where two buildings of different heights existed adjacent, the higher one battered against the lower and was fractured or broken above the top of the low building. Where two buildings of approximately the same height existed together and an open space occurred beyond one, the building was pushed into this open space and the front walls were fractured on the rebound by tensile forces.

Two-or-more-story store buildings having the street face open or glassed in, with small columns and no bracing in the plane of that face were fractured horizontally at the heads of the first story windows and were starting to pivot to failure on the narrow front columns and small corner sections. One-story stores and garages built (1) with long-span joists, (2) rafters or trusses unanchored to the tops of the walls, (3) having no continuous reinforced concrete bond beams, and (4) having no columns or pilasters to take the additional thrusts that occur, failed by the walls moving out or by the trusses moving off their seats. Unbraced, high store fronts built as thin walls on inadequate steel beam lintels pivoted or rocked on their narrow supports but in most cases stopped short of disaster, awaiting the added push of aftershocks that didn't occur. These street fronts should be designed as rigid frames and the structures should be given lateral stability in some acceptable manner determined by the structural engineer.

BECAUSE roof joists were not anchored to the wall, the framing pulled away and the roof collapsed. Tops of the parapet wall shook loose and fell onto the sidewalk.

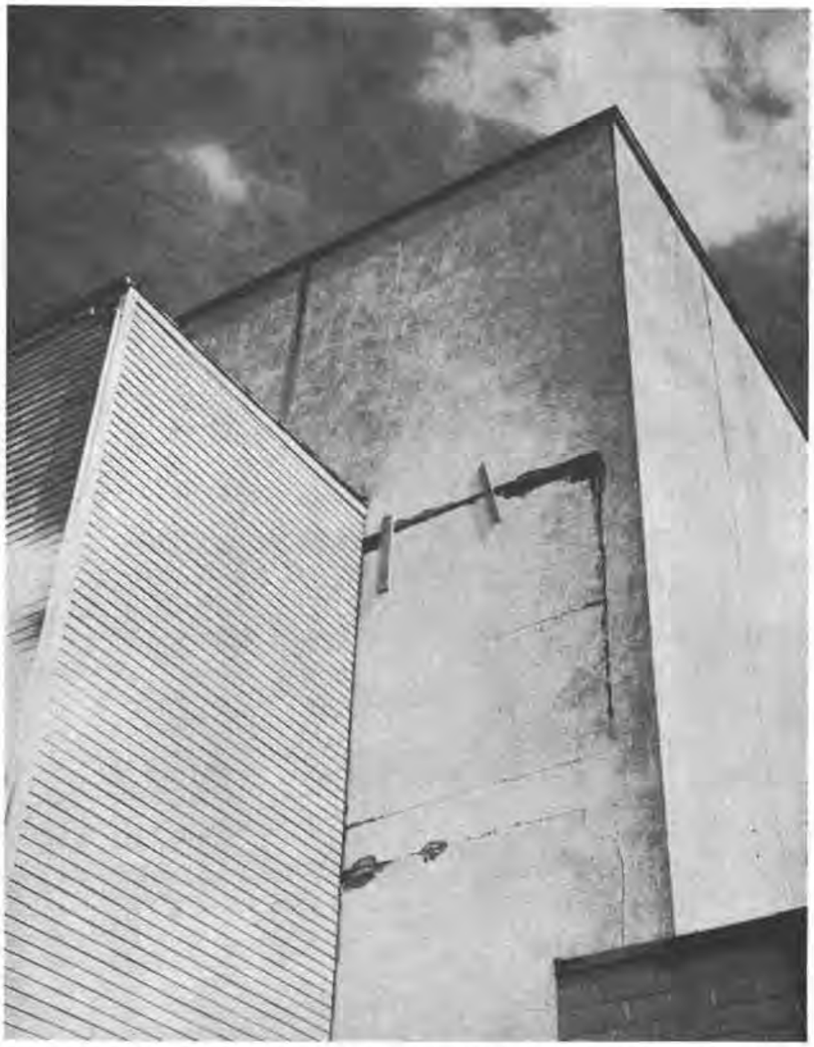
Good masonry is strong

Modern masonry buildings of rectangular plan built with strong mortar on adequate foundations showed inherent strength with little or no cracking. Their minimum of weakening openings, their well-braced roof systems, and in the larger buildings their continuous concrete bond beams enabled them to withstand the movements satisfactorily. However, this satisfactory performance this time should not give the over-confidence that they will do so again.

To withstand seismic forces, every structure must be so constructed and braced that it will move as a unit within the elastic limits of component materials. This means that not only bond beams are needed but that also strengthening steel reinforcement is required both horizontally and vertically in the walls and foundations, placed according to an adequate structural design which includes horizontal diaphragms or bracing installed at the roof or plate line.

Steel joist anchors and ties for rafters and gable ends are required by most codes, but it was surprising how many damaged buildings were found without them, after the earthquake. Without secure ties between masonry and wood construction, movement of the wood framing can occur at a different rate or period of vibration than that of the masonry, resulting in damage or demolition of part of the structure. This type of failure was the basic cause of much of the early destruction experienced in this quake.

Unreinforced brick chimneys, as has been stated, behaved badly. More than 10,000 chimneys in Northwest Washington required repair. Two thousand were estimated in Centralia and 1,351 were counted in Chehalis. Whether they merely turned in their sleep or fell off their perch, the hazard to the public was the same. Far too many chimneys fell, some into the buildings to create havoc in their path, others dropped onto the ground alongside. Still others were fractured badly, with heavy sections poised above the buildings awaiting the usual aftershocks to send them crashing through the roofs. Chimneys, like buildings, can be designed to resist earthquakes. All it takes is the will to do, and a competent designer.



ON THIS SCHOOL building at Chehalis the action of the earthquake broke out the masonry filler walls in this concrete frame with complete separation from beams and column.

Appraising concrete damage

Comparatively little visible loss was suffered by reinforced concrete buildings, though they too can be damaged if not properly designed and built. They can be cracked in ways which to the lay person are unimportant but which to the trained eye of the structural engineer who is experienced in seismic matters are definitely weakening. This is especially true when the buildings have their exterior frame concealed by veneer coverings making ready inspection of the concrete frame impossible.

In engineering, as in business, there is no substitute for experience. It is easy for the uninformed, inexperienced man **to pass over the damage unrecognized.** Training, experience and integrity should be the basic recommendations for an engineer when being considered for such special investigations. However, when cost is involved, it is unfortunate that there are penny-wise owners who seemingly will employ the person who will tell them only what they want to know or hear, regardless of the facts. It may be easy for the uninformed to pass up the tell-tale cracked stone, the spalling or bulging terra cotta facing over structural connections and the windows that break during succeeding days or months. But without exposing the vital connections between columns and beams or slabs back of these bulged areas to find out what really has happened, and without remembering that structures damaged in one quake proceed toward failure in the next, it is likely that some of these structures have been weakened and left to fail and cause heavy damage or loss of life in the next quake.

That such suspended destruction does occur was illustrated by one failure in this quake. In the 1946 earthquake a heavy reinforced concrete column and slab framework supporting a 50,000-gal. wood stave water tank 20 ft. above the roof of a large 7-story cold storage warehouse was cracked at the base and the top of the columns. The tank structure was located at the approximate center of the roof and was flanked on each side by an elevator headhouse. The building was on piles in fill along the waterfront. The damage seemed unimportant so nothing was done about it other than to clean out the breaks and fill them with gunite.

In the April 13, 1949 quake, this structure, weakened at the points of greatest stress proceeded from its state of "suspended destruction" to complete failure. The little-anchored, damaged columns broke from their moorings; the heavy concrete slab carrying the filled tank crashed down through the concrete roof to the floor below. As it fell, the reaction of the surging water and the sliding tank kicked the slab back over the headhouse of one of the elevators. The sliding tank broke over the superstructure of the other elevator, driving it, the elevator and tons of water into a heap at the bottom of the shaft 7 stories below. By some miracle the men working on the floors below had gone down on the elevator to lunch 5 minutes early that day or they, too, would have been included in the heap. The cost of extensive reinforcement or even the complete rebuilding of the tank structure in 1946 would have been far cheaper than the loss actually suffered!

In Longview and probably other places, too, connections of reinforced concrete columns to foundations and to beams of structures which had not been designed to resist the combined bending and direct stress due to earthquakes were fractured, the enclosing concrete

LEFT—Water and sewer lines fractured with pollution inevitable unless break is uncovered.
RIGHT—Movement in soft ground pulled open these conduits in spite of locknuts.

was spalled from the steel reinforcement and the steel was subjected to such loads that it bulged out beyond the column line, a spectacular damage. It was fortunate that, although this earthquake was of high intensity, aftershocks did not occur so comparatively little of this type of damage was seen.

Repair work is slow

It is significant of the penny-wise thinking of people that relatively few examinations of the bulging or cracked areas of building facings have been made or ordered. It would seem that the owners should want to know that their investment was safe and not "on the skids."

Elevator shaft walls are especially subject to damage, due to the rigid characteristics of such tall, rectangular units. These characteristics often conflict with the flexibilities of adjoining areas and thus cause trouble. Not only did the shafts suffer severe cracking in this quake, but also by their action as vertical girders they brought additional forces into play, which damaged nearby structural parts of the building.

Problems of elevators

Relative rigidities of elevator shafts must be carefully studied in the seismic design of structures so a uniformly-resisting building will result. One would ordinarily think an elevator a safe place to be in a quake but a number of them were rendered inoperative immediately, through their supporting cables jumping from their sheaves, through counterweights being projected from their guides, through jamming of operating equipment, or through cage guides being twisted and torn loose by building movement. In one warehouse most of the foregoing occurred to one elevator; the vibration started the elevator going up and the counterweight down and it ended by all crashing together. Fortunately no one was in it.

Stair wells were commonplace areas of failure within a building, in this quake as in most others, and the reason is not hard to find. Stair slabs, on which the steps are superimposed, are rigid units and usually extend from floor to floor either continuously or in two flights with a landing between. Since in the motion of a building the upper floors often move more than the lower, and in different rates and directions, the stairs become in effect battering rams breaking the opposing structural members within their zones of influence.

WATERFRONT STRUCTURES supported on piles driven into fill material shows a differential settlement of 8 in. on the fill side.

Means of emergency escape from buildings were cut off in a number of instances by the jamming of fire doors in their frames due to the deformation of the buildings. This introduces a serious question of code adequacy as it relates to temblors, for in these instances, what should have been open avenues to safety were actual areas of hazard within which those seeking to escape could have been trapped. Had the quake caused greater damage or had fire resulted, these places could have been the locations of many deaths.

Waterfront structures

In this quake, as in previous quakes, waterfront and similar structures were particularly susceptible to severe movement and damage. They were also affected in the same manner as structures on direct-bearing footings, but due to the flexibility of long piling, a greater lateral deflection and consequently a different period of motion occurred. Subject to the particular characteristics of the earthquake, it is possible that the harmful effects of seismic action on free-standing structures supported on long piles may be materially reduced due to the pile flexibility, but the evidence in this respect was not conclusive in this quake.

In design procedure, where such structures are connected to adjoining structures on earth or on piling which is materially restrained by earth fill, especial design consideration must be given to connections between such structures. Different periods and different amplitudes of movement tend to occur that can and did in this quake cause rupture and damage along these lines of connection in a number of waterfront structures.

The effects of earthquakes on friction piles, bulkheads and fills, together with the subsidence of such fills are matters logically associated with waterfront structures. Seismic vibration of natural and artificial fills is deep-seated, and often results in consolidation of material that otherwise would take many years to accomplish, starting at a considerable distance below the surface. In this earthquake such consolidation often brought a settlement of up to 8 inches in fills around and under structures, and 4 to 6 inches in friction piles under load, and dropped the ground level around bearing piles a similar amount. This consolidation around heavily-loaded friction piles increases the bearing capacity of the piles, but without load the piles tend to rise during the earthquake.

Subsidence of filled ground due to the earthquake caused breakage of water, sewer and other buried lines serving structures, with consequent great danger from fire. It is therefore pertinent to say here at the risk of repeating elsewhere, that particularly where facilities extend through bulkheads and exist at other places where shear stresses may be occasioned by fill subsidence, the hazard of piping breakage could and should be reduced by installing these lines with unbreakable pipe having flexible joints where necessary.

Three-part article to be concluded in the April issue.

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Third and Final Installment:

Lessons in Structural Safety Learned From the 1949 Northwest Earthquake

By HARLAN H. EDWARDS
Chairman, Earthquake Committee
Seattle Section, American Society of Civil Engineers

ALTHOUGH well-constructed and thoroughly-braced wood frame residences firmly attached to substantial foundations have withstood all earthquakes in this country with little damage, the April 13 quake demonstrated again that departures from good practice pay the penalty. The unreinforced concrete foundations of one group of homes being built on fill ground in West Seattle failed utterly and miserably and showed that the earth on which a building rests is also a part of the foundation and must be firm and thoroughly consolidated.

Needs for wood frame structures

Buildings must be securely bolted and braced to their foundations. If the first floor is set on posts, on short studs or on low, dwarf walls, these supports must be strongly braced; otherwise they merely act as pivot points on which the heavy structure moves to failure. The shocks of this quake were such that only a few homes slid off their foundations.

Buildings must be diagonally braced in the frame, or by diagonally-placed solid sheathing extending from plate to plate, thoroughly nailed to all bearings. Braces are most effective if they are the continuous 1 x 4 or 1 x 6 type or larger let into the plates and studs and well spiked to each bearing. The "cut-between" type of bracing often permits building movement to take place before it comes into solid bearing, resulting in broken plaster and a racked structure. To resist torsional or twisting forces buildings should have diagonal bracing over the ceiling joists in attics, extending from corner to corner of the structure, again well spiked in place.

Throughout the area affected by this quake, a disproportionate number of schools suffered severe damage. It was said of the California schools following the Long Beach earthquake on March 10, 1933, "the cities have accumulated in the guise of schoolhouses, the most shocking collection of deathtraps that ever disgraced a metropolis. The Long Beach earthquake was nicely timed and graduated to expose the condition without exacting the penalty, at least as far as the children were concerned, but if the schools had been occupied it would have been one of the greatest catastrophes in American history. The casualties would have been numbered not in hundreds, but in thousands or tens of thousands." So might it be said also in Washington and Oregon, and in practically all other parts of the country, should a similar quake occur.

Schoolhouse architecture as developed over the years has established a pattern of design, arrangement and ornamentation which almost invariably has been followed, regardless of location. High ceilings and large rooms with many high windows create a structural shell which is unable to resist the lateral force of earth shocks unless it is very strongly braced. Ornate entrances, usually embellished with heavy and often loosely placed terra cotta, brick and stone have been first to fail and rain their death-dealing load upon the children leaving the building.

With respect to seismic forces, school buildings almost universally have been built to be weaklings. As spindly, weak-kneed, heavy-headed and overgrown specimens of purportedly good architecture many of our schools costing millions of dollars can and probably will be deathtraps for the youngsters, come a strong quake when school is in session.

Damage to schools on April 13 was widespread but generally not spectacular. It did not approach the total destruction suffered by the schools in the Long Beach earthquake but the tell-tale fracturing and movement of wall on wall were there, mute evidence that a few aftershocks would have done the trick. Few, if any schools in Washington, however, have been strengthened since the shakeup.

Lessons in school construction

The lesson for educators and others responsible for school construction is very plain, and the results observed point up three courses of action, all of which should be worked at vigorously for safety's sake.

1. A careful inspection should be made by experienced engineers to locate potential hazards in existing buildings, and action should follow to eliminate them. Chief hazards during a mild quake are brick gable ends, parapets, cornices and chimneys, in addition to the entire structure if it is weak. At Lafayette Elementary School in Seattle,

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BRIDGES damaged by the quake. Left—Horizontal reinforced concrete struts between viaduct and trestle in Spokane were destroyed by differential movement of the structures. Below—Adna bridge over Chehalis River moved perpendicular to center line of road to bend pin plates on all shoes.

a typical 2-story structure of early days (now replaced) the east and north brick gable ends fell outward. The north end fell at the doorway where according to school routine pupils exit at 11:55 a. m., the time of the quake. Castle Rock School was in session and the students starting to leave for lunch when the quake occurred, sending a rain of brick from the gable end down upon them, killing one boy.

The north parapet at the Lower Columbia Junior College at Longview toppled two stories to the sidewalk entrance. Some students were inside at the time and lived through falling plaster and shattered plate glass. This was a rented building used "temporarily until some future time." Thus the town's worst damaged building was used, though not designed, for school purposes.

From cornices at Central Elementary in Seattle and at similar schools in many other cities assorted sizes and numbers of bricks and stones catapulted down. Only gross disregard of the history of earthquakes permits beauty and symmetry to transcend safety.

Chimneys are the telltales of mother earth's movements. A quiet antic bothers few well-built stacks but down they come in a violent vibration, laid out flat across the playgrounds, dropped down through roofs into toilets and classrooms, all spelling death to the children below them.

CONNECTIONS between structures must be rigid enough that both structures move as a unit or be separated so they move independently. Above, damaged base of an unbraced column.

Gingerbread versus safety

The most dangerous spot during a mild quake is just outside the entrance, the place where gingerbread architecture reaps its casualties. But other places can be dangerous, too, for a jolt of greater force or longer duration tends to "bring down the house." At Puyallup High School it has been told how the unanchored ceiling and roof beams over the stage slipped off their supporting masonry walls and dropped to the stage of the auditorium. At the Rainier Elementary School in Oregon a classroom of hollow tile construction split away from the main portion of the building and only conjecture can fix the added temblors needed to throw classroom, contents and all into the yard three stories below. In Castle Rock, Wash., the elementary pupils vacated a 3-story frame building and double-sessioned in the Junior High School, judged by experienced engineers to be more hazardous than the elementary school.

TYPICAL of pre-1900 buildings, this tall thin wall and unanchored gable were easily knocked out by flexing of wood structure. Crack to left shows side wall about to fail.

2. Continuing instruction and drill should be given concerning pupil conduct during earthquakes and other emergencies.

3. Adequate safeguards should insure the structural integrity of each new school. At best, heavy masonry units on top are dangerous. Modern architecture needs no such ornamentation, but bond beams alone in masonry walls are inadequate. In addition a complete lateral bracing system is required, designed by a structural engineer or architect experienced in seismic matters. The building and all its parts must be constructed and interconnected so that neither lives nor dollars will be placed in jeopardy.

Existing structures can be examined, tested, and analyzed to determine their performance in an earthquake, and means of strengthening can be designed by engineers trained in this specialty. If cracks or distortions in walls, or other indications of damage appear, it is advisable to have and it should legally be the owner's responsibility to obtain such a checkup, and to follow the recommendations made.

The owner, engineer, architect, contractor and public official all have definite legal responsibilities to see that the design, construction and maintenance of structures will make and keep them free from hazard to the public. These responsibilities have been defined and enforced by the courts time and again, sending to prison those found to be at fault such as was done with the contractor and building inspector following the Pasadena, Calif., grandstand disaster in 1925 in which 9 spectators of the Tournament of Roses were killed. These responsibilities should be reiterated in codes, and to establish them, the several parties involved should be required to certify in writing prior to final approval of the structure by the building department that the work has been done in accord with the plans, specifications and building codes.

Conclusions

Study of the effect of the earthquake of April 13, 1949, together with the experiences of other localities, supports the following conclusions:

1. The entire Pacific Northwest west of the Rocky Mountains, and particularly the area west of the Cascade Mountains, is a seismic area subject to strong motion earthquakes.

2. To minimize loss of life and property, all structures used by humans should be designed and built to provide reasonable resistance to seismic forces.

3. The design and construction of all structures, including those built by local, state and federal bodies, should be in accordance with the requirements of an adequate, modern building code.

4. Adequately designed structures of steel, reinforced concrete, reinforced masonry and wood can be earthquake resistant.

5. Adjoining structures or adjoining parts of the same structure are subject

to differential movements and hence to damage through dynamic contact, tension or torsion unless they are adequately anchored, braced, or sufficiently separated.

6. Inadequately anchored unit masonry partitions, filler walls, and veneers of the several kinds are vulnerable to damage or destruction by an earthquake and if only slightly damaged or weakened by one quake, they may be a serious potential hazard during a subsequent relatively mild quake.

7. Chimneys, parapet walls, cornices or other members cantilevered from the general structural mass are particularly subject to damage by seismic movement and where used should be especially designed and be securely anchored to their supports.

8. Due to their stiffness or rigidity, elevator shaft walls are especially subject to damage and are capable of damaging adjacent elements. They should be designed to resist horizontal forces proportional to their rigidity.

9. Due to relatively high rigidities in planes where relatively little other rigidity occurs, walls of stair wells and stairway slabs themselves are particularly subject to damage in an earthquake. Careful analysis should be given these elements to provide correspondingly resistant strength, and where the conditions are too highly indeterminate, slip joints should be provided.

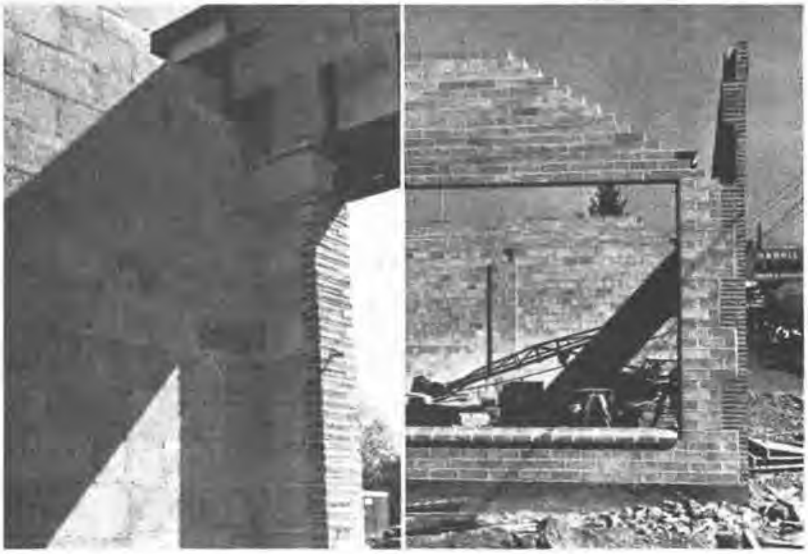
10. Soil conditions and the strength of foundations are vital elements affecting the ability of structures to resist earthquakes. On soft ground it is essential to tie footings together securely either by strong, stiff struts or by a continuous slab.

11. Water tanks supported by buildings are not only subject to the hazards of other cantilever members but have the added hazards of dynamic movement of the liquid in conjunction with the seismic forces, which can severely stress the building. Especial analysis should be made of tanks, tank structures, and the building members surrounding and supporting them.

12. Suspended piping is subject to sidesway and endsway. In strong earthquakes this sway may cause the rupture of fittings such as on fire sprinkler lines, gas, refrigeration and heating lines, with serious consequences. All such piping should be secured by supports from each side additional to vertical suspenders with due allowance for expansion and contraction of the system. Similar restraint should be given to heavy ventilation fans, air and water tanks and similar equipment in a building.

13. Subsidence of filled ground due to the vibratory action of earthquakes can cause breakage of water, sewer and other lines serving a building supported on piles or having deep foundations, and can damage lines extending from hard ground into such unstable soil. Such breakage hazards can be reduced by using flexible joints and by using pipe that is capable of withstanding the differential motion.

SUPERFICIAL damage was costly in high structures which flexed markedly. Interior partitions lost their plaster and fractured. Note vertically bowed condition of this interior wall.



STREET FRONTS and parapets must have strong support. Building under construction above was entirely inadequate. At left, note light I-beam bearing on thin veneer with concrete block above for back-up only. At right, note thin support for the front wall, giving no lateral stability.

Recommendations

On the basis of the foregoing findings and observations, the following recommendations are made:

1. That useless, superficial and dangerous ornamentation be deleted from plans or removed from the structure.

2. That the basic design be such that rigid resisting units are provided where needed, so that differential movement of various masses can be properly provided for and that torsional movement can be resisted or eliminated.

3. That ultimate economy be considered in addition to safety. In the architectural and structural design, if advantageous, conventional heavy materials should be discarded for modern lightweights, particularly in the upper portions of the building.

4. That the seismic design sections of the 1949 and succeeding editions of the Pacific Coast Uniform Building Code be adopted by all governing bodies and that a state organization be created to secure compliance in all areas not under the jurisdiction of city or county building departments.

5. That the minimum seismic design factor in the above-mentioned code be determined for any area by the zone of earthquake probability established by the Coast and Geodetic Survey.

6. That, due to the public hazards disclosed, legislation be enacted requiring potential earthquake hazards to be abated within a specified maximum time.

7. That legislation be enacted requiring owners of structures used by the public or located along public ways to bear responsibility for damage to the property of others and for injury or loss of life occasioned by their structures or parts of them due to seismic disturbance.

In conclusion

Seismic shocks have been of common occurrence in the Pacific Northwest in recent years (155 have occurred in the Pacific Northwest states since 1841, and 30 in the last 10 years) and therefore they should no longer be considered as "Acts of God."

It is obvious that buildings have been built so they can be shaken down in an earthquake, and equally obvious that they **can** be built so they will hold together under similar circumstances. Resourceful engineering in the specialized field of seismic design of structures and the cooperative interest of and intelligent understanding by capable architects will result in earthquake resistant structures often at little, if any, additional cost.

Guided by the modern seismic design section of the Pacific Coast Uniform Building Code, some owners are making their structures more safe to use and less costly to maintain. It is hoped that many more will learn the lessons taught by earthquakes and do likewise. Probably 5,000 persons in the Pacific Northwest are living today and property damage of $100 million was spared solely because the quake of April 13, 1949 did not last a little longer. **Next time we may not be so lucky!**

—The End

Reporting the Northwest Earthquake

JUST before noon on April 13 Seattle and a 150,000 square mile area of western Washington experienced the most destructive earthquake in the history of the region. The Pacific Coast Building Officials Conference requested Clyde N. Dirlam, chief building inspector of the Los Angeles County Department of Building and Safety and plan-checking director of the Conference, and Franklin P. Ulrich, chief of the Seismological Field Survey, United States Coast and Geodetic Survey, to visit the scene of the 'quake and report on the aspects of the disaster which would be interesting and instructive to building officials and all those concerned with safety regulations in construction. Mr. Dirlam reports on the damage to buildings from the standpoint of the building official. Mr. Ulrich reports the earthquake from the scientific point of view. Both papers are important additions to basic earthquake data.

FIG. 1—Parapet wall of the second story wall fell due to lack of anchorage and inferior masonry.

Damage to Buildings

By CLYDE N. DIRLAM
Chief Building Inspector
Los Angeles County Department of Building & Safety

IN accordance with instructions, I visited the Puget Sound area for the purpose of investigating the damage to buildings and other structures following the earthquake on April 13. I arrived in Seattle on the morning of April 15 and spent a considerable amount of time examining and photographing buildings damaged in Seattle. Later I visited Tacoma and Olympia for the same purpose.

This earthquake, which occurred on April 13 at 11:50 a.m., has been classed as a "near strong" shock. The epicenter has been located near Shelton, which is about forty-five miles southwest of Seattle. The shock was felt from Portland, Oregon, northward to Vancouver, B. C., and was apparently strongest along the coast, the principal damage having been in Olympia, Tacoma, Seattle and a few smaller cities. Press notices state that the intensity has been fixed at about seven or eight on the Modified Mercalli Scale. The building damage does not seem to bear out this value of intensity at the points of maximum damage.

There have been no destructive shocks in this region for many years. One notable shock occurred in 1939 and two in 1946.

SEATTLE

The principal building damage at Seattle is confined to an area adjacent to Pioneer Square. This area was at one time a tide flat, which has since been filled in. The damaged structures rest on wood pile foundations. Most of them

FIG. 2—This entire building is constructed with a very inferior grade of masonry, weak mortar and lack of joint filling. The parapet wall near the corner fell because of defective masonry and lack of anchorage.

FIG. 3—This is a wood frame building resting on concrete piers. Apparently the foundation collapsed, allowing the floor to slope and catapult the contents of the building through the exterior wall.

FIG. 4—Lafayette School in west Seattle. The gable fell because of lack of adequate anchorage and defective masonry. The masonry fell on the landing in front of the main entrance

FIG. 5—Lafayette School, west Seattle. A large number of brick from the chimney fell in the school play-yard.

FIG. 6—Lafayette School, west Seattle. Gable and chimney fell due to weak masonry and inadequate anchorage.

FIG. 7—This church steeple in Tacoma had a spire at each corner. The spires were thrown off and two of them went through the roof of the building.

FIG. 8—School in Tacoma. The gable wall fell and killed a small boy.

SCENES IN AND AROUND SEATTLE FOLLOWING APRIL 13 EARTHQUAKE

FIG. 9—Olympia. Parapet wall was knocked off and carried a canopy to the sidewalk with it.

FIGS. 10 AND 11—Old State Building, Olympia. Heavy sandstone walls, weak mortar and lack of adequate anchorage contributed to this damage.

were built about sixty years ago. They are of brick masonry of inferior quality with a weak mortar and are largely lacking in the anchorage of floor and roof joists. The story heights are high and there are generally many openings in the walls. These features, combined with the unstable foundation, together with neglect and deterioration of buildings, make such structures an easy prey to earthquake forces, although it should be noted that there are many buildings of the same age in the same area which are apparently undamaged. The damaged structures comprise only a small percentage of the total number of buildings in the area. Figures 1, 2 and 3 show the general type of construction referred to. Outside of this area an old school building located at California and Lander Streets in West Seattle was badly damaged, as shown in Figures 4, 5 and 6. There is a noticeable lack of joist anchors in the gables. The quantity of brick falling from the gables and chimneys could easily have produced fatalities had the school been in session. It is noteworthy that the interior of the building and walls below the roof line were not damaged beyond a few plaster cracks and that the building could be reoccupied with little repair work. Other school buildings in Seattle sustained only slight damage, principally from falling brick chimneys. Only two are to be abandoned for the present.

The larger and newer buildings in Seattle were only slightly damaged, mostly in the way of plaster cracks and cracked terra cotta facing. There are, however, a few loose parapet walls which will require rebuilding. The newer portion of the business district is built on higher and more solid ground. There were a few breaks in water and gas mains; not enough to be a serious menace, however.

Viaducts and bridges were not damaged with the exception of the movable bridges over the Duwamish Waterway. Movements of the earth banks caused displacement of the abutments. Lift bridges which were open at the time of the shock could not be closed, and those which were closed could not be opened. Tall chimneys, of which there are a number in Seattle, were undamaged and were obviously not subjected to the forces to which similar structures in Olympia were exposed.

Very little damage to residential chimneys was observed, although there are many brick chimneys of more than ordinary height on the dwellings in that city.

TACOMA

Only a comparatively small amount of damage was done in Tacoma. A school building similar to the Lafayette School in Seattle was damaged, a brick gable having fallen above an entrance, causing one fatality (see Figure 8). A steel cable saddle which was being placed on the top of the tower of the new Tacoma Bridge was shaken off and fell through a barge in the channel. The earthquake cracked ground adjacent to the banks of the Tacoma Narrows causing a landslide some time after the earthquake. This endangered a number of dwelling houses.

Little damage to residential chimneys was observed, although, as in Seattle, there are many brick chimneys of more than ordinary height.

FIG. 11

FIG. 12—State Insurance Building, Olympia. Stone cornice at upper righthand corner was shoved out and ready to collapse.

FIG. 13—State Insurance Building, Olympia. Heavy stone ornamental parapet was thrown off for the entire length of the building.

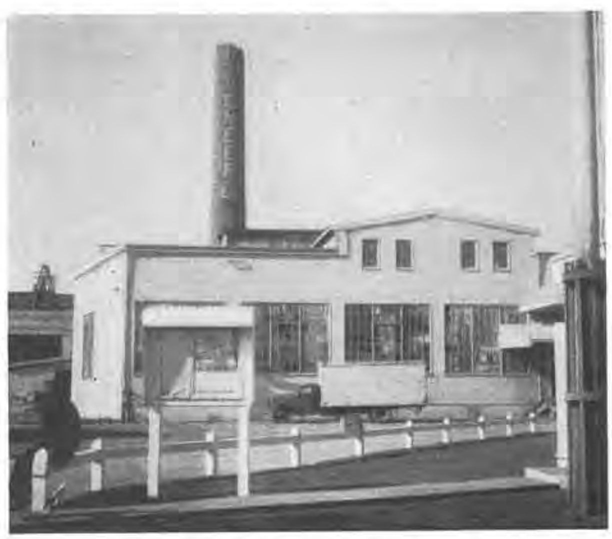


FIG. 14—Industrial plant at Olympia. Brick chimney was originally 250 feet high; about 60 feet of the top was thrown off, producing fatality.

OLYMPIA

Olympia is located nearer the epicenter than is Seattle or Tacoma. Damage was sustained by several industrial and commercial buildings, by the old State Building and by buildings on the new Capitol grounds. The dome on the Capitol is considered unsafe because of the shifting of a heavy stone lantern at the peak of the dome. The State Insurance Building was damaged as shown in Figures 12 and 13.

A brick chimney 250 feet high was broken off 60 to 75 feet from the top and masonry fell on a boiler house and on another structure, producing one fatality. This chimney rested on a wood pile foundation on a tide flat fill. Other brick chimneys close by were similarly shattered. Figure 14 shows the wrecked 250-foot chimney.

A considerable amount of damage to residential chimneys was observed, unlike the experience in Seattle and Tacoma.

The press reports eight fatalities in the entire state; only four of these, however, were due directly to the earthquake, in each case being caused by falling masonry. The total amount of damage seems small compared to the reputed violence and large extent of the shock, and the many places of habitation within the area of disturbance. Appreciable damage has been sustained by about eleven hundred dwelling houses in the western part of Washington. The total loss has been placed at various sums, but fifteen million dollars seems to be the average.

One of the principal lessons to be learned from our study of building behavior in this shock is a re-emphasis on the hazard due to unanchored and improperly built parapet and gable walls which can be thrown to the sidewalk during an earthquake shock. These are usually located over the entrances where people are likely to be exiting during the course of an earthquake. If existing hazardous walls could be eliminated, lives could be saved when a heavy shock visits the community. Consideration should be given to the enactment of legislation that would make this possible in localities where earthquakes are to be expected.

My observation indicates that our present Uniform Building Code provisions regarding lateral force do not need to be changed. It is my opinion that any structure designed in compliance with the Uniform Building Code would have passed through this shock with practically no structural damage.

SUMMARY

1. Damage in this shock was confined largely to old buildings of inferior construction.

2. A building can be a serious menace to life through falling parapet or gable walls although the total damage to the building may be light.

3. Old masonry structures whch have high story heights and are of inferior construction and may have been neglected become a serious hazard in an earthquake.

4. Parapet walls should be properly designed and anchored to resist lateral forces.

5. If the masonry parapet walls on existing buildings could be removed or rebuilt through legislation or persuasion, lives could be saved in the event of an earthquake.

Reporting the Northwest Earthquake

From the Scientific Point of View

By FRANKLIN P. ULRICH
Chief, Seismological Field Survey
United States Coast and Geodetic Survey

THE destructive earthquake of April 13, 1949 occurred at 11:55:41 a.m. Pacific Standard Time (120th Meridian Time).

The Coast and Geodetic Survey using instrumental data from thirty-five seismological stations received by April 21, fixed a provisional epicenter at 47.1° north latitude and 122.7° west longitude (between Olympia and Tacoma). The following is abstracted from a recent press report: "The Geology Department of the University of Washington at Seattle tentatively placed the epicenter along the Bordeaux Fault near the junction of Lewis, Thurston and Grays Harbor counties. This fault runs from Independence Creek, near the counties' juncture, northeastward toward Olympia." (In the direction of the epicenter determined by the Coast and Geodetic Survey). "The evidence of the existence of this fault is the marked difference in the kind of rock on the west side which is largely hard lava while on the east side it is shale and sandstone in which original layers have been raised and folded. The extent of this fault is not known as several hundred feet of glacial deposit cover the

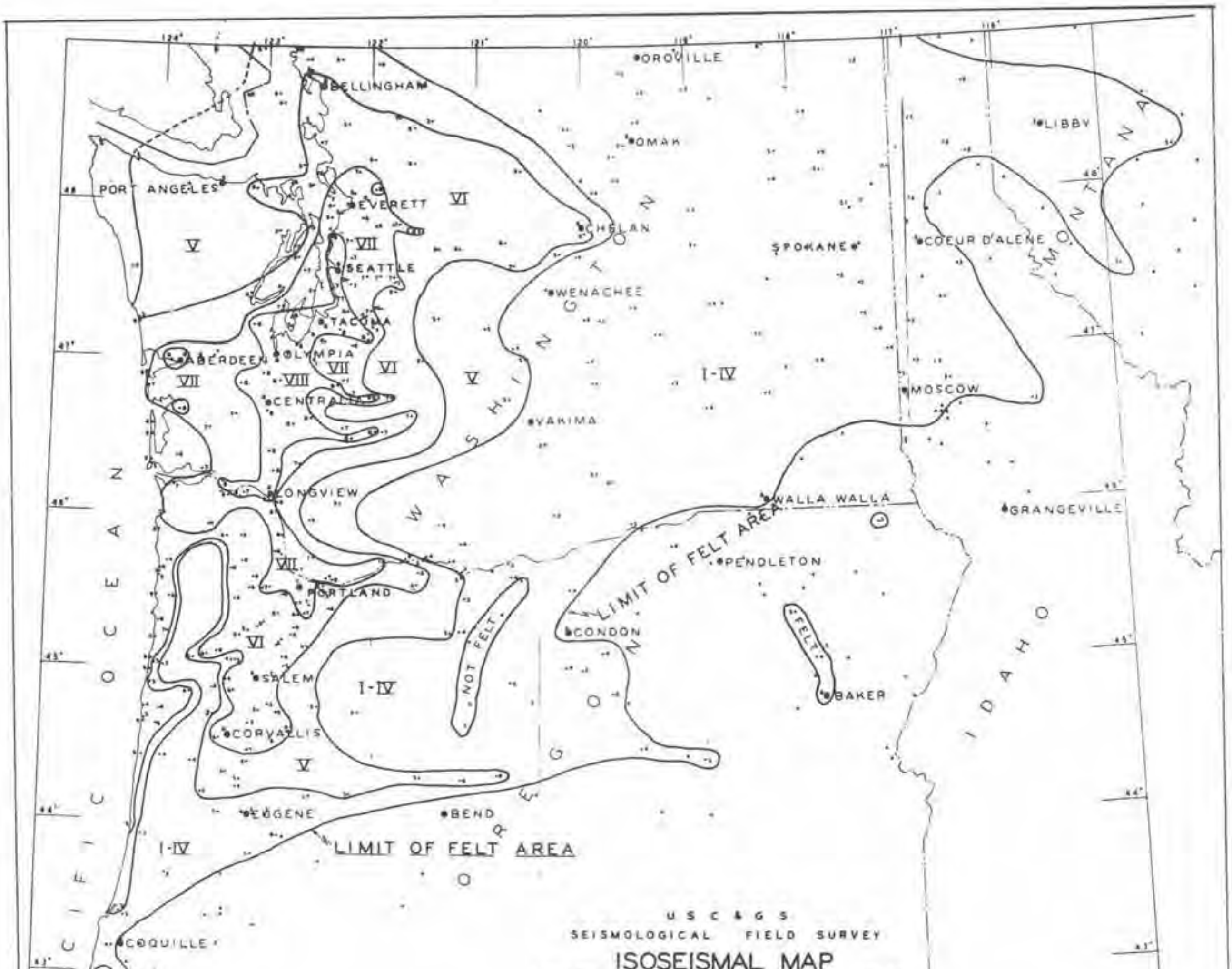


FIG. 1—Isoseismal Map—Northwest earthquake, April 13, 1949, prepared by the United States Coast and Geodetic Survey, Seismological Field Survey.

earth from Olympia to Tacoma." The extent and direction of the most heavily damaged area would indicate possible movement along the fault for a considerable distance. (In the 1906 earthquake in California the surface rupture was visible for about 270 miles.) Locations of the epicenter immediately after the earthquake and from only a few stations were considerably in error as the severity of the shock and inadequate time control made interpretation of records of near-by stations very uncertain.

The isoseismal map (subject to revision as additional information becomes available) shows the extent of the area over which the shock was felt and also the intensities at the various places. The information for the isoseismal map was compiled from many press reports; from field investigations by C. K. Stiff (engineer, Factory Mutual Insurance Companies) and S. E. Warner (geophysicist, U. S. Coast and Geodetic Survey); from a special questionnaire to building inspectors in the damaged area and regular questionnaire coverages made by State Collaborators in Seismology for the Coast and Geodetic Survey: Professor Harold A. Culver, Pullman, Washington; Dr. Vernon E. Scheid, Moscow, Idaho; and Professor E. L. Packard, Corvallis, Oregon. The isoseismal map shows that the shock was felt over an area in the United States of approximately 150,000 square miles. The area of greatest intensity extended from Granite Falls south along the east side of Puget Sound to Olympia then south through Chehalis, Castle Rock to Longview and east and west of this line in river valleys.

In the region of greatest intensity eight deaths were caused directly or indirectly by the earthquake and at least sixty-five persons were seriously injured. Shortly after the earthquake the press estimated damage at twenty million dollars. From latter and more complete information it is believed that this estimate is entirely too small and the writer tentatively estimates that the ultimate total damage will be nearer to fifty million. A representative of a group of insurance companies tentatively estimated that the total damage would probably be between thirty and fifty million dollars. Other preliminary estimates of damage range from ten million upwards. The Washington State Superintendent of Schools estimated the damage to thirty public schools in western Washington as between six and ten million dollars. Damage from an earthquake is not always immediately apparent. Settlement of foundations and walls with consequent cracking of walls and plaster may not be discovered until several months after the shock.

Detailed reports of all damage would be beyond the scope of this report. The University of Washington is undertaking the collection and compilation of the earthquake damage as a special project which will require months to complete. In general, damage was confined mostly to the less stable ground, such as marshy, alluvial or filled land and to older structures, particularly old masonry construction with lime mortar which was built prior to modern building regulations. However, there were many exceptions where old buildings on firm ground and new buildings on soft ground were destroyed. There was considerable cracking of ground, ejection of sand and water by temporary geysers; considerable damage to bridges, docks, water mains

FIG. 2—Open-air theater: Three members of the stage crew at Puyallup High School survey the wreckage of the stage, where the roof was caved in by the earthquake just as they were leaving for lunch. Under the debris are a ping-pong table and a grand piano.—Seattle Times staff photo by Larry Dion.

AT LEFT:

FIG. 3—Building occupied by the Cohen Bag Company, 3435 Klickitat Avenue, Seattle, showing failure of brick veneer—Seattle Times photo.

FIG. 4—Failure of parapet wall and collapse of fire escape. —Photo by U. S. C. & G. S.

FIG. 5—Collapse of brick filler wall. This wall at the Crane Company, East Marginal Way and Hinds Street, Seattle, boiler and radiator shop, fell outward in the earthquake, saving workmen inside.—Seattle Times photo.

and pavements. A cliff 300 feet high and a half-mile long in the northern part of Tacoma toppled into Puget Sound.

Abstracts of damage for a number of the larger cities are given as follows:

Auburn: Injuries: One. Damage estimated at half million dollars. Junior High School condemned. Four blocks of downtown district damaged severely. Fall of parapet walls and many chimneys.

Castle Rock: Deaths: One. Injuries: Several. Damage considerable. One school damaged severely. Considerable damage in brick and concrete buildings. Many chimneys fell.

Centralia: Deaths: One. Injuries: 10 hospitalized. Damage very heavy—estimated at three million dollars. Collapse of building walls and many chimneys. Two city schools permanently closed. Methodist church condemned, continued settling of ground caused extensive damage. Water mains broken and 5000 feet of concrete pipe in city intake water supply damaged severely. Traffic through city still restricted one week after earthquake. Water and sand spouted from ground.

Chehalis: Injuries: Several severely. Damage: City officials on April 20, 1949 estimated it at three million dollars. City library condemned. Most downtown buildings, schools and churches damaged. 1351 chimneys found damaged up to April 20, 1949. Water mains damaged.

Olympia: Deaths: Two. Injuries: Many. Damage: Total estimated between five and ten million. Eight capitol buildings damaged, two closed. Damage to state buildings estimated at two million. Nearly all large buildings were damaged with cracked or fallen walls and cracked or fallen plaster. All buildings in downtown region and all school, city, county, and state offices were evacuated for fire marshal inspection. Two large smokestacks and many chimneys fell. A large portion of a sandy spit jutting into Puget Sound north of Olympia disappeared during the earthquake. Streets were damaged extensively. Water and gas mains broken. Train service suspended for several days.

Puyallup: Injuries: Many. Damage estimated $300,000 by building department. High school damaged severely with collapse of stage in auditorium (see Figure 2.) Fish hatchery damaged severely. Many buildings damaged. Nearly every house chimney toppled at roof line. Hundreds of walls were cracked. Several houses jarred off foundations. Roads were blocked for several hours. Water mains broken. Utility services were interrupted. Geysers ejected water and sand.

Seattle: Deaths: One indirectly. Injuries: Many seriously, with scores reporting shock, bruises and minor cuts. Damage estimated between five and ten million dollars. Many houses on filled ground were demolished. A preliminary survey right after earthquake showed seventy-five buildings suffered considerable damage up to $50,000 apiece. Many old buildings on soft ground were damaged considerably. Collapse of top of one radio tower and one wooden water tank, with damage to many tanks on weak buildings. One schoolhouse partially destroyed and closed. Many chimneys toppled. Heavy damage to docks and stores awaiting shipment. Several bridges damaged and closed temporarily. Many water mains in soft ground were broken and many basements were flooded. Telephone and power service were temporarily interrupted. Large cracks in filled ground, some cracking of pavement, and water spouted six feet or more from many ground cracks. (See Figures 3 to 6 and Figure 4 of Mr. Dirlan's article.)

Tacoma: Deaths: One. Injuries: At least a dozen. Damage estimated at five million. Two schoolhouses damaged and closed. Many buildings damaged and parts fell. Few homes escaped some damage with many chimneys damaged and toppled. Several houses slid into Puget Sound. One smokestack fell. One 23-ton cable saddle thrown from top of tower of Tacoma Narrows bridge causing considerable loss. Railroad bridges south of Tacoma thrown out of line and traffic held up for hours. Railroad tracks kinked, buckled and sank four feet in one place. Tremendous rock

FIG. 6—Collapse of 54,000-gallon wooden tank on roof of six-story reinforced concrete cold storage plant at Seattle.—Photo by Harry Davis, Seattle.

slide followed the earthquake, a half-mile section of a 300-foot cliff slid into Puget Sound.

INSTRUMENTAL RECORDS (STRONG MOTION)

In September 1948, the Coast and Geodetic Survey installed two accelerographs in the Puget Sound region, one at the U. S. Army Engineers' Base, on the tide flats at Seattle, and the other in a small building adjacent to the Transportation Building in the central part of Olympia. This is on filled ground. Figure 7 shows the records of this earthquake from these two stations. The accelerograph does not operate continuously but the earthquake itself sets off a trigger device to cause the instrument to operate. This trigger device is set to operate when the earthquake reaches a certain intensity (normally at a point just before cracking of plaster). The instrument is a high speed recorder and automatically stops after about 75 seconds of operation but will continue to operate if the earthquake continues. After stopping it is ready to operate again until the photographic paper is used up or for a total registration of about ten minutes. Inasmuch as the earthquake has to reach a predetermined intensity before the instrument operates, the instrument does not record the first small vibrations but it will record the strongest vibrations which normally are too severe to be recorded on sensitive seismographs. On the records are time scales showing the speed of the record and intensity scales showing the amplitude of motion for 0.1g or one-tenth of the acceleration of gravity. The records show that the principal portion of the Olympia record lasted about 23 seconds, that the vibrations were very rapid and that the maximum acceleration was about one-fourth of the acceleration of gravity. The Seattle trace shows a longer drawn-out record with slower vibrations and that the maximum acceleration was about one-thirteenth of gravity. In both cases the maximum acceleration was associated with a period of about 0.3 seconds.

SEISMICITY OF PUGET SOUND REGION

A compilation of felt earthquakes shows that the Puget Sound region is moderately seismic. Prior to the earthquake of April 13, 1949, there have been within the past ten years, one earthquake of intensity VIII and three of intensity VII as shown in Table I.

TABLE I—SEISMICITY OF PUGET SOUND REGION

Date	Locality	Felt Area (Sq. Mi.)	Intensity	Remarks
Nov. 12, 1939	Few miles northwest of Olympia	60,000	VII	Felt over most of Washington and northwest Oregon
Apr. 29, 1945	Southeast of Seattle	50,000	VII	Felt over most of Washington and north Oregon and west Idaho.
Feb. 14, 1946	About 20 miles west of Tacoma.	70,000	VII	Felt over most of Washington, northwest Oregon southwest British Columbia.
June 23, 1946	West of Bellingham and possibly in British Columbia.	100,000	VIII	Strongest shock on record to that date in the Puget Sound area.

(Continued on Page 16)

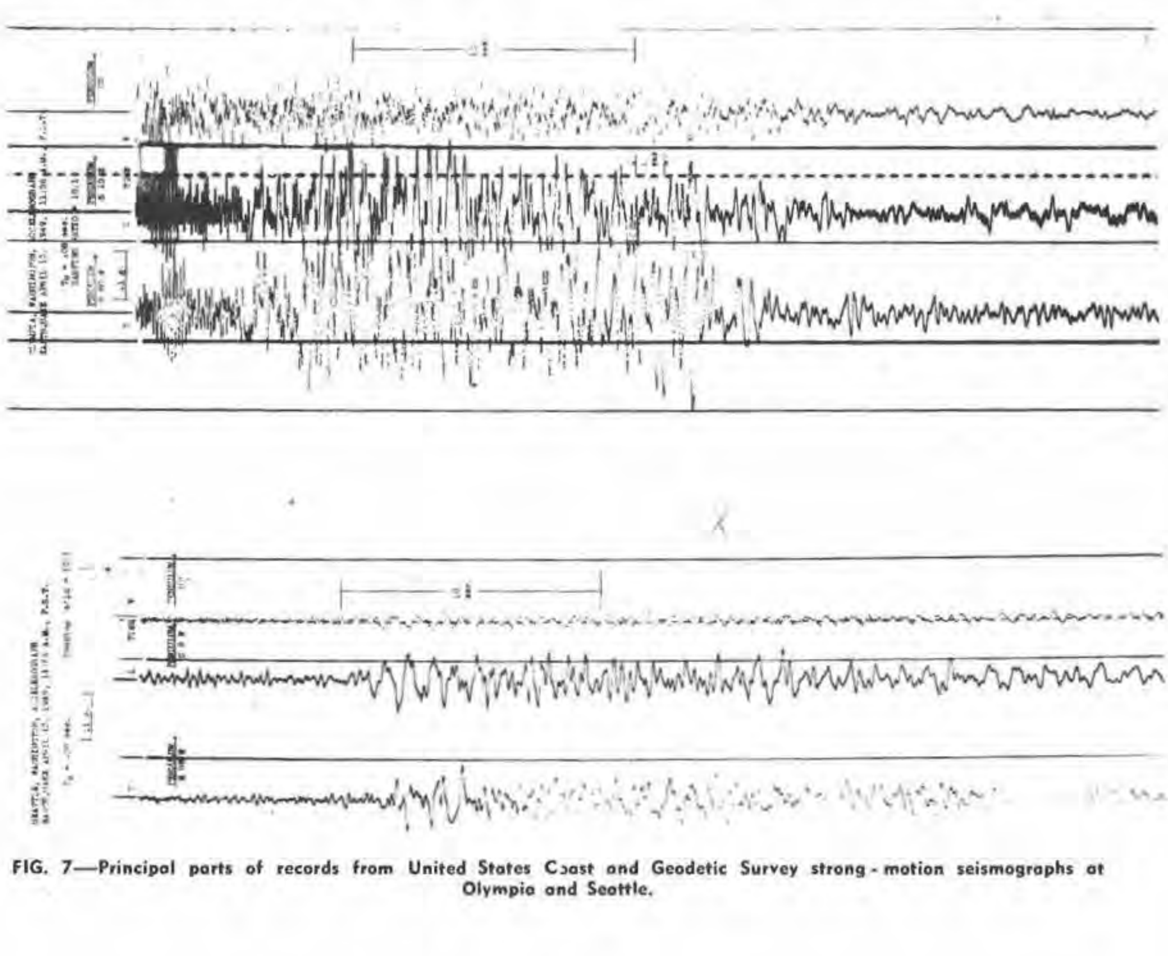


FIG. 7—Principal parts of records from United States Coast and Geodetic Survey strong-motion seismographs at Olympia and Seattle.

TABLE IX — COMPARATIVE DATA PER INSPECTOR EMPLOYED (Continued)

CITY	OPERATING COST				REVENUES RECEIVED			
	Building	Plumbing	Electrical	Smoke	Building	Plumbing	Electrical	Smoke
Atlanta	$ 8,091.81	$ ——	$ 5,653.51	$ 6,992.09	$ 3,156.90	$ 4,276.00	$ 5,817.51	$ 2,918.33
Baltimore	4,473.89	5,463.71	3,824.44	2,505.36	1,741.18	3,501.53	1,450.98	380.62
Birmingham	4,051.68	8,864.77	4,851.09	5,000.00	13,981.15	7,900.30	6,273.12	100.00
Boston	17,655.55	3,775.00	4,511.19	5,135.62	4,573.77	842.62	2,777.04	——
Buffalo	4,298.64	4,225.00	3,477.00	3,737.50	2,493.08	——	1,547.00	1,500.00
Chicago	22,437.88	6,680.10	5,956.52	——	——	——	14,347.82	——
Cincinnati	6,101.33	6,250.00	——	7,388.88	4,147.14	4,386.74	——	2,944.44
Cleveland	5,779.05	4,860.90	4,456.26	——	2,809.09	2,068.93	2,152.97	——
Denver	13,608.68	5,022.14	11,260.61	——	30,188.37	9,607.41	11,317.90	——
Detroit	5,512.77	4,424.20	4,288.05	1,559.12*	5,899.98	4,455.80	6,441.37	12.78*
Kansas City	——	——	——	——	4,904.66	3,604.45	3,026.20	——
Los Angeles	10,523.29	5,494.73	5,801.34	5,833.33	11,849.60	4,486.64	4,308.91	125.00
Louisville	——	——	——	5,000.00	10,946.58	15,056.60	8,695.65	1,475.00
Memphis	6,006.21	3,350.33	1,520.00	——	17,433.75	9,148.66	9,195.66	——
Miami	5,849.75	6,000.22	6,013.55	——	9,757.26	9,909.61	8,432.61	——
Milwaukee	——	5,327.77	——	——	6,308.40	——	3,783.45	——
Minneapolis	6,962.40	8,184.92	6,658.94	4,851.00	8,042.90	6,163.46	4,899.00	——
Montreal	7,763.86	21,041.11	——	——	2,460.03	801.66	——	——
New York	——	——	5,014.74	——	8,022.08	——	——	——
Philadelphia	7,789.47	4,591.91	——	12,000.00	7,766.21	2,999.72	——	——
Pittsburgh	——	6,166.66	——	5,155.50	1,241.53	2,694.82	3,797.58	1,861.25
Rochester	15,930.21	4,555.84	——	3,000.00	11,894.68	——	——	——
San Francisco	8,235.29	3,432.99	——	——	6,735.46	3,064.85	4,973.38	——
Seattle	5,066.99	4,337.76	4,412.63	——	6,905.13	4,309.39	6,901.93	——
St. Louis	5,000.00	5,460.00	5,444.44	5,998.60	4,691.39	5,849.00	6,946.85	3,566.92
Toronto	2,891.11	4,765.47	6,750.00	——	2,333.33	3,032.00	7,750.00	——
Washington, D. C.	6,327.48	5,047.75	4,164.38	4,675.60	5,378.10	2,524.91	2,984.52	1,803.00

* Operated with partial staff during first part of the year.

DEATH OF F. D. HOLMES

FRANCIS D. Holmes, widely known among building officials from coast to coast for his activities with the Red Cedar Shingle Bureau, died on March 1 in Ann Arbor, Michigan. Mr. Holmes had been in ill health since October when he was stricken with pneumonia.

Although he traveled widely and contacted many building

F. D. HOLMES

officials after his illness, he never seemed to recover fully from the effects of it, according to Virgil G. Peterson, assistant manager of the bureau. His death followed a heart attack after an operation. Funeral services were held in Columbus, Ohio, on March 4.

Mr. Holmes first joined the Red Cedar Shingle Bureau in 1939. Since that time, he devoted all his efforts to the public relations field of the organization.

REPORTING THE NORTHWEST EARTHQUAKE

(Continued from Page 11)

In view of this apparently increasing seismic activity, the Coast and Geodetic Survey, in a new Seismic Probability Map published in 1948, raised this region from Zone 1 to Zone 2. (See Building Standards Monthly for March 1948.)

Because of this activity and the possibility of a recurrence of strong shocks in this region, the Advisory Committee on Engineering Seismology in May 1948 recommended to the Coast and Geodetic Survey the installation of at least three strong-motion seismographs in the Puget Sound region. Only two instruments were available and, as previously mentioned, these were installed in September 1948 at Olympia and Seattle.

A summary of felt earthquakes for the past hundred years is given in Table No. II. The record for the period 1856-1933 was compiled by Donald C. Bradford and published in the Bulletin of the Seismological Society of America, Volume 25, Number 2, April 1935. The summary for the period 1934-1948 was compiled from publications of the Coast and Geodetic Survey. In Bradford's compilation, the Rossi-Forel Scale was used, whereas in the Coast and Geodetic Survey reports, the Modified Mercalli Scale was used. The Rossi-Forel Scale is about the same as the Modified Mercalli Scale for the first three intensities but about one-half an intensity higher for intensities IV to VIII, inclusive. Hence, a summation of both compilations would not cause a serious error. The column marked "?" includes those shocks where the available information was insufficient to determine a definite intensity.

TABLE NO. II—FELT EARTHQUAKES IN THE PUGET SOUND REGION 1856-1948

Source	Period	Intensities									Total
		?	1	2	3	4	5	6	7	8	
Bradford	1856-1933	64		14	34	30	13	10	13	1	179
C&GS	1934-1948	43		1	4	8	8	3	3	1	71
Total		107		15	38	38	21	13	16	2	250

THEATER CEILING COLLAPSES

Fifty-four persons were injured, thirty-nine of them seriously, when the ceiling of the Park Theater, Houma, Louisiana, collapsed during a performance on April 19. The manager of the theater, Everett Talbot, said he was just entering the auditorium when he became aware of a loud cracking sound which grew in intensity for about one minute, whereupon the ceiling came down in a sheet from the stage to the projection booth. The reason for the collapse of the ceiling has not yet been determined.

U. S. DEPARTMENT OF COMMERCE
CHARLES SAWYER, Secretary

COAST AND GEODETIC SURVEY
Robert F. A. Studds, Director

Serial No. 748

UNITED STATES EARTHQUAKES 1949

By

LEONARD M. MURPHY

and

FRANKLIN P. ULRICH

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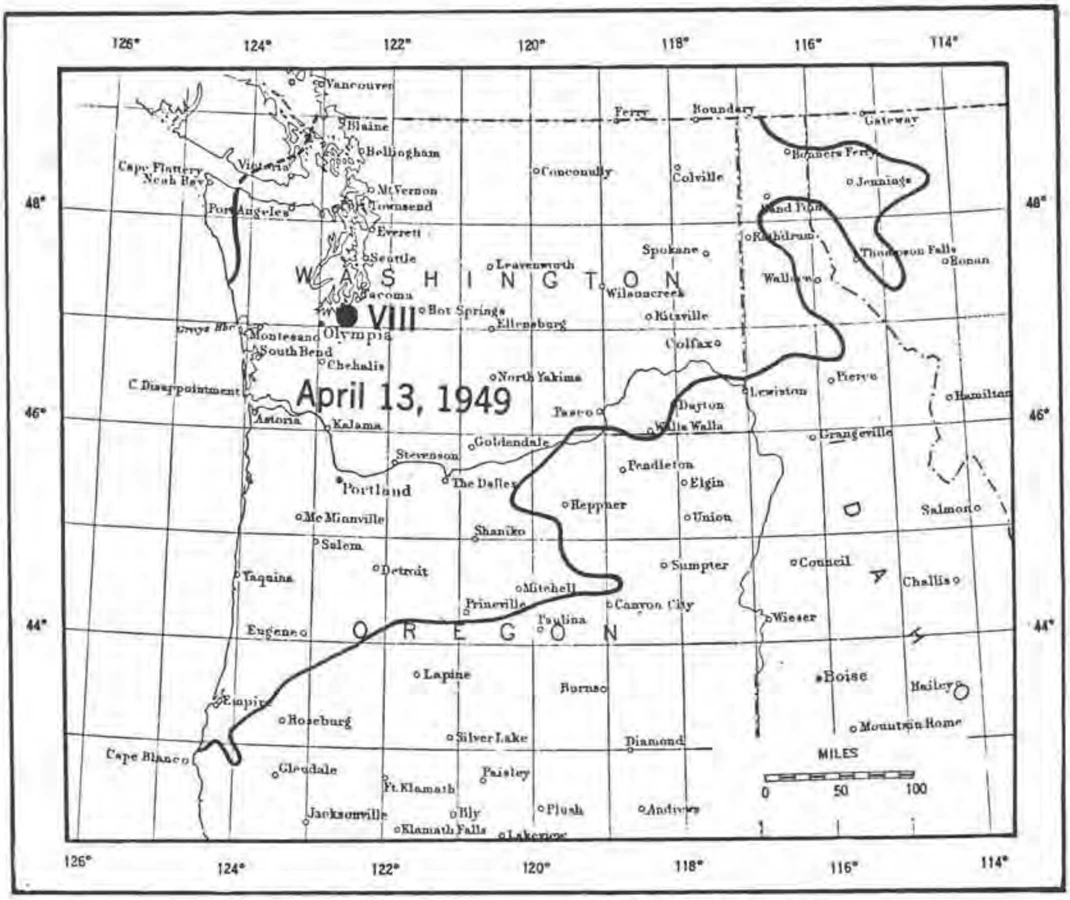

FIGURE 6.—*Area affected by the earthquake of April 13.*

April 13: 11:55:41.* Epicenter 47.1° north, 122.7° west, between Olympia and Tacoma, Wash. W. Felt over an area of 150,000 square miles in the United States. See map. Magnitude was 7.1 for a depth slightly greater than normal. Maximum intensity VIII was reported for an unusually large distance, about 85 miles, and mainly on soft ground with a high water table. Eight deaths were caused either directly or indirectly, many were injured, and damage was estimated at upwards of 25 million dollars. A school, church, and library were condemned and widely separated schools were seriously damaged. In Olympia eight capitol buildings were damaged with a loss of 2 million dollars. Elsewhere heavy property damage was caused by falling parapet walls, toppled chimneys, and cracked walls.

Public utilities suffered seriously when water and gas mains were broken and electric and telegraph services were interrupted. Railroad service into Olympia was suspended for several days, and railroad bridges south of Tacoma were thrown out of line, delaying traffic for several hours.

A large portion of a sandy spit jutting into Puget Sound north of Olympia disappeared during the earthquake. Near Tacoma a tremendous rockslide involving a half-mile section of a 300-foot cliff toppled into Puget Sound. One 23-ton cable saddle was thrown from the top of the Tacoma Narrows bridge tower, causing considerable damage.

INTENSITY VIII IN WASHINGTON:

Aberdeen.—One death. Several brick and concrete buildings cracked, brickwork fell. Scores of chimneys tumbled at roof levels. Water main cracked. Many cracked walls and chimneys; many broken dishes and windows.

Adna.—Chimneys cracked or twisted. Knickknacks, books, and pictures fell; many dishes broke. Furniture and small objects overturned. Considerable damage to brick. Trees and bushes shaken strongly.

Ashford.—Cracked windows, walls, and chimneys; many chimneys twisted or fell. Considerable damage.

Auburn.—One person injured. Four blocks of downtown district severely damaged. Parapet walls and many chimneys fell. Junior High School condemned. Many wall and plaster cracks; many broken dishes.

Buckley.—Part of high school building fell. Most chimneys in town toppled at roof line. Cracked plaster, chimneys, and ground. Books, plaster, and walls fell. Large trees shaken like small bushes. Several brick buildings damaged considerably.

Castle Rock.—One death, several persons injured. One school damaged severely with brick and masonry falling on children. Upper wall over entrance fell. Many cracks up to 6 inches wide in fields and on river dikes. Landslides. Many twisted or fallen chimneys and fireplaces, most falling north and south. Trees and power lines swayed. Plaster, windows, walls, and chimneys cracked; many dishes broken.

Cathlamet.—Chimneys fell, plaster cracked. Knickknacks, books, pictures, and plaster fell. Pendulum clocks facing north stopped. Trees and bushes swayed violently.

Centralia.—One death, 10 persons hospitalized. Very heavy damage. Collapse of building walls and many chimneys. Two city schools permanently closed; 1 church condemned, continued settling of ground caused extensive damage. Water mains broken, and 5,000 feet of concrete pipe in city intake water supply damaged. Water and sand spouted from ground. Violent swaying of buildings and trees. Most chimneys either damaged or fallen. Many walls cracked, worst damage to north walls. Most walls fell to north or south, some to west, very few to east; chimneys twisted clockwise. Telephone lines twisted together for many miles. Many objects moved, including pianos. Objects moved from shelves on all walls. Large amounts of plaster knocked down. Pendulums swinging east–west stopped. Many persons panic-stricken. Four miles southwest of town, water spouted 18 inches high in middle of field, leaving a very fine sand formation for a considerable space around each hole, the holes varying from 1 to 3 inches in diameter. Water spouted from inch-wide crack 8 or 10 feet long. Caretaker on Newaukum River intake noticed gas or air boiling up through water in the river.

Chehalis.—Several persons severely injured. Great damage to downtown buildings, schools, and churches. Water mains damaged, 1,351 chimneys damaged. City Library condemned. Twisting or fall of chimneys, columns, and monuments. Most damage to brick and masonry. "It didn't seem to make any difference in new or old construction as far as chimneys were concerned; certain paths took them all and other places not any." Many broken windows and dishes; knickknacks, pictures, books, and plaster fell. Shifted heavy furnishings if on castors, overturned floor lamp.

Cinebar.—Cracked plaster, windows, walls, chimneys, and ground. Many chimneys twisted or fallen. Some trees twisted and uprooted. Books, pictures, and plaster fell. Damage considerable.

Forest.—At the Niels Paulsen farm, two springs appeared; the first came in the 1946 temblor and another appeared close by during this shock.

Granite Falls.—Twisting and fall of a few chimneys, many chimneys twisted. Considerable damage to brick and masonry. Plaster cracked and fell. Trees and bushes shaken strongly.

Hoquiam.—At least a dozen water mains and pipes broken. Several cracked sidewalks. Considerable damage to brick and masonry. Many cracked windows and walls, many plaster cracks.

Index.—Three 6-inch water mains broken. Considerable damage to chimneys, twisted or fallen, and considerable damage to brick. Many cracked walls and chimneys. Books, pictures, and plaster fell.

Kelso.—Two persons injured. Extensive property damage in business and industrial districts. Stocks in stores knocked from shelves. Three-foot section of theater corner wall fell. Many plaster, window, wall, chimney, and ground cracks. Twisting and fall of chimneys.

Kosmos.—Cracked plaster, walls, windows, chimneys, and ground. Knickknacks, pictures, and plaster fell; dishes broke. Twisting and fall of chimneys. Considerable damage to brick and masonry. Bells rung. Visible swaying of buildings and trees. Many light fixtures torn off. Objects fell west–east.

La Grande.—Damage considerable to brick and masonry. Walls cracked south–north, objects fell north–south. Chimneys fell. Plaster, windows, and walls cracked. Visible swaying of buildings and trees. Ground cracks on steep side hills 1 inch wide to 25–30 feet long. Landslides. Pictures, books, and dishes fell.

Lakebay.—Twisting and fall of many brick chimneys. Cracked plaster and chimneys. Trees and bushes shaken strongly. Small objects and furnishings shifted; many dishes broken.

Littlerock.—Many chimneys broken off and fallen to ground, very few left standing. Trees and bushes shaken strongly. Plaster, windows, and walls cracked; knickknacks, books, pictures, and plaster fell. Trees and bushes shaken strongly.

Longview.—Two minor injuries. Thousands of dollars damage in Cowlitz County. Gable of community church fell; water main at high school broke, beams cracked in cafeteria. Damage extensive, but scattered, to business buildings, industrial properties, and residences. Upheaval action broke a concrete basement floor, pushing up as much as 7 inches. Water came through cracks in sizable quantity for about 3 hours after the shock, stopped entirely about 12 hours after the shock. Water and sand spouted from ground. Ground cracks in yards and road over dikes. Landslides on cuts along highway. Objects fell in all directions, one piano on glass cups rolled about 8 inches in easterly direction. One fireplace mantle moved 1½ inches from wall at one end but not at all at other end; glass figurine resting on end of mantle that moved was thrown a distance of 12 feet, similar figurine at other end of mantle did not even tip over.

Nisqually.—Damage considerable to brick, masonry, and concrete. Many toppled chimneys. Plaster, walls, chimneys, and ground cracked; pictures, books, knickknacks, and plaster fell. Trees and bushes shaken strongly.

Oakville.—One minor injury. Only damage to chimneys which twisted or fell. Twenty-five percent of chimneys damaged. Walls in high school cracked, top of one entrance column broke. Many broken dishes and windows. Wells and creeks were very muddy after shock. Goats raced around.

Olympia.—Two deaths, many persons injured. Eight capitol buildings damaged. Nearly all large buildings were damaged through cracked or fallen walls and plaster. Two large smokestacks and many chimneys fell. Streets were damaged extensively; water and gas mains were broken. A large portion of a sandy spit jutting into Puget Sound north of Olympia disappeared during the earthquake.

Olympia (4 miles south of).—Fifty percent of chimneys down or severely damaged; plaster and masonry walls cracked in every direction. Top 50 feet of a 250-foot plant stack fell. Only one major water main broken and that was on filled waterfront ground. Objects on southwest–northeast shelves fell; objects on northwest–southeast shelves were little disturbed. Eight cubic-foot refrigerator moved about 1½ inches in southeast direction, full bureau moved 6 inches from north wall. Pendulum clock with 16-inch pendulum stopped. One man at airport claimed he observed waves in ground similar to waves on water.

Onalaska.—Damage considerable to brick; many chimneys twisted, fallen, or badly cracked. Milk bottles overturned, many dishes broken. Trees and bushes shaken strongly.

Orting.—Cracks on several dirt roads, small landslide on road to powerhouse. Very loud roaring and whistling subterranean sound heard. Visible swaying of buildings and trees. Several chimneys damaged. Puyallup River turned quite muddy soon after the shock. Mt. Rainier was observed and quite a mist had formed due to falling snow; through glasses new cracks could be seen. Right after shock air was filled with small flies and gnats that disappeared in about two hours. Deer seemed badly frightened.

Puyallup.—Many injured. High school building severely damaged with collapse of stage in auditorium. Nearly every house chimney toppled at roof line. Hundreds of walls cracked, several houses were jarred off their foundations. Roads were blocked by landslides for several hours. Water mains broken. Multiple story brick buildings most severely damaged, walls facing east and west most severely damaged. Narrow dimensional buildings facing east and west not so badly damaged. Some basement floors raised several feet, driving supports through floor above. Everything loose crashed. Plaster badly damaged. Geysers erupted in fields bringing up much sand.

Randle.—Twisting and fall of chimneys, about one-fourth of all chimneys fell. Damage considerable. Water spilled from containers and tanks. Plaster and walls fell, dishes and windows broke. Lights went out.

Richmond Beach.—Damage considerable. Twisted and fallen chimneys, cracked plaster, windows and walls. Dishes and windows broken. Trees and bushes shaken strongly.

Seattle.—One death indirectly, many persons seriously injured with scores reporting shock, bruises, and minor cuts. Many houses on filled ground demolished; many old buildings on soft ground damaged considerably. Collapse of top of one radio tower and one wooden water tank with damage to many tanks on weak buildings. Many chimneys toppled. Heavy damage to docks and stocks awaiting shipment. Several bridges damaged, many water mains in soft ground broken and many basements flooded. Telephone and power service temporarily interrupted. Large cracks in filled ground, some cracking of pavement. Water spouted 6 feet or more from many ground cracks.

At the Federal Office building, bookcases and stands against east walls were thrown face down. North, west, and south wall furniture not displaced. East wall cabinets had drawers pulled out about halfway toward west, none disturbed in other directions. Plaster badly cracked and broken on north-south walls, bulged in great masses with pieces 1 to 3 feet square thrown from walls. Pictures on north-south walls were canted, those on east-west wall showed little cant. Some doors did not fit door casings after shock. In this central section, chimneys, cornices, and parts of sidewalls were thrown down, but not on modern buildings. Many old brick buildings were partially destroyed.

Seattle (south section).—Many old brick buildings damaged, largely on south and east walls. Objects fell mostly north or south, some twisted 30° but left standing. North-south water mains broken. Plaster cracked, broken, and thrown down. Water observed spouting 6 feet or more from many ground faults. Blue silt forced up through minor cracks in basement floors. Many basements completely filled with silt, with floors forced upwards until failure resulted. Loaded tanker reported moving about 1 inch vertically at about 3 cycles per second; tanker was tied to dock in Puget Sound with keel north-south. Visible swaying of buildings and trees.

Shelton.—Most damage to business buildings with some houses damaged. School chimney collapsed. Twisting and fall of chimneys and columns. Severe visible swaying of buildings and trees. Few masonry walls cracked, brickwork damaged in a few buildings. Objects swayed violently, chairs and tables moved, pictures displaced, dishes and other glassware broken. Considerable damage to stocks in stores.

South Bend.—Cracked windows and chimneys, some chimneys fell. Many broken dishes and windows. Books, pictures, and plaster fell; damage considerable to brick.

Steilacoom.—Considerable damage to State Hospital, consisting of collapsed walls and other interior damage. Four chimneys fell. Some cracking of plaster, windows, and walls. Knickknacks and books fell. Merchandise spilled from shelves.

Tacoma.—One death, at least a dozen injured. Many buildings damaged and parts fell. Many chimneys damaged and toppled. Several houses slid into Puget Sound. One smokestack fell. One 23-ton cable saddle was thrown from the top of tower of Tacoma Narrows Bridge, causing considerable loss. Railroad bridges south of Tacoma were thrown out of line. Tremendous rockslide followed earthquake when a half-mile section of a 300-foot cliff slid into Puget Sound. Considerable damage to brick; plaster, windows, walls, and ground cracked.

Tenino.—City Hall and every business house and dwelling suffered some damage. Stores and stocks damaged severely. Damage considerable to brick. Windows, plaster, and chimneys cracked.

Tumwater.—Twisting and fall of chimneys and monuments. Damage considerable to brick and masonry. Plaster, windows, walls, chimneys, and ground cracked. Knickknacks, books, pictures, plaster, and walls fell. Pendulum clocks facing south stopped.

Vader.—Twisting and fall of chimneys, damage to three-fourths of all chimneys. Windows and dishes broken. Damage considerable to wood, brick, and masonry. Shifted everything, overturned vases, small objects, and furniture.

Wilkeson.—Twisting and fall of many brick chimneys, damage considerable to brick. Several houses moved a few inches off their foundations. Plaster, windows, and chimneys cracked. Books and pictures fell. Dishes and windows broke.

INTENSITY VIII IN OREGON:

Clatskanie.—Twisting and fall of chimneys. Damage considerable to brick and masonry. Overturned vases and small objects; plaster cracked and fell. Knickknacks, books, and pictures fell. Hanging objects swung, pendulum clocks stopped.

Rainier.—Building shook with great violence. Knickknacks, books, pictures, plaster, and walls fell. Twisting and fall of chimneys. Damage considerable.

INTENSITY VII:

Arlington.—Cracked chimneys. Knickknacks fell. Hanging objects swung north by northeast. Trees and bushes shaken strongly, small objects overturned.

Black Diamond.—Cracked walls, chimneys, and wallpaper. Pictures fell. Twisting of chimneys. Slight damage to brick.

Bothell.—Cracked plaster and chimneys, broke dishes and windows. Slightly damaged buildings, plastered walls, and chimneys. Frightened people into streets. In central section of town several chimneys fell to west. Light fixtures, pictures, and doors swung.

Bremerton.—One death. Cracked plaster and walls, bricks cracked where steel rested on brick. Set off sprinkler system in National Bank of Commerce. Pulled elevator counterweights out of guides and put several out of service in Navy Yard. Visible swaying of buildings and trees.

Camas.—Twisting and fall of chimneys, slight damage. Small furnishings shifted, hanging objects swung northeast.

Concrete.—Severe trembling. Visible swaying of buildings and trees. One cement floor in new building cracked.

Cosmopolis.—One death caused by heart attack.

Cove.—All buildings creaked. Visible swaying of old frame building. Few old brick chimneys fell. Few small plaster cracks. People ran out of stores and homes.

Des Moines.—One chimney cracked, many dishes broken. Slight damage. Hanging objects swung, trees and bushes shaken strongly.

Doty.—Twisting and fall of chimneys, several cracked chimneys. Small objects and furnishings shifted, vases overturned. Pictures and knickknacks fell. Trees and bushes shaken strongly.

Eatonville.—In east half of town more than half the chimneys were toppled, not so much damage in west half of town. Plaster fell in large pieces in schoolhouse. Extensive damage to dishes. Difficult to maintain balance. Some water pipe connections were loosened, causing leaks.

Elbe.—Cracked chimneys, broke dishes, shifted small objects. Knickknacks fell. Twisting and fall of few chimneys. Trees and bushes shaken strongly.

Enumclaw.—Few chimneys damaged, plaster cracked. Damage slight. Trees and bushes shaken strongly.

Everett.—Loaded coal car broke loose from its blocking and rolled down grade. Considerable minor damage to store stocks thrown from shelves. Pictures thrown from walls. Water tanks splashed over. Slight cracking of plaster, some things fell out of bookcase.

Fall City.—Several chimneys fell. Hanging objects swung north. Trees and bushes shaken strongly.

Frances.—Twisting and fall of chimneys. Plaster and chimney cracks. Hanging objects swung, small furnishings shifted, books and pictures fell.

Grapeview.—Cracked plaster and chimneys. Slight damage. Knickknacks, books, pictures, and plaster fell; small objects and furnishings shifted; vases overturned. Electric lights and telephone wires swayed violently and long after shock stopped.

Grayland.—Some chimneys cracked and some dishes broken. Overturned vases and small objects, shifted small objects. Hanging objects swung.

Hobart.—Cracked plaster and chimneys. Knickknacks fell, vases overturned. Trees and bushes shaken strongly.

Issaquah.—Chimneys cracked, pictures fell, small objects overturned. Hanging objects swung north. Trees and bushes shaken strongly.

Kirkland.—Cracked plaster, walls, and chimneys. Some store windows broken. Knickknacks, books, pictures, and plaster fell.

Lacey.—Rattled windows, house shook violently. Knickknacks fell. Twisting and fall of some chimneys.

La Conner.—Hanging objects swung, pendulum clocks stopped. Trees and bushes shaken strongly. Cracked a few chimneys, broke a few dishes. Damage slight.

Landsburg (one-half mile east of).—Trees and buildings swayed violently. Several chimneys collapsed, some plaster walls cracked in easterly direction. Several poorly constructed buildings with old brick chimneys were damaged. Wires, parked cars, and water tanks swung west–east. Most objects fell in easterly direction.

Langley.—Cracked plaster and chimneys, broke dishes. Shifted all small objects and furnishings, overturned all vases. Knickknacks, books, pictures, and plaster fell. Pendulum clocks facing northeast stopped.

Leavenworth.—Cracked plaster and walls, fall of plaster. Damage slight. Shifted small objects and furnishings. Hanging objects swung.

Longbranch.—Damage slight to wood and brick. Shook small buildings hard. Plaster, windows, walls, and chimneys cracked; knickknacks, books, pictures, and plaster fell. Trees and bushes shaken strongly.

Longmire.—Chimneys cracked, knickknacks fell. Damage slight. Shifted or overturned small objects. Hanging objects swung. Several rockslides on Rampart Ridge, Eagle Peak, and Mt. Rainier; some snow avalanches occurred. Dishes fell eastward, walls cracked slightly in only one building.

Morton.—Plaster, windows, walls, and chimneys cracked; knickknacks, books, and pictures fell. Dishes and windows broke, twisting and fall of few chimneys. Trees and bushes shaken strongly.

North Bend Ranger Station.—Cracked plaster and chimneys. Knicknacks fell. Some slight damage. Cars and trucks shifted.

Olalla.—Twisting and fall of chimneys. Many plaster, window, and wall cracks. Windows and dishes broke. Trees and bushes shaken strongly.

Orchards.—Cracked plaster and chimeys, fall of chimney brick. Damage slight to brick and concrete. Overturned furniture. Trees and bushes shaken strongly.

Packwood.—Hanging objects swung, furnishings shifted. Chimneys cracked, knickknacks and books fell. Dishes broke. Trees and bushes shaken strongly.

Packwood (north section).—Several landslides. Bells rung. Visible swaying of buildings and trees. Pendulum clocks stopped. Electric wires swung violently. One chimney broken off at roof, plaster on chimney broke at District Guard's house. Books fell out of bookcase.

Preston.—Trees and bushes shaken strongly. Fires in oil stoves extinguished. Chimneys cracked, vases overturned, small objects shifted. Damage slight.

Roy.—Plaster, windows, chimneys, and ground cracked. Several chimneys fell, windows broke. Hanging objects swung east to west.

Satsop.—Cracked ground. Broke dishes. Hanging objects swung, pendulum clocks stopped. Trees and bushes shaken strongly. Furnishings shifted.

Satsop (west section).—Visible swaying of buildings and trees. Cupboard doors swung open, pendulum clock stopped. Thunderous subterranean sound heard before shock, rattling heard after shock.

Seahurst.—Plaster and ground cracked. Knickknacks, books, pictures, and plaster fell. Hanging objects swung, small objects and furnishings shifted.

Snoqualmie.—All damage confined to brick chimneys, dishes, and plaster. Overturned vases and floor lamps. Shook coffee out of cups. Rockslides on Mt. Si. Trees and bushes shaken strongly.

Startup.—Chimneys slightly damaged. Some vases, small objects, and furniture overturned.

Stevenson.—Plaster on ceiling of several store buildings cracked. Heavy light fixtures swayed with arc of about 8 inches. Groceries in stores fell from shelves. Landslide occurred at Table Mountain, with dust visible for 10 miles. About eight shocks were felt.

Sultan.—Cracked plaster, walls, and chimneys. Books fell and dishes broke. Small objects shifted or overturned, hanging objects swung north. Pendulum clocks facing northeast stopped.

Toutle.—Log house creaked. Trees and bushes shaken strongly. Twisting and fall of chimneys.

Vancouver.—Cracked oil tank. Pendulum clock facing north stopped. Trees and bushes shaken moderately. Hanging objects swung east–west. Visible swaying of buildings and trees. Dishes and stand lamps fell. Some plaster cracked east–west.

Vashon.—Cracked plaster and chimneys. Two chimneys fell.

Winlock.—One injured. Damage extensive. Store windows shattered, store merchandise damaged. Bricks fell from buildings, general damage to residences.

INTENSITY VII IN OREGON:

Astoria.—Several injured. Several chimneys fell, considerable fallen plaster, mostly north–south walls. Wall of courthouse shifted one inch and glass dome was badly broken. Several water mains broke and flooded basements. Lamps fell, chandeliers swung, water from fish bowl spilled on table, water below rim about 1¼ inches, spilled mostly to east. Whistling subterranean sounds heard at time of shock.

Astoria (16 miles east of).—Man working in garden saw ground move back and forth about 3 inches in east–west direction. Slight rumble heard.

Hebo.—Shifted small objects from shelves, overturned vases and small objects. Walls and chimneys cracked, knickknacks fell. Hanging objects swung.

Hillsboro.—Shifted furnishings, overturned some vases and small objects. Some plaster cracks, windows and walls cracked. Twisting and fall of some chimneys. Some people made ill from motion and nervousness.

Jewell.—Cracked and twisted chimneys, some chimneys fell. Small objects overturned. Hangings objects swung. Trees and bushes shaken strongly.

North Portland.—Heavy swaying motion. Cans fell off shelves, cupboard doors opened. Rocking chairs rocked. Top bricks fell from chimneys and light fixtures swayed very strongly. Trees and bushes shaken strongly.

Oregon City.—Plaster and chimneys fell. Considerable merchandise fell from shelves. House rocked back and forth, lights swung southwest-northeast. Chandelier and flowerpot swung for 20 minutes after shock.

Oswego.—Hanging objects and doors swung. Shifted furnishings, overturned vases and small objects. Columns twisted. Loud subterranean roar at time of shock.

Oswego (1 mile south of).—Shifted small objects and furnishings about 1½ inches.

Portland.—Three minor injuries. Started rockslides and bent rails on the Spokane-Portland-Seattle railway. Cracks opened in several buildings; walls and roofs were damaged, chimneys fell, window panes cracked, merchandise knocked from shelves, and bric-a-bric broken in many homes. Tops of tall buildings swayed considerably. Pictures and mirrors on all four walls tilted. Plaster cracked in many areas in Weather Bureau building. At Weather Bureau airport station, automobiles parked in north-south direction rolled back and forth.

Pratum.—Hanging objects swung. Concrete floor cracked in 8 or 10 places as much as ⅛ inch. Floor badly damaged.

Quincy.—Cracked plaster, windows, walls, chimneys, and ground. Pictures and plaster fell. Some damage to columns and monuments. Trees and bushes shaken moderately.

Rockaway.—Cracked plaster and chimneys, three chimneys twisted and fell. Shifted small objects and furnishings, pendulum clocks stopped, dishes broke.

Sandy.—Cracked walls and chimneys, cracked concrete wall in garage. Canned fruit fell. Trees and bushes shaken strongly.

Seaside.—Cracked plaster, windows, and chimneys. Knickknacks and plaster fell. Twisting and fall of chimneys. Books, pictures, and canned goods fell. Pendulum clocks stopped, hanging objects swung. Felt by people in parked cars, but not by people driving. Accompanied by a heavy roaring and rumbling sound.

Shedd.—Pendulum clocks facing east stopped. Small objects shifted. Several chimneys twisted and fell. Plaster and chimneys cracked.

INTENSITY VI:

Anacortes.—Felt by all. Hanging objects swung north, pendulum clocks stopped. Few chimney cracks.

Ariel.—Very loud rattling of windows, doors, and dishes. Hanging objects swung. Books fell, few cracked chimneys.

Bay Center.—Small objects shifted, books fell. "Too excited to do much observing."

Belfair.—Shifted small objects and furnishings, broke two dishes. Car bounced up and down.

Bellingham.—Hanging objects swung southeast-northwest. Visible swaying of buildings and trees. Pendulum clock stopped.

Bryn Mawr.—Hanging objects swung. Trees and bushes swayed.

Bumping Lake Ranger Station.—Visible swaying of buildings and trees, slight damage to buildings. Few chimney and plaster cracks. Objects swung north–south.

Carrolls.—Trees and bushes shaken strongly. Slight damage to brick and concrete. Hanging objects swung west–east.

Cedar Falls.—Cracked plaster in one place. Knickknacks fell, small objects overturned.

Chelan.—Slight damage and falling bricks in one old two-story wooden frame house. Hanging objects swung east–west, pendulum clocks stopped.

Chelan Falls.—Felt by and frightened many.

Chimacum.—Rattled windows, doors, and dishes. Hanging objects swung. Small objects and furnishings shifted. Trees and bushes shaken strongly.

Chimacum Ranger Station.—Visible swaying of buildings and trees. Few walls cracked around doors and windows. Two concrete-block buildings partially damaged. Pictures displaced on north–south walls. Electric clock stopped.

Clallam Bay.—Felt by and frightened all. Windows, doors, and dishes rattled. Hanging objects swung northeast. Trees and bushes shaken moderately.

Cle Elum.—Pendulum clocks stopped. Small objects and furnishings shifted. Trees and bushes shaken moderately.

Clinton.—Hanging objects swung north. Trees and bushes shaken strongly. Damage slight to brick and masonry.

Coupeville (south of).—Disturbed objects observed by many. Visible swaying of buildings and trees. Walls cracked. Pictures on walls and dishes swung, chandeliers swayed, water moved north-south. Pendulum clocks stopped.

Coupeville.—Houses creaked, hanging objects swung. Water in containers both indoors and outdoors spilled out in south–north direction. Pendulum clocks stopped.

Darrington.—Strong motion up and down at first, then east–west. Telephone wires shook severely. Hanging basket swung for about 20 minutes. Plaster cracked. Cans fell off shelves at store. Snow and rock avalanches in mountains. Thunderous subterranean sounds heard in mountains.

Gig Harbor.—Slight damage to few chimneys.

Greenbank.—Windows, doors, and dishes rattled; house creaked. Hanging objects swung, small objects and furnishings shifted. Vases overturned.

Greenwater.—Buildings creaked, loose objects rattled. Trees swayed for 5 minutes after shock. Objects fell northwest–southeast, lamp chimneys swayed northwest–southeast. Pendulum clock stopped. Moderately loud subterranean sounds heard before shock.

Hartford.—Rattled windows, doors, and dishes. Small objects shifted and pictures fell.

Hoodsport.—Houses creaked, windows and dishes rattled. Plaster cracked, knickknacks, pictures, and plaster fell. Shifted small objects and furnishings.

Hyak.—Rattled windows, doors, and dishes. Trees and bushes shaken strongly. Small objects and furnishings shifted, Power station D. C. voltmeter made line on chart 1½ inches long.

Laurier.—Windows rattled, hanging objects swung northwest. Pendulum clocks stopped. Trees and bushes shaken slightly. Few plaster cracks.

Lucerne.—Rattled windows, doors, and dishes. Hanging objects swung, small objects shifted. Trees and bushes shaken slightly.

Marietta.—Hanging objects swung north, pendulum clocks stopped. Knickknacks and books fell.

Mercer Island.—Slight damage. Trees and bushes shaken strongly. Small objects and furnishings shifted.

Monroe.—Hanging objects swung. Slight cracking of plaster.

Montesano.—Hanging objects swung, pendulum clocks stopped. Plaster cracked, knickknacks fell.

Mount Adams Ranger Station.—Visible swaying of buildings. Lanterns swung north–south. Saws and chains thrown to floor. Pendulum clock stopped.

Naselle Junction.—Hanging objects swung, some knickknacks fell. Motion shook loaded truck, trees, and buildings.

Omak.—Hanging objects swung. Few plaster cracks. Damage slight. Ceiling lights and rocking chairs swayed.

Orting.—Hanging objects swung. Trees and bushes shaken strongly.

Pacific Beach.—Hanging doors swung northwest. Knickknacks and pictures fell. Slight damage.

Palmer.—Hanging objects swung. Some plaster cracked. Trees and bushes shaken strongly.

Parkway.—Hanging objects swung north. Trees and bushes shaken strongly. Shock preceded by loud crack-like blast.

Port Townsend.—Pendulum clocks facing northeast stopped. Hanging objects swung northwest–southeast. Slight damage. Subterranean sounds heard during shock.

Potlatch.—Rocked building, pendulum clocks facing east stopped. Knickknacks, books, and pictures fell.

Prevost.—Ten fruit jars fell from shelf. Slight damage.

Prosser.—Pendulum clocks stopped. Plaster cracked. Knickknacks fell. Damage slight.

Quilcene.—Visible swaying of buildings and trees. Pictures fell from wall.

Quinault.—Visible swaying of electric wires. Slight damage to buildings, few chimneys cracked.

Ridgefield (¼ miles southeast of).—Water in cistern sloshed back and forth almost directly west–east. Seemed to go up and down about 8 inches.

Rockport.—Hanging objects swung northeast. Trees and bushes shaken.

Scienic.—Hanging objects swung north. Trees and bushes shaken strongly. Books fell.

Sequim.—Hanging objects swung east–west. Plaster cracked. Slight damage to masonry.

Silverdale.—Cracked plaster very little. Pictures fell. Trees and bushes shaken moderately.

Skykomish.—Hanging objects swung, vases overturned. Plaster, chimneys, and walls cracked. Dishes and windows broke. Damage slight.

Skykomish Ranger Station.—Slight damage to plaster and chimneys. Flower pot fell off sill, dry battery thrown off pile toward east. Pendulum clock stopped.

Snohomish.—Cracked plaster, one old chimney toppled. Merchandise shaken from shelves in stores. Trees and bushes shaken strongly.

Spanaway.—Hanging objects swung north–south. Pendulum clocks facing east stopped. Shifted stove pipe, overturned vases and small objects. Knickknacks fell. Lake was choppy.

Washougal.—Hanging objects swung north–south and east–west. Cracked plaster, some cracks in brick and masonry walls were enlarged.

Washougal (about 8 miles from highway in the Columbia Gorge, near Cape Horn).—House swayed back and forth, loose objects bounced around. Wires connected to house whipped up and down. Tree tops, cables, and ropes swayed strongly. Arm of telephone pole broke off.

White Salmon.—Visible swaying of buildings and trees. Dressing table moved 6 inches south–north.

Willapa Harbor Station.—Visible swaying of buildings and trees. Many chimneys shaken down in Raymond and South Bend. Objects fell west–east. Pendulum clock stopped. Roaring subterranean sounds at time of shock.

Winton.—Cracked plaster. Damage slight. Trees and bushes shaken strongly.

INTENSITY VI IN OREGON:

Antelope.—Hanging objects swung. Plaster cracked. Damage slight.

Baker.—Light fixtures swung, small objects and furnishings shifted. Some clocks stopped. Knickknacks and books fell.

Bay City.—Hanging objects swung north–south, pendulum clocks facing south stopped. Cracked plaster and windows. Damage slight. Broke wallpaper in a few homes, some plaster on brick flues cracked. Some canned goods knocked off shelves, broke jam and catsup jars.

Beaverton.—Hanging objects swung. Trees and bushes shaken noticeably. Damage slight. Large easel picture toppled.

Buxton and vicinity.—Water heard sloshing in well. Trees, electric poles, and 30-gallon hot-water tank swayed. Boards on ground moved as if on water. Merchandise fell from shelves in grocery store. Old post office building swayed violently.

Corvallis.—Cracked plaster in high school, damage slight to concrete. Elevator swayed, pictures shifted, pendulum clocks stopped, rocked swivel chair.

Cutler.—Knickknacks and pictures fell. Damage slight. Pendulum clocks stopped, hanging objects swung northeast.

Dallas.—Hanging objects swung east. Knickknacks fell. Damage slight.

Dallas (5 miles west of).—Couch moved. Electric light cord swayed east–west. Dishes rattled.

Delake.—Piano jiggled. Bushes and power poles shaken, wires swung. Glassware in cabinet shifted.

Depoe Bay.—Hanging objects swung. Knickknacks fell, vases overturned.

Dundee.—Rattled windows, doors, and shingles on roof. Telephone wires swayed. Stove pipes jarred. Made observer and others ill.

Eagle Creek.—Water in pan swayed north–south. Hanging objects swung south. House and drain pipes creaked.

Florence.—Cracked plaster. Damage slight. Hanging lights swung.

Forest Grove.—Cracked plaster. Hanging objects swung. Trees and bushes shaken strongly. Damage slight. Made some dizzy.

Glenwood.—Hanging objects swung northeast. Electric clocks stopped. Trees and bushes shaken strongly. People rushed outdoors.

Gable.—One can of coffee fell. Hanging objects swung. Trees and bushes shaken moderately.

Gable (2 miles west of).—Swung hinged panel of radio cabinet open. Water tumblers thrown off shelves and broken.

Gresham.—Hanging objects swung, small objects shifted and overturned. Knickknacks fell. Slight damage.

Hubbard.—Pendulum clocks facing northeast stopped. Plaster cracked, knickknacks fell. Very slight damage.

Keasey.—Strongly felt. Cracked plaster and broke dishes. Knickknacks and plaster fell.

Lacomb.—Trees and bushes shaken strongly.

Lacomb (3 miles northeast of).—House shaken strongly, occupants ran outside. Saw woodshed bouncing back and forth, east–west. Shook light wires strongly. Clock stopped.

Lake Grove.—Rattled articles. Pendulum clocks stopped, vases overturned. Plaster cracked and knickknacks fell. Slight damage to masonry.

Lebanon.—Cracked plaster and windows. Hanging objects swung.

McMinnville.—Cracked plaster, broke dishes. Hanging objects swung north–northeast, knickknacks fell. Few ground cracks.

Manhattan Beach.—Trees and bushes shaken strongly.

Manning.—Plaster cracked, knickknacks fell. Slight damage to concrete.

Maplewood.—Shifted small objects and furnishings. Slight damage.

Marion Forks.—Light cords and pictures on wall swung. Trees and bushes shaken strongly.

Marshland.—Hanging objects swung, pendulum clocks stopped. Plaster cracked. Slight damage.

Molalla.—Hanging objects swung, small objects and furnishings shifted.

Monmouth.—Hanging objects swung north–south, pendulum clocks facing west stopped. Plaster cracked and fell. Slight damage.

Mount Angel.—Hanging objects swung east, pendulum clocks facing east stopped. Small objects shifted and knickknacks fell.

Mount Hood.—Plaster cracked and fell. Slight damage. Hanging objects swung.

Nelscott.—Pendulum clocks facing west stopped, hanging objects swung north–south. Cracked plaster and chimneys. Cans fell in grocery store. Slight damage to brick, masonry, and concrete.

Newberg.—Hanging objects swung north. Plaster and chimneys cracked. Slight damage.

Newberg (6 miles northwest of).—House swayed so strongly observer thought it would leave foundation.

Newport.—Cracked walls and chimneys. Knickknacks fell. Slight damage.

Oak Grove.—Cracked plaster. Slight damage.

Oceanlake.—Cracked plaster, walls, and chimneys. Overturned small objects.

Oceanside.—Hanging objects swung. Made everyone dizzy.

Odell.—Hanging objects swung east–west, pendulum clocks stopped. Cars moved.

Orenco.—Hanging objects swung, pendulum clocks stopped. Trees and bushes shaken strongly. Chimneys cracked; knickknacks and dishes fell. Slight damage to brick.

Parkdale.—Hanging objects swung, small objects shifted and overturned. Trees and bushes shaken strongly.

Philomath.—Bars in post-office windows rattled. Hanging objects swung north. Well caved in.

Prinville.—Hanging objects swung, pendulum clocks stopped, knickknacks fell. People felt seasick.

Redmond.—Pendulum clocks facing north stopped. Knickknacks fell.

Roy.—Cracked plaster and walls, some plaster fell. Motion like small boat on choppy water.

Salem.—Chandeliers, hanging plants, and bird cages swung north–south. Small objects and furnishings shifted. Plaster cracked. Slight damage.

Salem (Weather Bureau Office at airport).—Radio tower swayed, slight damage to buildings, few walls cracked north to northeast.

Sandlake.—Car shaken strongly. Hanging objects swung.

Sauvies Island.—Felt by all on picnic field. Trees and bushes shaken moderately.

Scappoose.—Felt by and frightened all. Windows, doors, and dishes rattled.

Scio.—Small objects and furnishings shifted. Slight damage.

Sheridan.—Hanging objects swung, pendulum clocks stopped. Plaster cracked and knickknacks fell.

Sherwood.—Hanging objects swung north–south, pendulum clocks facing south stopped. Trees and bushes shaken strongly. Plaster cracked. Slight damage.

Siletz.—Cracked a few chimneys. Slight damage in a few old brick buildings.

Silverton.—Hanging objects swung. Nearly all people felt seasick.

Spray.—Knickknacks fell.

Tigard.—Large trees and all telephone poles weaved.

Tillamook.—Plaster cracked, knickknacks fell. Slight damage to masonry. Objects fell from shelves. Most people felt nauseated and dizzy.

Toledo.—Hanging objects swung, small objects shifted, vases overturned. Slight damage. Some cracked plaster and walls. Knickknacks and plaster fell.

Troutdale.—Cracked plaster, walls, and chimneys. Knickknacks, books, and pictures fell. Slight damage to masonry. Wires swung.

Troutdale (airport).—Large mirror on north wall fell and was broken. Car (not in gear) rolled in east–west direction about 3–4 feet.

Tualatin.—Shifted dishes, overturned small objects. Plaster and chimneys cracked, books and knickknacks fell. Parked cars rolled back and forth (east–west, about 8 inches). Light wires swung.

Twin Rocks.—Cracked plaster and ground. Knickknacks and books fell.

Valsetz.—Hanging objects swung northwest. Trees and bushes shaken strongly. Small objects and furnishings shifted; knickknacks, books, and pictures fell.

Vernonia.—Hanging objects swung north–south. Cracked plaster, walls, and chimneys. Knickknacks and plaster fell, dishes broke. Slight damage.

Waldport.—Shifted cars.

Waldport (Ranger Station).—Five-ton chain hoist suspended free about 20 inches from ceiling swung east–west for 5 minutes.

Williamette.—Felt like bed moved 6 inches east–west. Electric stove moved back and forth. Hanging objects swung.

Wilsonville.—Railroad trestle swayed and cross members rattled.

Woodburn.—Plaster cracked, few knickknacks fell. Damage slight.

INTENSITY V: Almira, Bangor, Bellevue, Brookfield, Camano Island, Colfax, Colville, Cougar, Deer Park, Diablo Dam, Eastsound, Ellensburg, Entiat, Ferndale, Gifford, Glacier, Hemlock Ranger Station (Carson), Illwaco, Malott, Marblemount, Marysville, Moclips, Mulikteo, Naches, Neah Bay, Nooksack, Ocean Park, Oroville (3½ miles northwest of), Oso, Oysterville, Point Roberts, Pomeroy, Port Angeles, Port Gamble, Possession, Sedro-Woolley, Sekiu, Spokane, Stampede Pass, Stehekin, Valley, Walla Walla, Wenatchee, White Swan, Willard, and Yakima.

INTENSITY V IN OREGON: Agate Beach, Albany, Blachly, Cherry Grove, Cottage Grove, Gresham (2 miles east of), Halsey, Harriman (12 miles northwest of), Harrisburg, Hood River, Jefferson, Junction City, Kernville, Lafayette, La Grande, McCoy, McKenzie Bridge, Mill City, Milwaukee, Monroe, Neskowin, North Bend, Pacific City, Springbrook, Sisters, The Dalles, and Wamic.

INTENSITY V IN IDAHO: Fairfield and Juliaetta.

INTENSITY IV: Blaine, Cascade, Chesaw, Chewelah, Clearbrook, Clearwater, Connell, Cook, Coulee Dam, Custer, Edmonds, Ephrata, Forks (1¼ miles east of), Garfield, Hunters, Irby, Klickitat, Lake Cle Elum, Lake Crescent, Laurel, Leavenworth, Lyle, Metaline Falls, Monroe, Monse, Newport, North Bend, Okanogan, Oakesdale, Olga, Palomas, Pateros, Riverside, Thorp, Trinidad, Vantage, Wapato, Washtucna, Waterville, Wauconda, Winona, and Winthrop.

INTENSITY IV IN OREGON: Alsea, Dayville, Dilley, Eugene, Eugene (9 miles south of), Fairview, Fossil, Grand Ronde, Hoskins, Idanda, Kings Valley, Kinzua, Lonerock, North Powder, Olex, Otter Rock, Otis, Perrydale, Riverton, Stanfield, Tidewater, Timberline, Tygh Valley, Veneta, Vida, and Wasco.

INTENSITY IV IN IDAHO: Deary, Harvard, Paul Jones Beach, Saint Maries, and Sandpoint.

INTENSITY I TO III: Beverly, Bickelton, Cheney, Dallesport, Lind, Loomis, Othello, Paterson, Pullman, Quincy, Ritzville (¾ mile southwest of), Rosalia, Spangle, Tonasket, and Twisp.

INTENSITY I TO III IN OREGON: Dufur, Eastside, Falls City, Flora, John Day, Marion, Powers, Rose Lodge, Rufus, Scottsburg, Siltcoos, Springfield, and Thurston.

INTENSITY I TO III IN IDAHO: Bonners Ferry, Coeur d'Alene, Dudley, Headquarters, Hope, Kotenai, Moscow, Potlatch, Spirit Lake, Tensed, and Viola.

INTENSITY I TO III IN MONTANA: Kalispell, Libby, and Plains.

Negative reports were received from 15 places in Washington, 73 places in Oregon, 51 places in Idaho, and 22 places in Montana.

April 14: No time given. Pullman, Wash. Slight earthquake reportedly stronger than previous day's earthquake. Windows rattled and mirrors shook.

April 19: 22:45. Toutle, Wash. Light shock rattled windows, doors, and dishes. Also felt in Eatonville.

August 21: 20:01:12.* Epicenter 54° north, 133° west, Queen Charlotte Islands region, west. Small power lines and water mains broke in Seattle, and boats broke loose from their moorings. Tidal rise observed in Seattle lakes such as Lake Union and Lake Washington. Water sloshed from a swimming pool in Tacoma. Strong wave action reported in Bea Lake north of Nelport and from Clear Lake northwest of Cheney, pulling boats loose from docks and leaving many fish on beaches. Light fixtures swung in Sedro-Woolley; observer in fishing boat on Commencement Bay, Tacoma, noted swell in bay. Also felt at Clearbrook, Eatonville, and Lake Whatcom.

Negative reports were received from 20 places.

September 26: 17:45. Wenatchee, Wash. Brief, rapid jolt felt by three in home.

THE PUGET SOUND, WASHINGTON EARTHQUAKE OF APRIL 29, 1965

PRELIMINARY SEISMOLOGICAL REPORT
By
S. T. ALGERMISSEN
and
SAMUEL T. HARDING

PRELIMINARY ENGINEERING REPORT
By
KARL V. STEINBRUGGE
and
WILLIAM K. CLOUD

U.S. DEPARTMENT OF COMMERCE

JOHN T. CONNOR, *Secretary*

COAST AND GEODETIC SURVEY

H. ARNOLD KARO, *Director*

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INTRODUCTION

On April 29, 1965, at 8:29 a.m., Pacific Daylight Saving Time, the Puget Sound, Washington region was shaken by the second largest earthquake known to have occurred in the area since 1833. This report is a preliminary interpretation of seismological data obtained from permanent seismograph stations throughout the world, temporary seismograph stations established in the epicentral area immediately following the earthquake, intensity reports, and inspection of the epicentral area.

Seismological data available were unusually abundant. Four permanent seismograph stations recorded the earthquake at distances less than 80 km from the epicenter, thus permitting the determination of a somewhat more accurate focal depth for this earthquake than is normally possible. Excellent seismograms were written by three strong motion seismographs, all located within 50 km of the epicenter. Felt data reports were received from locations in British Columbia, Washington, Oregon and Idaho. Four temporary seismograph stations were in operation within three days after the earthquake. The widespread cover of glacial material in the area reduced the operating magnification of the temporary stations and is also believed to be an important factor in explaining the distribution of seismic intensities near the epicenter.

GEOLOGIC SETTING

The Puget Sound region is a geomorphic and structural depression characterized by low rolling hills and depressions occupied by rivers, lakes, or the waters of Puget Sound. It separates the Cascade Mountains to the east from the Olympic Mountains to the west. The two ranges are arches or broad anticlines and Puget Sound is a broad depression consisting of a series of shales, sandstones and lavas of Tertiary age folded into anticlines and synclines. The Olympic Mountains are composed of folded and faulted quartzites, graywackes and highly indurated sandy shales probably of pre-Tertiary age. Fringing the Olympics is an enormous thickness of basaltic flows and pyroclastics of early Eocene age (Coombs and Barksdale, 1942). The Cascade Range is a post-batholithic volcanic complex in southern Washington but consists of the Nevadan complex in northern Washington (Eardley, 1962).

The Puget Sound area consisted of a vast erosion surface at the beginning of Tertiary time. Early in the Eocene epoch this erosion surface began to subside and was subsequently covered with Metchosin volcanics with a minimum average thickness of approximately 3,000 feet. A north-south trough with its axis in the approximate position of the present Puget Sound depression had formed by the close of Metchosin volcanism. Eight to fourteen thousand feet of sediments, known as the Puget group in the Seattle region, were deposited in this trough. Liesch, Price, and Walters (1963) have summarized the Tertiary and Quaternary history of the Puget Sound area as follows:

"Tertiary:

A. Late in the Eocene epoch over 12,000 feet of carbonaceous shale, sandstone, coal beds, andesitic tuff and volcanic breccia accumulated on a gradually sinking coastal plain.

B. During the Oligocene and Miocene epochs about 8,000 feet of marine shale, sandstone and conglomerate were deposited, probably concurrently with the extrusion of andesitic flows of unknown thickness.

C. Commencing late in Miocene time, the area was deformed by folds trending approximately N70°W.

D. The north-trending Cascade and Olympic Mountains were uplifted in the Pliocene.

Quaternary:

E. The Puget Sound Basin was partially filled by at least three periods of glaciation separated and followed by lacustrine, alluvial, and marine deposition of clay, silt, sand, gravel, and peat.

F. Relative uplift of the Puget Sound Basin resulted in a period of canyon cutting. Much of the present depth and width of the Puget Trough, and the valleys occupied by Lake Washington, Sammamish Lake, and the Snoqualmie River, may have been formed during this period.

G. Advance of the Vashon glacier in Wisconsin time deepened and widened north-trending valleys. Thick bodies of sand, gravel, and till were deposited over the area, particularly in valleys transverse to the direction of ice movement.

H. Retreat of the Vashon ice occurred at least 14,000 years ago. A series of ice-dammed finger-shaped lakes eroded spillways across the uplands. Ice-contact stratified drift was deposited over much of the area.

I. Period of alluvial valley filling and localized peat deposition, minor erosion, and soil development."

Folding occurred in Miocene time which, according to Eardley (1962), was of low to medium intensity and trending generally northwest. It has, in general, been difficult to identify faulting in the Puget Sound area because of the predominance of glacial material. In most cases faults have been shown in the literature as normal.

The preponderance of glacial deposits in the epicentral area has a significant influence on the seismic intensity observed. Liesch, Price, and Walters (1963) have prepared geologic maps of northwestern King County, Washington, and Poulson, et al. (1952), have presented a comprehensive soil survey of the same area. It is hoped that subsequent work may be able to closely relate the known geology to the observed seismic intensity.

The western slope of the Cascade Mountains is an abrupt escarpment which rises from the lowlands bordering Puget Sound at elevations of 50 to 200 feet, to a height of several thousand feet above sea level. The northern part of the Cascades is composed mostly of a complex mass of plutonic and metamorphic rocks which represent the basement upon which the lavas of the southern Cascades were poured. In the northern Cascades, volcanics occur only as a discontinuous veneer. The northwest-southeast folding in the Puget Sound area consequently intersects the north-south escarpment of the western slope of the Cascades at an angle. This relationship has suggested to geologists that the northern Cascades were bordered on the west by a great fault. Bradford and Waters (1934), in the course of their study of the Tolt River earthquake of July 17, 1932, investigated this suggestion of faulting and discovered evidence for a fault striking more or less north-south between the towns of North Bend and Sultan. They gave the following evidence for faulting: (1) At a point about 4 miles from North Bend a section of sedimentary rock more than 3,000 feet thick dips toward Mount Si at angles of 20° or more and the exposures can be traced continuously to within 100 yards of the 4,000 foot escarpment of Mount Si. In the space of 100 yards the thick section of uniformly dipping rocks could not be bent into a position so that it could pass over the top of the mountain in unconformable relation, and the contact cannot be intrusive because of the age relationship of the rocks, the absence of metamorphism, and the lack of veins and dikes in the sedimentary strata. They concluded that only a major fault could explain the observed field relations. (2) Fault breccia and slickensides were found at several locations discussed in detail by the authors. Geologic mapping in western Washington and particularly in the Puget Sound area is extremely difficult because of the widespread cover of glacial material. Consequently, the nature of faulting is difficult to establish and much of it is unknown at the present time.

SEISMICITY

The Puget Sound region is part of a moderately active zone of seismicity extending from the vicinity of Portland, Oregon north through Puget Sound to the Canadian border and Vancouver Island. The first earthquake listed by Townley and Allen (1939) in their catalogue of Washington earthquakes occurred on June 29, 1833 in Thurston County, near the southern end of Puget Sound. The same authors state that their listing is practically complete for moderate shocks perceptible over areas of 50,000 square miles for that portion of the State lying west of the Cascade Range. Heck and Eppley (1958) and records of the Coast and Geodetic Survey since 1958 list 113 earthquakes with a Modified Mercalli intensity of V or greater in Washington from 1841 through April 1965. The earthquakes are distributed in maximum intensity as follows: One of intensity VIII; seven of intensity VII; thirty-one of intensity VI; sixty-three of intensity V; and eleven others for which the maximum intensity could not be determined but are believed to have an intensity of V or greater.

Historically, the Puget Sound area has been subjected to frequent earthquakes of moderate intensity. Table 1 lists the earthquakes with a maximum Modified Mercalli intensity of V or greater that are known to have occurred since 1833. Figure 1 shows the locations, where possible, of the earthquakes listed in Table 1. The four largest earthquakes in the Puget Sound area since 1833 occurred in 1939, 1946, 1949, and 1965. The largest known earthquake in the history of the State occurred on April 13, 1949. The epicenter was located between Olympia and Tacoma along the southern edge of Puget Sound. The maximum Modified Mercalli intensity was VIII and the magnitude was 7.1 (Murphy and Ulrich, 1951). The spatial relationship between the April 13, 1949 and the April 29, 1965 shock is shown in Figure 1. Eight people were killed in the 1949 earthquake and many injured. Property damage in Seattle, Tacoma and Olympia was approximately $25,000,000. The earthquake was felt over an area of 150,000 square miles. The seismological aspects of the 1949 earthquake have been discussed by Nuttli (1952).

The November 12, 1939 earthquake with a maximum intensity of VII and a magnitude of 5¾ was felt over an area of 60,000 square miles in the United States. The felt area in Canada could not be completely determined. Earthquake damage was confined to fallen and twisted chimneys, cracked masonry, concrete and plaster (Bodle, 1941). No structural collapse of buildings was reported. The most severe damage was in Centralia, Elma and Olympia. Coombs and Barksdale (1942) have discussed the macroseismic effects of the earthquake in some detail.

The epicenter of the February 14, 1946 earthquake was 18 miles north of Olympia and about 7 miles northeast of the 1949 shock. The magnitude was 5¾ and the maximum reported intensity was VII. The felt area was 70,000 square miles. A few deaths were charged indirectly to the shocks, and damage was estimated at $250,000, most of it occurring in Seattle. The depth of focus was estimated at 25 km or more (Bodle and Murphy, 1948). Felt aftershocks occurred 20 to 30 seconds af-

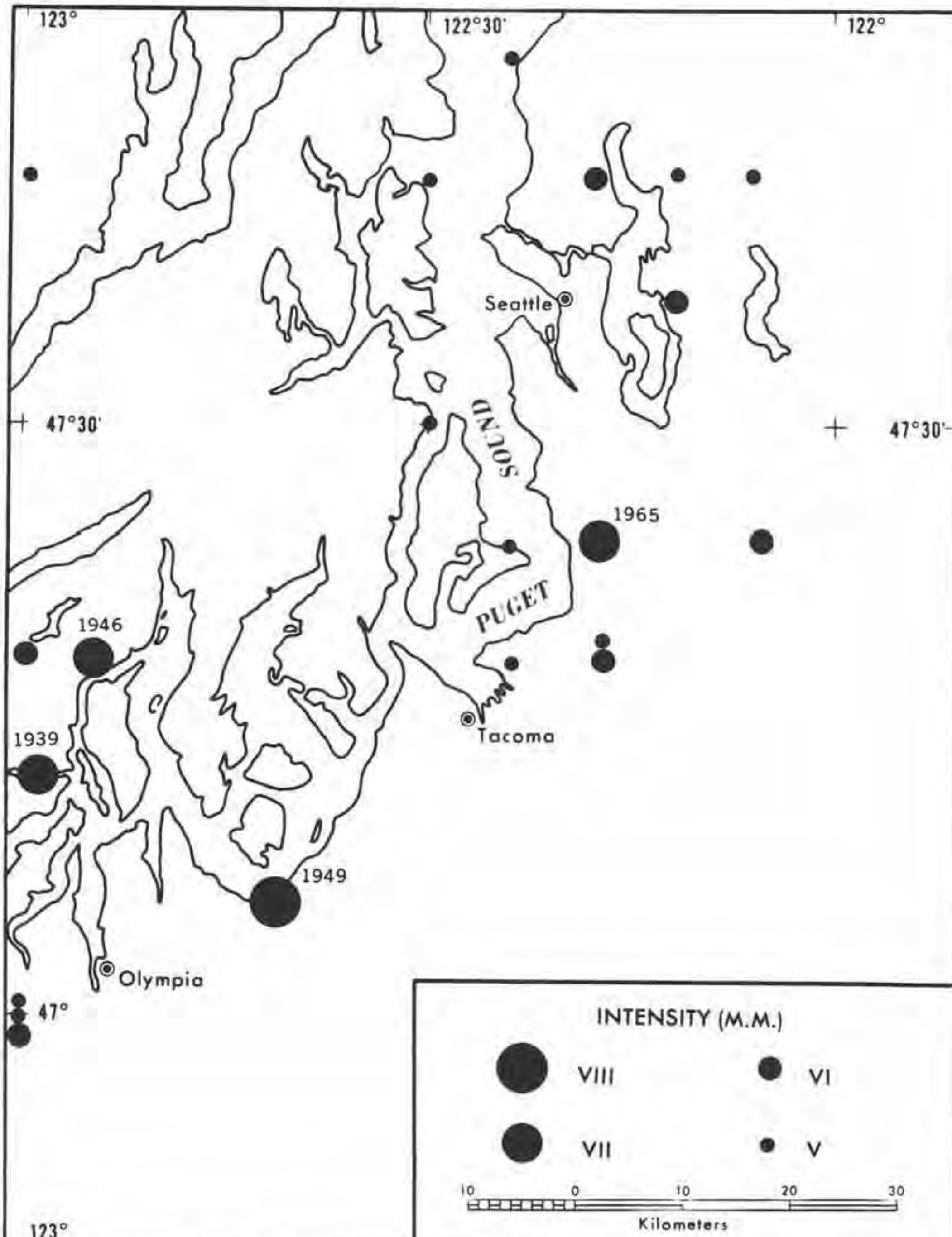

Figure 1.—Earthquakes in the Puget Sound, Washington area, 1833–April 1965.

TABLE 1.—*Earthquakes in the Puget Sound Area, 1833–April 1965*

Year	Date	Pacific Standard Time	N Latitude	W Longitude	Depth	Area	Intensity M.M.	Magnitude	Authority**
		h m s	*deg.*	*deg.*	*km.*	*sq. mi.*			
1859	Apr. 2	02 30	—	—	—	—	V	—	1
1872	Dec. 14–16	—	—	—	—	150,000	VI	—	1
1880	Dec. 12	20 40	—	—	—	—	VI	—	1
1885	Oct. 9	08 00	47	123.0	—	—	VI	—	1
1885	Dec. 8	22 40	47.5	122.5	—	—	V	—	1
1903	Mar. 13	18 15	47.7	122.2	—	10,000	V	—	1
1913	Dec. 25	06 40	47.7	122.5	—	8,000	V	—	1
1914	Sept. 5	01 35	47	123	—	1,000	V	—	1
1916	Jan. 1	16 52	47.3	122.3	—	12,000	V	—	1
1931	Dec. 31	07 25	47.5	123.0	—	10,000	VI	—	1
1932	Aug. 6	14 16	47.7	122.3	—	500	VI	—	1
1938	Jan. 6	05 11	47.8	122.4	—	—	V	—	1
1939	Nov. 12	*23 45 54	47.2	123.0	—	60,000	VII	5.8	1
1944	Mar. 31	14 15	47	123	—	2,500	V	—	1
1946	Feb. 14	*19 17 47	47.3	122.9	—	70,000	VII	5.8	1
1949	Apr. 13	*11 55 41	47.1	122.7	—	150,000	VIII	7.1	1
1954	May 4	*17 42 29	47.3	122.4	—	1,500	V	—	1
1954	May 15	*05 02 13	47.4	122.3	—	17,000	VI	—	1
1956	Jan. 6	*20 30 35	47.3	122.4	—	2,500	V	—	1
1957	May 4	*13 09 27.2	47.4	122.4	40	2,000	V	—	2, 3
1960	Apr. 10	*22 47 35	47.6	112.3	—	600	VI	—	2
1963	Jan. 24	*13 43 11.8	47.4	122.1	17	5,500	VI	—	2
1964	Oct. 15	*06 32 37.5	47.7	122.1	33	—	V	—	4
1965	Apr. 29	*07 28 43.6	47.4	122.3	59	130,000	VII	6.5	4

* Instrumental epicenters.
** Authorities are as follows:
1. Heck, N. H. and R. A. Eppley, *Earthquake History of the United States, Part I: Continental United States and Alaska*, U.S. Department of Commerce, Coast and Geodetic Survey Report No. 41-1, 1958.
2. *United States Earthquakes, 1928–1963*, U.S. Department of Commerce, Coast and Geodetic Survey.
3. Neumann, F., "Crustal Structure in the Puget Sound Area," *Travaux Scientifiques*, Serie A, Fascicule 20, pp. 153–167, 1959.
4. "Preliminary Determination of Epicenters, October 1964–April 1965," cards distributed by the U.S. Department of Commerce, Coast and Geodetic Survey.

TABLE 2.—*Summary of Hypocenter Computations*

Hypocenter Computation No.	Origin Time G.M.T.	N Latitude	W Longitude	Depth	No. of Stations	Average Residual*	Comments
	h m s	*deg.*	*deg.*	*km.*		*sec.*	
1	15 28 43.6	47.4	122.3	59	120	1.1	Depth free.
2	15 28 43.6	47.3	122.2	60	80	1.0	Depth fixed at 60 km; stations with $\Delta > 25°$ only.
3	15 28 43.5	47.4	122.4	60	25	0.9	Station distributed approximately equally in azimuth; depth fixed at 60 km.
4	15 28 43.5	47.4	122.4	61	25	0.9	Station distributed azimuth; depth free.

*As used in this table, the average residual is defined by the equation

$$\text{Average Residual} = \frac{\Sigma\,|\,0-C\,|}{\text{Number of Stations}}.$$

ter the main shock and the following morning at 4:18 a.m. (Barksdale and Coombs, 1946).

In July 1949, modern seismic instrumentation was installed in Seattle and a much clearer picture of local seismicity emerged. During 1950, the Seattle station recorded 77 earthquakes with epicentral distances of 7° or less from Seattle (Vesanen and Jones, 1951). Thirty-nine of these shocks were within a distance of 1° from Seattle. Neumann (1959) discussed the instrumental location of earthquakes in the Puget Sound area from 1951 to 1957, developed travel times, and studied the crustal layering and velocity distribution. Perhaps the most remarkable feature of the seismicity of Puget Sound and vicinity is the increase in seismic activity within the last quarter century. With the possible exception of a shock in 1872, no earthquake with a reported intensity greater than VI has been known to occur between 1833 and 1939. From 1939 through April 1965, three earthquakes of intensity VII and one of intensity VIII occurred within an area of approximately 800 square miles.

Several authors (Heiskanen, 1951; Bodle and Murphy, 1948) have remarked on the large gravity anomaly associated with Puget Sound. The epicenters of all four large earthquakes that have occurred in the last 26 years are located on the flanks of rather large Bouguer anomalies as shown on the Bouguer Gravity Map of the United States (1964).

HYPOCENTER, ORIGIN TIME AND MAGNITUDE

The digital computer program described by Engdahl and Gunst (1965) was used for the computation of the hypocenter of the April 29 earthquake. Four hypocenter computations were made using various data sets. In some cases, the depth of focus was constrained to an arbitrary, but reasonable value. The first computation used P phase arrival time from 120 stations. These data were considered to be the most reliable that were available. The depth of focus was not constrained. Stations located at distances greater than 25° were used in the second hypocenter computation in order to eliminate the effects of velocity and crustal layering variations in the crust and upper mantle on hypocentral location. The focal depth was constrained to 60 km since there is practically no focal depth resolution possible when all the data are recorded at distances greater than 25°. Twenty-five stations grouped to provide as nearly as possible uniform coverage in azimuth were used in the fourth hypocenter computation. Table 2 is a summary of these hypocenter computations. Table 3 shows the travel time residuals for the four hypocenter calculations summarized in Table 2. Figures 3, 4 and 5 show graphically some of the residual data contained in Table 3. Examination of Table 2 shows that for the three data sets used, there is a variation of only .1° in latitude and .2° in longitude among the epicenters computed. For the two data sets in which the depth was computed, the variation in depth of focus is only 2 km. The calculation using 60 stations at distances greater than 25° probably displaces the epicenter eastward for the following reasons: First, the crustal velocity is, on the average, lower than it is to the west of the epicenter and second there were more stations used that are east of the epicenter than west of it. The calculation using stations distributed as equally as possible in azimuth may be significant. Unfortunately, only a rather small number of stations are available for this type of calculation. The depth of focus is believed to be well determined, probably within ±10 km. Four stations were within 80 km of the epicenter and the largest residual among these stations was 1.2 seconds. It is concluded that the best hypocentral location was obtained using readings from 120 stations. This location is 47.4°N latitude and 122.3°W longitude, focal depth, 59 km. The origin time was 15:28:43.6 G.M.T. This epicenter is plotted in Figure 2.

TABLE 3.—*Summary of Travel Time Residuals for Four Hypocenter Computations*

Station		Phase	Distance	Observed—Jeffreys-Bullen Travel Time Residuals			
				1*	2*	3*	4*
			deg.				
Seattle (Marshall)	(STT)	eP	0.1	1.2	......	0.8	0.7
Seattle	(SEA)	iP	0.3	−0.1	......	......	......
Tumwater	(TUM)	iP	0.5	−0.6	......	0.1	0.0
Longmire	(LON)	iP	0.7	−0.2	......	−0.6	−0.7
Victoria	(VIC)	iP	1.4	−1.5	......	−1.0	−1.0
Bellingham	(BLL)	iP	1.4	0.5	......	0.6	0.6
Corvallis	(COR)	iP	2.9	−2.1	......	−1.7	−1.7
Penticton	(PNT)	iP	2.7	2.3	......	......	......
Spokane	(SPO)	iP	3.4	0.3	......	......	......
Blue Mountain	(BMO)	iP	4.3	0.3	......	......	......
Port Hardy	(PHC)	iP	4.8	−2.4	......	......	......
Butte	(BUT)	iP	6.8	0.1	......	......	......
Fort St. James	(FSJ)	iP	7.2	−0.2	......	......	......
Oroville	(ORV)	eP	8.0	−3.5	......	......	......
Edmonton	(EDM)	iP	8.3	−1.8	......	......	......
Ukiah	(UKI)	iP	8.3	−1.0	......	......	......
Byerly	(BKS)	iP	9.5	0.3	......	......	......
Dugway	(DUG)	iP	9.9	2.4	......	......	......
Salt Lake City	(SLC)	iP	10.0	2.4	......	......	......
Uinta Basin	(UBO)	iP	11.6	1.9	......	......	......
Woody	(WDY)	iP	11.9	−0.3	......	......	......
King Ranch	(KRC)	eP	12.2	0.3	......	......	......
Sitka	(SIT)	iP	12.5	2.0	......	......	......
Boulder City	(BCN)	iP	12.7	−0.0	......	......	......
Goldstone	(GSC)	iP	12.7	0.1	......	......	......
Pasadena	(PAS)	iP	13.6	2.1	......	......	......
Riverside	(RVR)	iP	13.9	1.2	......	......	......
Golden	(GOL)	iP	14.5	1.1	......	......	......
Tonto Forest	(TFO)	eP	15.5	1.8	......	1.4	1.4
Albuquerque	(ALQ)	iP	17.2	1.1	......	0.6	0.6
Tucson	(TUC)	iP	17.4	1.1	......	0.8	0.8
Lubbock	(LUB)	eP	20.7	−0.9	......	......	......
Copper Mine	(CMC)	eP	20.9	−0.3	......	......	......
Anchorage	(AMU)	iP	21.0	1.6	......	2.2	2.4
Lawrence	(LAW)	iP	21.4	−0.8	......	......	......
Wichita Mountain	(WMO)	eP	21.8	−1.0	......	......	......
College	(COL)	iP	22.3	0.3	......	......	......
Tulsa	(TUL)	iP	22.8	−0.2	......	......	......
Fayetteville	(FAY)	iP	23.7	−0.1	......	......	......
Chicago	(CHK)	iP	25.2	−0.1	......	......	......
Oxford	(OXF)	eP	27.8	−1.7	−0.8	......	......
Barrow	(BRW)	iP	28.9	−1.0	−1.6	−0.6	−0.5
Mould Bay	(MBC)	iP	29.0	0.1	−0.3	......	......
Cleveland	(CLE)	iP	29.5	−2.3	−1.6	......	......
Cumberland Plateau	(CPO)	eP	29.7	−2.7	−1.9	......	......
Resolute	(RES)	eP	29.8	−0.8	−1.0	......	......
Morgantown	(MRG)	iP	31.4	−2.1	−1.3	......	......
Ottawa	(OTT)	iP	31.8	−2.8	−2.2	......	......
Atlanta	(ATL)	iP	31.8	−1.2	−0.4	−1.6	−1.5
State College	(SCP)	iP	32.2	−2.4	−1.7	......	......
Blacksburg	(BLA)	iP	32.3	−1.0	−0.2	......	......
Frobisher Bay	(FBC)	eP	33.4	−2.4	−2.2	......	......
Georgetown	(GEO)	iP	33.7	−2.1	−1.4	......	......
Columbia	(CSC)	iP	33.6	−0.5	0.3	......	......
Chapel Hill	(CHC)	iP	33.9	−1.8	−1.1	......	......
Philadelphia	(PHI)	iP	34.5	−0.4	0.3	......	......
Palisades	(PAL)	iP	34.8	−2.6	−1.9	......	......
Adak	(AD-)	eP	34.8	−1.9	−2.5	−1.1	−1.0
Fordham	(FOR)	iP	34.9	−0.3	0.4	......	......
Hawaiian Volcanic Observatory	(HVO)	iP	38.7	0.5	0.4	1.2	1.3
Kipapa	(KIP)	eP	38.7	0.8	0.6	......	......
Honolulu	(HON)	iP	38.8	0.6	0.4	1.4	1.5
Godhavn	(GDH)	iP	39.4	0.2	0.3	......	......
Bermuda	(BEC)	iP	45.7	−1.1	−0.5	......	......
Kap Tobin	(KTG)	iP	49.5	0.5	0.4	......	......
Akureyri	(AKU)	iP	53.2	0.7	0.8	......	......

See footnote at end of table.

TABLE 3.—*Summary of Travel Time Residuals for Four Hypocenter Computations*—Continued

Station		Phase	Distance	Observed—Jeffreys-Bullen Travel Time Residuals			
				1*	2*	3*	4*
			deg.				
San Juan	(SJG)	iP	54.1	−0.1	0.6	----------	----------
Chinchina	(CHN)	eP	58.2	1.0	1.8	----------	----------
Caracas	(CAR)	iP	59.2	−1.1	−0.3	−1.3	−1.2
Bogota	(BOG)	iP	59.3	0.6	1.3	0.4	0.5
Tromsoe	(TRO)	iP	59.9	−0.6	−0.8	----------	----------
Kevo	(KEV)	iP	61.0	−0.2	−0.3	----------	----------
Kiruna	(KIR)	iP	61.7	−1.2	−1.3	----------	----------
Trinidad	(TRN)	iP	62.6	−3.3	−2.6	----------	----------
Sodankyla	(SOD)	eP	63.2	−1.4	−1.5	----------	----------
Valentia	(VAL)	iP	65.3	−0.4	−0.2	----------	----------
Lillehammer	(LHN)	iP	65.5	0.2	0.2	----------	----------
Eskdalemuir	(ESK)	iP	65.6	−0.2	−0.1	----------	----------
Kongsberg	(KON)	iP	66.3	0.3	0.3	0.3	0.5
Ponta Delgada	(PDA)	iP	67.4	0.5	0.8	0.3	0.4
Uppsala	(UPP)	iP	68.2	−0.6	−0.7	----------	----------
Papeete	(PPT)	iP	69.1	−0.8	−0.5	−0.3	−0.2
Nurmijarvi	(NUR)	iP	69.2	−0.3	−0.4	----------	----------
Matsushiro	(MAT)	iP	69.8	−1.8	−2.2	−1.2	−1.0
Copenhagen	(COP)	eP	70.5	1.4	1.5	----------	----------
Nana	(NNA)	iP	71.6	0.2	0.8	----------	----------
Uccle	(UCC)	eP	72.0	2.0	2.0	----------	----------
Huancayo	(HUA)	iP	72.4	1.8	2.4	----------	----------
Warmifontaine	(WRM)	eP	73.2	2.7	2.8	----------	----------
Porto	(PTO)	iP	74.1	1.1	1.3	----------	----------
Collmberg	(CLL)	iP	74.5	1.0	1.0	----------	----------
Moxa	(MOX)	iP	74.6	0.2	0.3	----------	----------
Afiamalu	(AFI)	iP	75.3	−0.7	−0.7	−0.1	0.0
Strasbourg	(STR)	iP	75.1	1.6	1.7	----------	----------
Pruhonice	(PRU)	iP	76.1	0.7	0.7	----------	----------
Toledo	(TOL)	iP	77.2	1.6	1.7	----------	----------
Arequipa	(ARE)	iP	78.1	1.4	2.1	----------	----------
Isola	(ISO)	iP	78.5	1.4	1.5	----------	----------
Trieste	(TRI)	iP	79.6	0.8	0.8	----------	----------
La Paz	(LPB)	iP	80.0	−0.2	0.4	−0.3	−0.2
Ifrane	(IFR)	eP	81.7	−0.4	−0.2	−0.5	−0.4
Guam	(GUA)	eP	82.0	−1.9	−2.2	−1.3	−1.2
Rome	(ROM)	eP	82.5	−0.5	−0.4	----------	----------
Beograd	(BEO)	iP	82.5	2.4	2.5	----------	----------
Istanbul	(IST)	iP	88.4	0.6	0.6	----------	----------
Honiara	(HNR)	eP	88.7	1.0	0.9	----------	----------
Kastamonu	(KAS)	iP	89.1	2.4	2.4	----------	----------
Rabaul	(RAB)	iP	80.0	−2.2	−2.3	----------	----------
Hong Kong	(HKC)	iP	94.1	0.3	0.0	----------	----------
Baguio City	(BAG)	iP	95.2	−0.4	−0.6	----------	----------
Manila	(MAN)	eP	96.3	0.9	0.7	----------	----------
Port Moresby	(PMG)	iP	97.2	−0.5	−0.7	----------	----------
Teheran	(TEH)	iP	97.1	2.1	2.0	----------	----------
Warsak	(WRS)	eP	97.9	−0.1	−0.3	----------	----------
Jerusalem	(JER)	iP	98.7	1.6	1.6	----------	----------
Lahore	(LAH)	eP	100.0	0.2	0.0	----------	----------
Shillong	(SHL)	iP	101.1	0.4	−0.6	----------	----------
Quetta	(QUE)	eP	102.4	0.6	0.4	----------	----------
Shiraz	(SHI)	eP	103.2	0.9	0.8	----------	----------
Wellington	(WEL)	eP	104.4	0.4	0.5	----------	----------

*Numbers refer to the hypocenter computation numbers of Table 2.

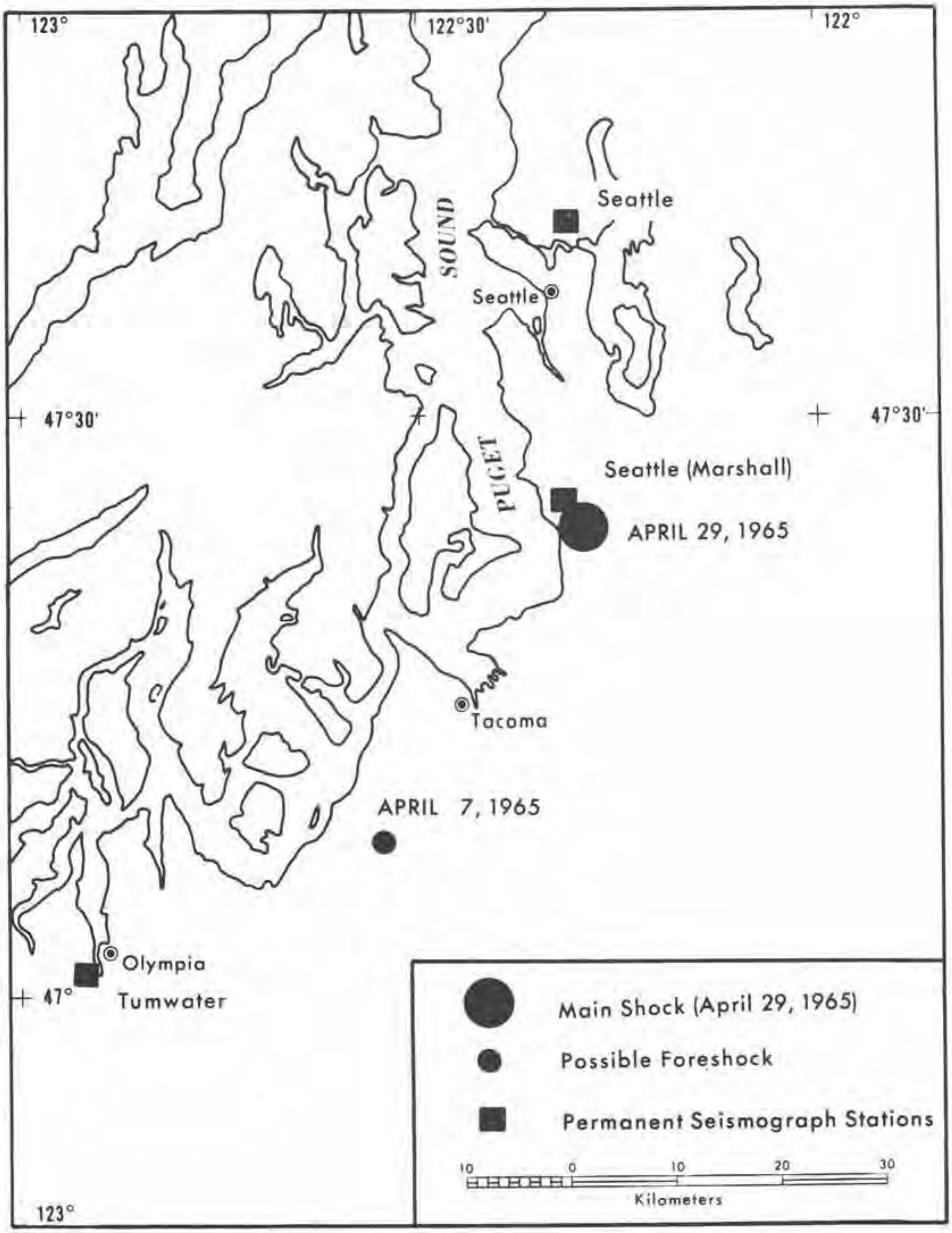

Figure 2.—Location map of the epicentral area showing permanent seismograph stations, epicenter of the April 29 earthquake and a possible foreshock on April 7, 1965.

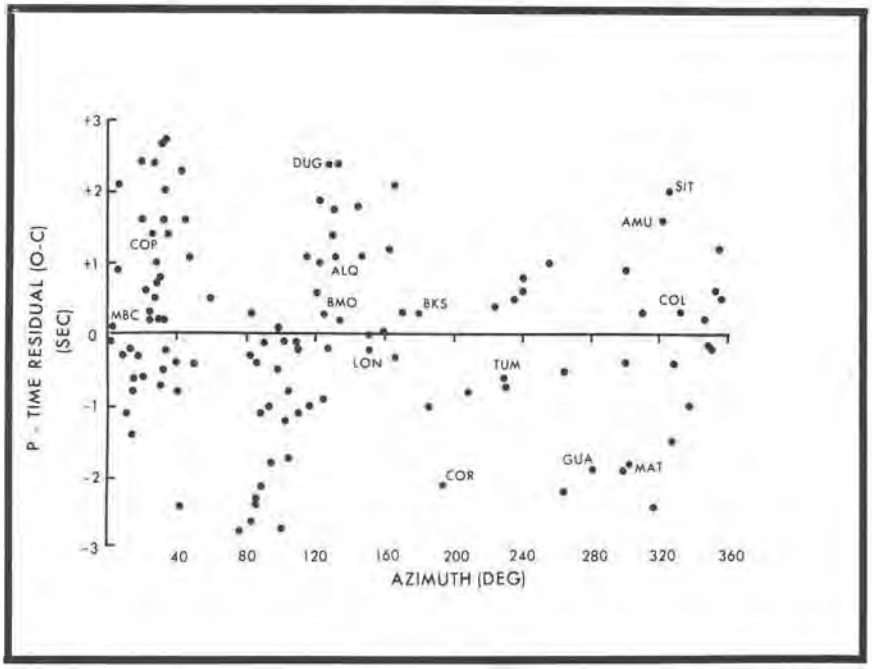

Figure 3.—Residual distribution with azimuth for 120 station hypocenter solutions, depth not constrained.

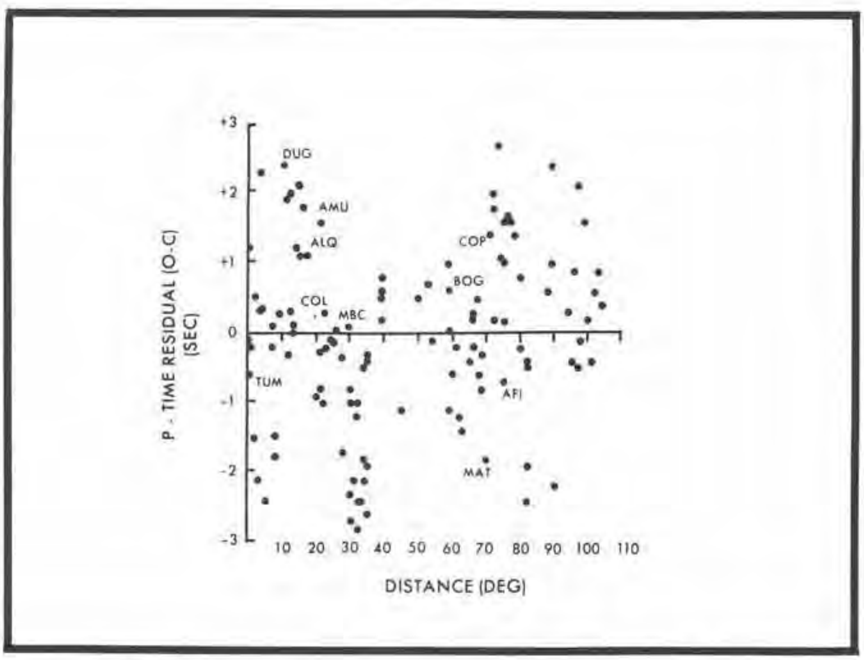

Figure 4.—Residual distribution with distance for 120 station hypocenter solutions, depth not constrained.

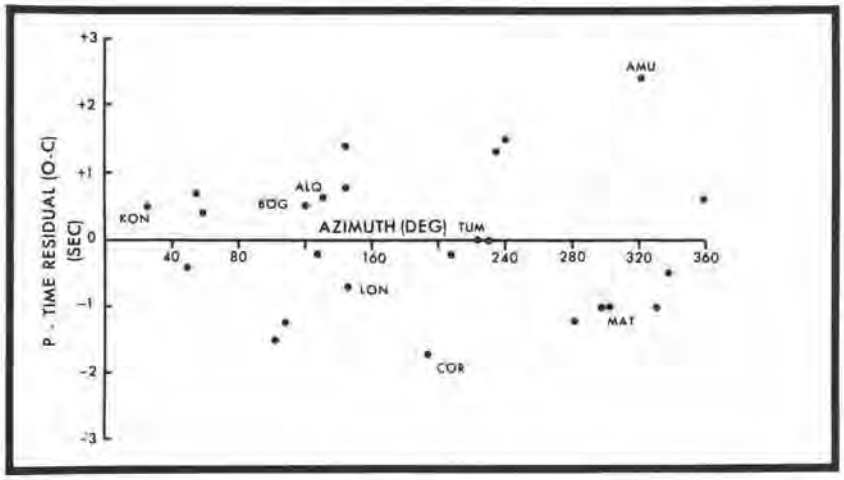

Figure 5.—Residual distribution with azimuth for 25 station hypocenter solutions, depth not constrained.

The body wave magnitude (m_b) as computed routinely by the Coast and Geodetic Survey was 6.5. This magnitude is corrected for a focal depth of 59 km using the charts published by Gutenberg and Richter (1956). A surface wave magnitude (M_s) was also computed using the computed horizontal ground amplitude, in microns, of the maximum amplitude surface wave with periods near 20 seconds recorded on a horizontal seismometer. In practice, the amplitudes determined from each horizontal seismometer are combined vectorially. No depth correction was applied to the surface wave magnitude. The magnitude results are summarized in Table 4. No station corrections were applied to any of the magnitude calculations.

TABLE 4.—*Magnitude Calculations*

Station		Distance	m_b	M_s
		deg.		
Godhavn	(GDH)	39.4	6.1	6.6
Quito	(QUI)	60.2	6.8	6.5
Valentia	(VAL)	64.1	6.7	6.8
Eskdalemuir	(ESK)	64.6	6.5	6.4
Ponta Delgada	(PDA)	67.4	(*)	6.9
Copenhagen	(COP)	69.4	6.4	6.5
Athens University	(ATU)	86.6	6.2	6.2
Average			6.5	6.5

*No short period seismograms.

INTENSITY

The April 29 earthquake was felt over 130,000 square miles, a felt area exceeded only by the 1949 earthquake in the same vicinity. The Modified Mercalli intensity map of the April 29 earthquake is shown in Figure 6. This map was prepared from reports of Coast and Geodetic Survey investigators who visited the areas of greatest damage and from an analysis of 584 earthquake intensity questionnaire cards returned to the Coast and Geodetic Survey by voluntary cooperators. The intensity cards are based on the Modified Mercalli Intensity Scale.

The earthquake was characterized by a relatively large intensity VII area and small pockets of intensity VIII damage in Seattle and surrounding suburbs. Extensive damage to chimneys was noted in West Seattle. The number of damaged chimneys in 188 city blocks of West Seattle were counted. It was found that 1,712 chimneys of the 5,005 in this area were damaged. The results of this damage survey are shown in Figure 7. The ratio of damaged chimneys to the total number in each block has been plotted for each block surveyed. Since the city blocks in

778-883 O—65——3

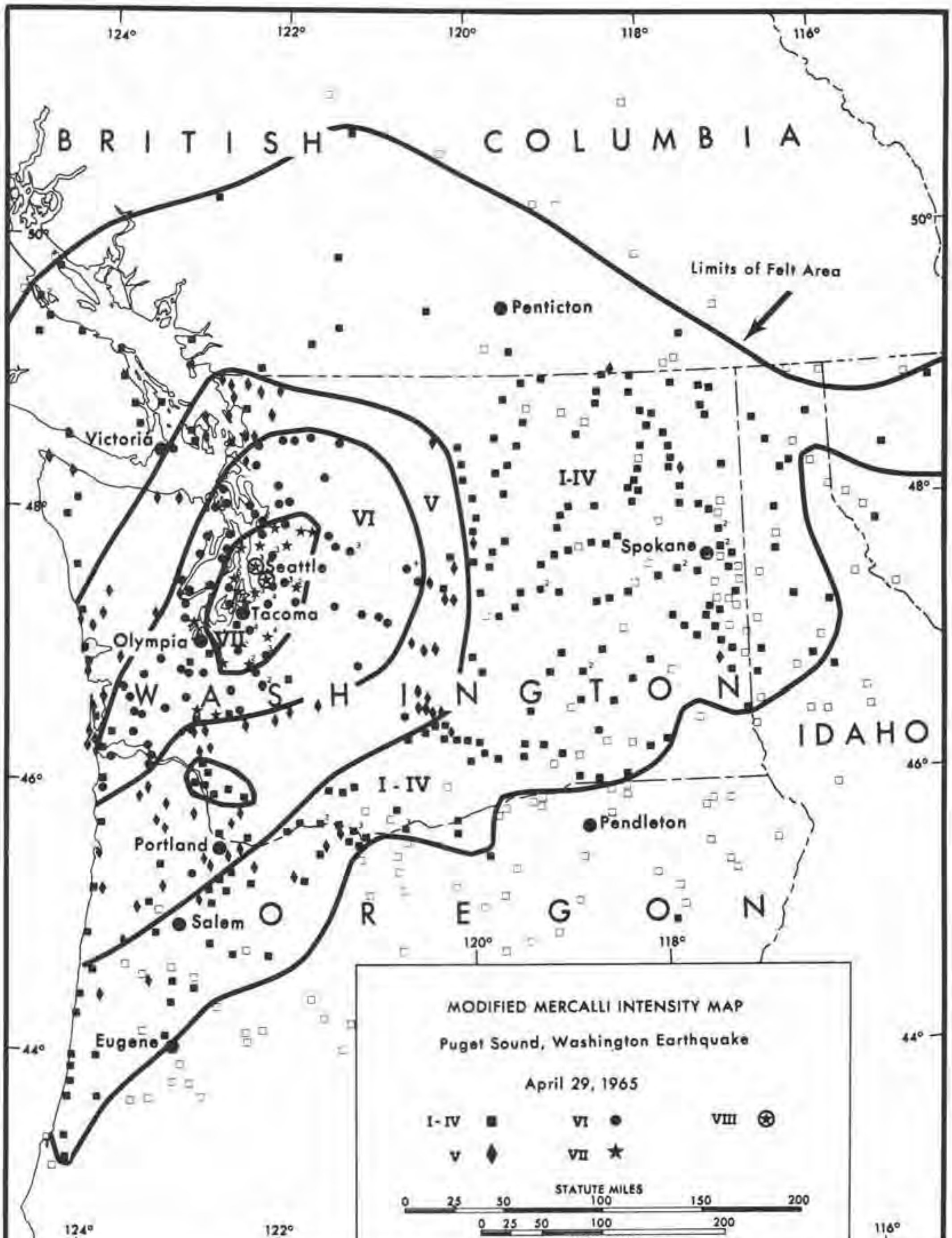

Figure 6.—Intensity map of the Puget Sound, Washington earthquake of April 29, 1965.

this area are rectangles of approximately the same size, the ratio of damaged to total number of chimneys is representative of the damage in the area. The relation of this observed damage to the local geology, particularly the distribution and

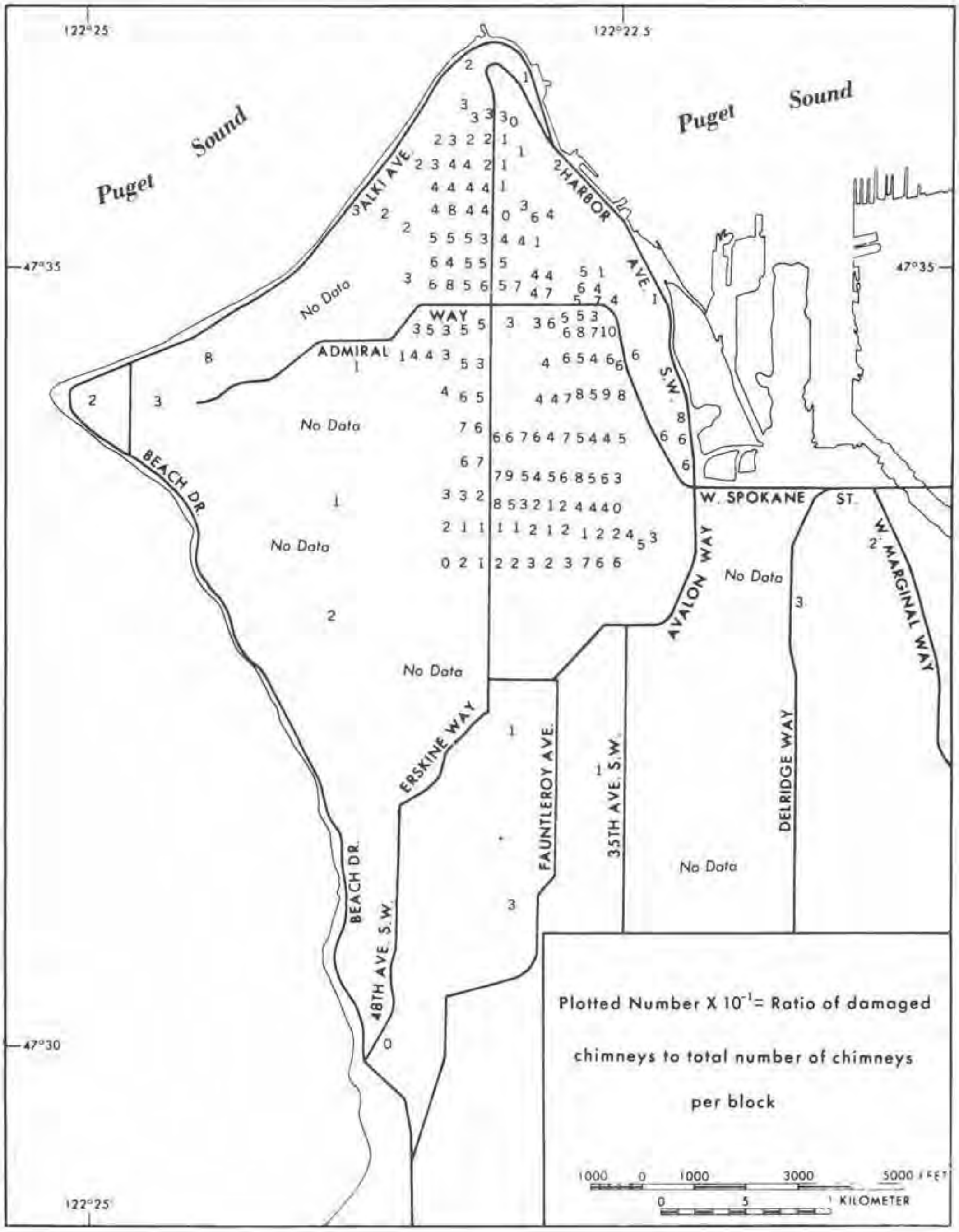

Figure 7.—Map of West Seattle showing the damage to chimneys in the area.

lithology of the underlying glacial deposits, is presently under study. In addition to the extensive chimney damage in West Seattle, two schools were considerably damaged. Slumping was observed along a steep slope adjacent to 36th Avenue S.W. near Admiral Way. Other pockets of high intensity which might be considered as fitting marginally into the Modified Mercalli VIII intensity were Harbor Island in South Seattle and Issaquah, about 15 miles east of Seattle. A brick garage partially collapsed and one school was extensively damaged in Issaquah. There was also considerable damage to chimneys in this area. Damage in the Harbor Island area of Seattle and the other observed vibration damage are discussed in detail in the engineering portion of this report.

Although intensity VIII damage was observed in a few areas, this earthquake is best described, in terms of intensity, as an earthquake with maximum intensity near the upper limit of intensity VII. Observed intensity VIII effects are difficult to evaluate because many of the buildings in these areas were damaged in previous earthquakes, notably in 1949. The following list summarizes the localities experiencing a given intensity of V or greater during the earthquake. For reference, an abridged version of the Modified Mercalli Intensity Scale of 1931 (Wood and Neumann, 1931) with equivalent intensities according to the Rossi-Forel Scale is given following the list of intensity data.

WASHINGTON

INTENSITY VIII

Issaquah, Seattle.

INTENSITY VII

Allyn, Black Diamond, Buckley, Carnation, Cumberland, Dash Point, Des Moines, Dockton, Duvall, Eatonville, Electron, Enumclaw, Ethel, Gold Bar, Gorst, Grapeview, Kenmore, Kingston, La Grande, Lakeview, Longbranch, Manchester, Maple Valley, McCleary, Milton, North Bend, Oakville, Olalla, Olympia, Orting, Port Orchard, Preston, Puyallup, Quilcene, Ravensdale, Retsil, Ronald, Seattle, Skykomish, Snoqualmie, Snoqualmie Falls, South Colby, Sultan, Tacoma, Tumwater, Wauna.

INTENSITY VI

Adna, Amanda Park, Ardenvoir, Arlington, Auburn, Beaver, Belfair, Bothell, Bremerton, Bridgeport, Brinnon, Brooklyn, Bucoda, Burley, Burlington, Carbonado, Cashmere, Cathlamet, Centralia, Chehalis, Chelan Falls, Cinebar, Clallam Bay, Clinton, Concrete, Conway, Copalis Beach, Coupeville, Darrington, Dryden, Dupont, Easton, Elbe, Everett, Fall City, Fort Steilacoom, Fox Island, Frances, Gate, Gig Harbor, Gooseprairie, Graham, Granite Falls, Grotto, Hadlock, Harper, Hobart, Index, Kapowsin, Kent, Kosmos, La Center, Lakebay, Lake Stevens, Lakewood, Langley, Leavenworth, Lebam, Lilliwaup, Longview, Lyman, Maple Falls, Marblemount, McKenna, Medina, Menlo, Mercer Island, Midway, Mineral, Monroe, Montesano, Morton, Mossyrock, Mukilteo, Napavine, Nooksack, Nordland, Omak, Palmer, Pe Ell, Peshastin, Portage, Porter, Port Gamble, Port Ludlow, Poulsbo, Rainier, Raymond, Redmond, Renton, Rochester, Rollingbay, Roslyn, Roy, Satsop, Selah, Selleck, Shelton, Silverdale, South Bend, Southworth, Stanwood, Suquamish, Tahuya, Tokeland, Toutle, Tukwila, Union, Vader, Vashon Island, Vaughn, Woodinville.

INTENSITY V

Acme, Ajlune, Aloha, Amboy, Anderson Island, Baring, Bay Center, Beaver, Bellevue, Blaine, Blanchard, Bow, Brewster, Bridgeport, Burien, Bush Prairie, Carlsborg, Castle Rock, Chelan, Chewelah, Clearlake, Colfax, Copalis Crossing, Cosmopolis, Cougar, Cowiche, Curtis, Custer, Deep River, Doty, Eastsound, Edmonds, Ellensburg, Elma, Everett, Ferndale, Freeland, Galvin, Gardiner, Glenoma, Glenwood, Grayland, Grays River, Hamilton, Heisson, Hoodsport, Humptulips, Ilwaco, Inchelium, Indianola, Joyce, Keller, Keyport, Kittitas, Lacy, La Conner, Lakewood, La Push, Littlerock, Long Beach, Loon Lake, Lopez, Lynden, Lynnwood, Malaga, Malone, Marysville, Matlock, Mazama, Methow, Monitor, Moxee City, Naches, Nahcotta, Neah Bay, Neilton, Oak Harbor, Onalaska, Orondo, Oysterville, Pacific Beach, Packwood, Port Angeles, Potlatch, Pullman, Randle, Redondo, Richmond Beach, Rock Island, Ryderwood, Seabeck, Seahurst, Seaview, Sekiu, Silvana, Silver Creek, Silverlake, Skamokawa, South Cle Elum, South Prairie, Startup, Sumner, Swift Dam, Tenino, Thorp, Toledo, Tracyton, Waldron, Wilkeson, Winlock, Yakima, Yelm, Zenith, Zillah.

OREGON

INTENSITY VI

Astoria, Clatskanie, Fort Stevens, Newberg, Seaside, Wauna.

INTENSITY V

Beaverton, Buxton, Cannon Beach, Cornelius, Dee, Fairview, Gales Creek, Gresham, Hubbard, Idanha, McMinnville, Netarts, Philomath, Portland, Sandy, Scappoose, Tidewater, Timber, Tygh Valley, Valsetz, Warrenton, Wemme, Willamina.

BRITISH COLUMBIA

INTENSITY VI

Victoria.

INTENSITY V

Grand Forks.

MODIFIED MERCALLI INTENSITY SCALE OF 1931

All intensities used by the Coast and Geodetic Survey refer to the Modified Mercalli Intensity Scale of 1931. The abridged version of this scale is given here with equivalent intensities according to the Rossi-Forel scale.

(ABRIDGED)

I. Not felt except by a very few under specially 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 building, but many people do not recognize it as an earthquake. Standing motorcars 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 motorcars 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. Disturbances 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 motorcars. (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. Persons driving motorcars disturbed. (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 riverbanks 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 pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

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

FORESHOCKS AND AFTERSHOCKS

Coast and Geodetic Survey geophysicists were sent to Seattle, Washington immediately following the April 29 earthquake to survey damage, service strong motion instruments in operation at Seattle, Tacoma, Olympia and Ross Dam, and to install four temporary seismographs in the epicentral area to record aftershocks. Table 5 describes the aftershock instrumentation and lists the coordinates of each station. All stations were equipped with crystal clocks and radio time checks were made one or more times daily. The first temporary seismograph station was in operation on May 2. The stations were located at Bremerton, Issaquah, Seattle, Pacific and Enumclaw.

The stations at Pacific and Enumclaw were not occupied at the same time. The Pacific site was used from May 3 until May 5. The equipment was then transferred from Pacific to Enumclaw because of the lower seismic background at Enumclaw. Operation of all temporary seismograph stations was discontinued on May 15. Figure 8 shows the location and the period of operation of each of the temporary stations.

During the 14 days of operation of the temporary seismograph stations, only one aftershock was recorded at a sufficient number of stations to permit an epicentral location. Twenty-seven additional aftershocks were recorded but could not be located because of insufficient data. No aftershocks could be located from permanent station data in the time period immediately following the earthquake up until the time the temporary stations were in operation. One aftershock on May 30 was located using permanent seismograph station data. The foreshock and aftershocks were located graphically using Neumann's (1959) travel time curves. Table 6 lists all of the phases identified on seismograms from the temporary stations and gives the locations of the foreshock and aftershocks just discussed. The epicenters were graded as to relative quality in the following manner:

- A. Four or more stations used in the solution. Average of the absolute values of the residuals was less than 0.5 second.
- B. Three stations used in the solution. Average of the absolute values of the residuals was greater than 0.5 and less than or equal to 1.0 second.
- C. Three stations used in the solution. Average of the absolute values of the residuals was greater than 1.0 second.

Figure 8 shows the epicenters of the aftershocks located through May 30, 1965.

A review of the three other large earthquakes that have occurred in the Puget Sound area in the last 26 years, that is, in 1939, 1946 and 1949, shows that Puget Sound earthquakes are not noted for aftershock sequences. Four small shocks, three in the vicinity of Chelan and one near Toutle, are reported by Bodle (1941), on the basis of felt data, to have occurred in the nine days following the 1939 earthquake. Barksdale and Coombs (1946) report that two aftershocks followed the 1946 earthquake, the first, 20 to 30 seconds after the main shock and the second the following morning. Bodle and Murphy (1948) report two small aftershocks the day after the main shock and one eight days after the main shock. Murphy and Ulrich (1951) report only one small shock near Toutle, Washington for the six month period following the April 13, 1949, magnitude 7.1 earthquake. Evidently, the April 29, 1965 earthquake is following the pattern of previous shocks in the region.

Seismograms from the Seattle, Seattle (Marshall), Longmire and Tumwater stations were carefully examined for the month preceding the April 29 earthquake Only one possible foreshock could be located during this period of time. The epicenter of this foreshock is shown in Figure 2. A more comprehensive study of seismograms recorded during the year

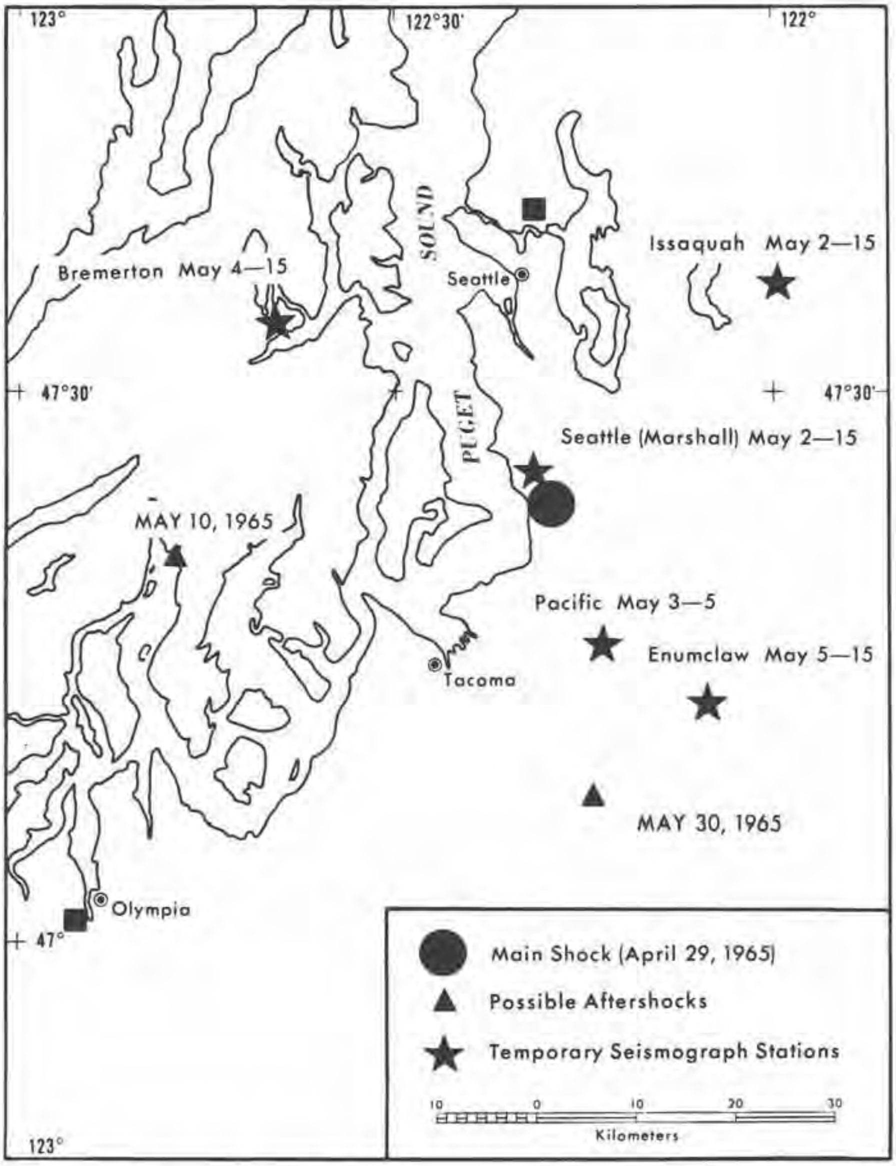

Figure 8.—Location of temporary seismograph stations, epicenter of the April 29 earthquake and possible aftershocks.

TABLE 5.—*Location and Description of Portable Seismic Equipment*

Location	Coordinates	Seismometer	Recording	Magnification
	deg. min.			
Bremerton	122 39.5 W 47 33.6 N	Portable Benioff Vertical	Paper recorder; 60 mm/min	15,000
Enumclaw	122 05.8 W 47 12.7 N	Johnson-Matheson Vertical	Paper recorder; 60 mm/min	15,000
Issaquah	121 59.9 W 47 35.5 N	Portable Benioff Vertical	Paper recorder; 60 mm/min	14,000
Pacific	122 13.8 W 47 16.4 N	Johnson-Matheson Vertical	Paper recorder; 60 mm/min	8,000
Seattle (Marshall)	122 18.8 W 47 25.4 N	Wood-Anderson N-S, E-W	35 mm film; 15 mm/min	*2,800

*When viewed through an 8x viewer.

TABLE 6.—*Chronological Listings of Foreshock and Aftershock Data, April 7–May 30, 1965*

Station	Date	Phase	Time	O–C Residual	Phase	Time	Hypocenter and Origin Time	Quality†
			h m s	*sec*		*h m s*		
Seattle	Apr. 7	eP	04 40 39.8	*−5.7			OT 04:40:37.6	C
Tumwater	Apr. 7	eP	04 40 42.3	−0.4	eS	04 40 52.7	Long. 47.1° N	
Seattle (Marshall)	Apr. 7	eP	04 40 43.0	−0.4			Lat. 122.6° W	
Longmire	Apr. 7	eP	04 40 48.0	+0.4	eS	04 41 00.6		
Issaquah	May 3	eP	05 14 42.0					
Issaquah	May 3	eP	07 39 11.3					
Issaquah	May 5	eP	01 00 12.3					
Issaquah	May 5	eP	18 30 38.4		eS	18 30 47.4		
Bremerton	May 6	e	07 39 01.2					
Issaquah	May 6	iP	19 29 05.6					
Bremerton	May 7	e	09 35 13.0					
Issaquah	May 7	eP	09 35 05.8		e	09 35 09.6		
Issaquah	May 8	iP	00 08 37.4					
Bremerton	May 8	iP	06 03 54.5					
Issaquah	May 8	iP	06 03 58.7		e	06 04 11.4		
Issaquah	May 8	eP	11 45 41.2					
Issaquah	May 8	eP	22 13 27.2		e	22 13 31.3		
Bremerton	May 9	eP	11 45 47.5					
Bremerton	May 9	eP	12 23 46.1					
Bremerton	May 9	eP	14 20 19.9					
Enumclaw	May 10	e	05 18 47.6					
Enumclaw	May 10	e	05 21 23.6					
Bremerton	May 10	iP	06 34 23.4	−1.0	eS	06 34 28.0	OT 06:34:17.5	A
Tumwater	May 10	eP	06 34 24.7	−0.7	eS	06 34 30.4	Depth (12.5-25)**	
Enumclaw	May 10	iP	06 34 28.4	−0.2			Long. 47.4° N	
Seattle (Marshall)	May 10	e	06 34 30.2	*+5.8	iS	06 34 33.0	Lat. 122.8° W	
Issaquah	May 10	eP	06 34 28.5	+0.2	eS	06 34 41.4		
Longmire	May 10	eP	06 34 33.5	0.0	eS	06 34 44.5		
Enumclaw	May 10	e	11 51 25.3					
Issaquah	May 10	e	13 30 21.0					
Issaquah	May 10	e	17 58 39.0					
Issaquah	May 11	e	01 46 24.3					
Bremerton	May 11	e	08 43 55.6					
Enumclaw	May 11	e	09 15 18.4					
Issaquah	May 11	e	13 29 32.7					
Bremerton	May 11	e	17 42 15.0				Teleseismic	
Issaquah	May 11	eP	17 42 20.1				Teleseismic	
Enumclaw	May 11	eP	17 42 22.9				Teleseismic	
Bremerton	May 11	eP	18 19 16.1				Teleseismic	
Longmire	May 11	eP	18 19 16.4				Teleseismic	
Enumclaw	May 11	eP	18 19 21.0				Teleseismic	
Issaquah	May 11	eP	18 19 21.4				Teleseismic	
Enumclaw	May 11	eP	19 17 35.5					
Enumclaw	May 12	e	01 01 05.1					
Enumclaw	May 12	e	14 48 47.4					
Issaquah	May 12	e	18 44 45.7					
Issaquah	May 12	e	20 19 13.7					
Seattle (Marshall)	May 30	eP	08 46 19.4	−1.0	eS	08 46 23.2	OT 08:46:12.8	B
Tumwater	May 30	iP	08 46 22.0	−0.8	iS	08 46 31.3	Depth (12.5-25)**	
Longmire	May 30	iP	08 46 22.4	−0.5	iS	08 46 29.7	Long. 47.1° N	
Seattle	May 30	eP	08 46 30.6	*+7.3			Lat. 122.2° W	

*Indicates station not used in solution.
**Values enclosed in parentheses are questionable.
† Quality is assigned (A through C) as discussed in the text.

preceding the April 29 earthquake at stations in the Puget Sound area is presently underway, but the results are not yet available. The only other earthquake located by the Coast and Geodetic Survey in the year preceding the April 29 earthquake was on October 15, 1964, 37 km northeast of the April 29, 1965 shock.

DIRECTION OF FAULTING

A fault plane solution was made using Byerly's (1938) extended distance technique. Tables developed by Hodgson and Storey (1954), based on the Jeffreys-Bullen travel time curves, were used to compute extended distances. The directions of first motion recorded at 76 stations (see Table 7) were used for the solution. The seismograms from 55 of these stations were read by the authors and the other 21 readings were obtained from the stations that routinely report the direction of first motion. Eight of the seventy-three first motions were found to be inconsistent with our solutions, which amounts to 11% error.

Figure 9 is an extended distance plot in stereographic projection of the direction of first-motion of the 76 stations used in the solution. The circles represent the A and B planes found for this earthquake. The larger circle in Figure 9 represents the A plane and the smaller circle the B plane. The A plane strikes N18°W and dips 69°E. The B plane, restrained by the orthogonality criterion, strikes N53°W and dips 35°W. Regardless of which plane is taken as the fault plane, the faulting is predominantly dip slip. If the A plane is taken as the fault plane, the plunge of the motion vector is 55° and strikes N37°E. If the B plane is taken as the fault plane, the plunge of the motion vector is 21° and strikes N108°W. Figure 10 shows the detail of the central area of the fault plane solution.

Hodgson and Storey's (1954) tables for a focal depth of 0.01 of the earth's radius were used in computing the extended distances of the stations. The focus of this earthquake is somewhat shallower than 0.01 R. Tumwater is the only significant station appreciably affected by using extended distance tables for a depth of focus slightly greater than the depth of focus of the earthquake. If the extended distance for Tumwater is computed using tables for a shallower depth of focus, Tumwater plots closer to the epicenter (see Figure 9). Plotting Tumwater nearer to the epicenter makes this dilatational first motion clearly inconsistent. The diameter of the larger circle can then be increased to include Kongsberg, thereby changing the dip of the A plane by about 3°.

Nuttli (1952) published a fault plane solution of the April 13, 1949 earthquake. His solution was later modified by Hodgson and Storey (1954) on the basis of additional data. Figures 11 and 12 show a comparison of our solution for the April 29, 1965 earthquake with the solution of the April 13, 1949 earthquake presented by Hodgson and Storey. Hodgson and Storey selected the B plane (strike N76°W, dip 12°S) as the most plausible solution for the 1949 earthquake.

It is difficult to choose the fault plane for the 1965 earthquake because both planes represent faults that strike northwest, the direction that is believed to be the trend of the regional structures in the area. Both planes represent dip slip faulting which is consistent with Hodgson's (1957) observation that the general rule of strike slip faulting in the circum-Pacific does not, in general, apply between Alaska and California.

Accordingly, our B plane (strike N53°W dip 35°W) is chosen as the most reasonable choice for the fault because it is parallel to the regional tectonic structure and most nearly agrees with the strike of the fault presented by Hodgson and Storey (1954) for the 1949 earthquake. The motion on the 1965 earthquake represents gravity faulting whereas the solution presented by Hodgson and Storey for the 1949 earthquake represents thrusting.

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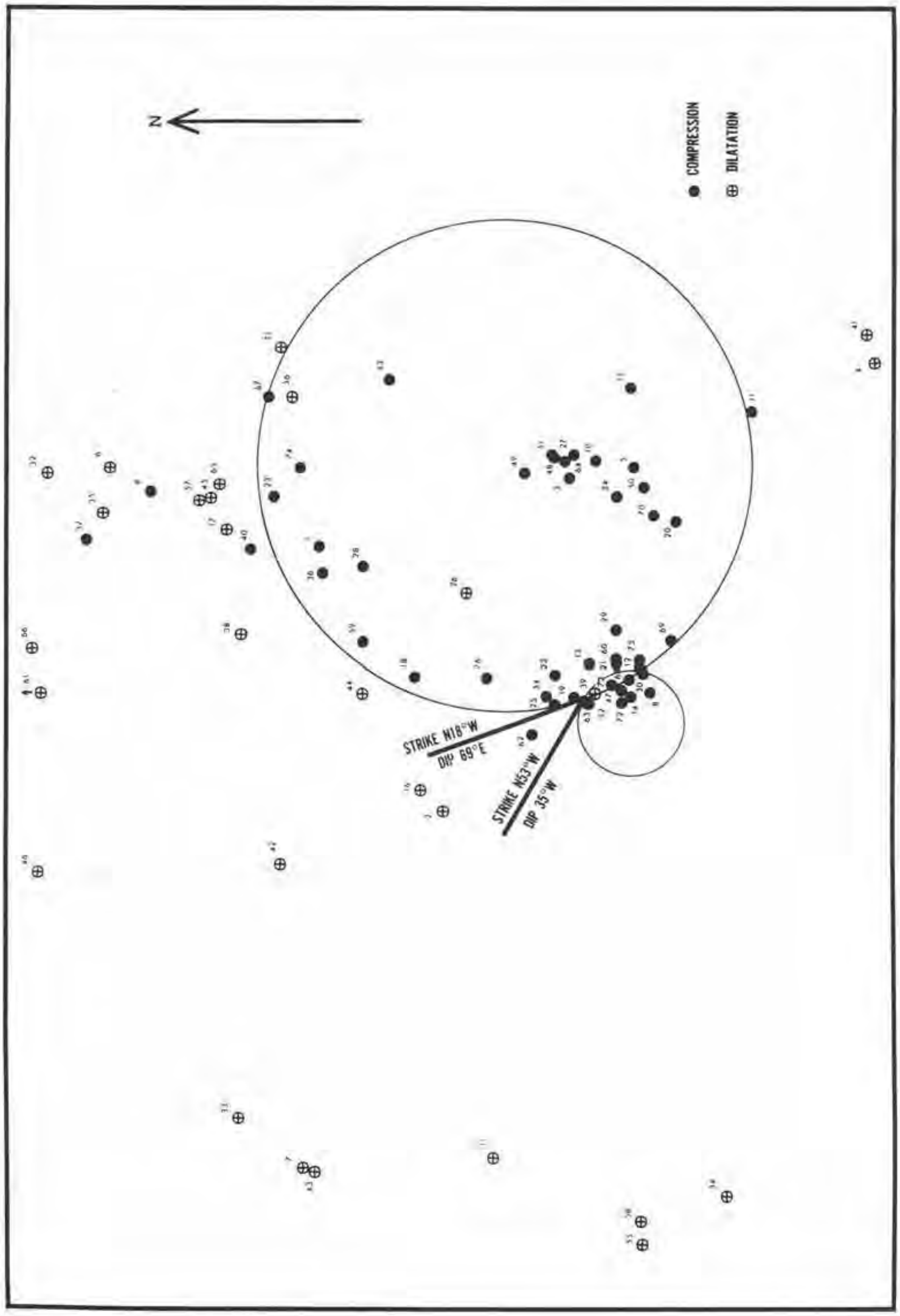

Figure 9.—Stereographic projection showing the first motion and direction of faulting.

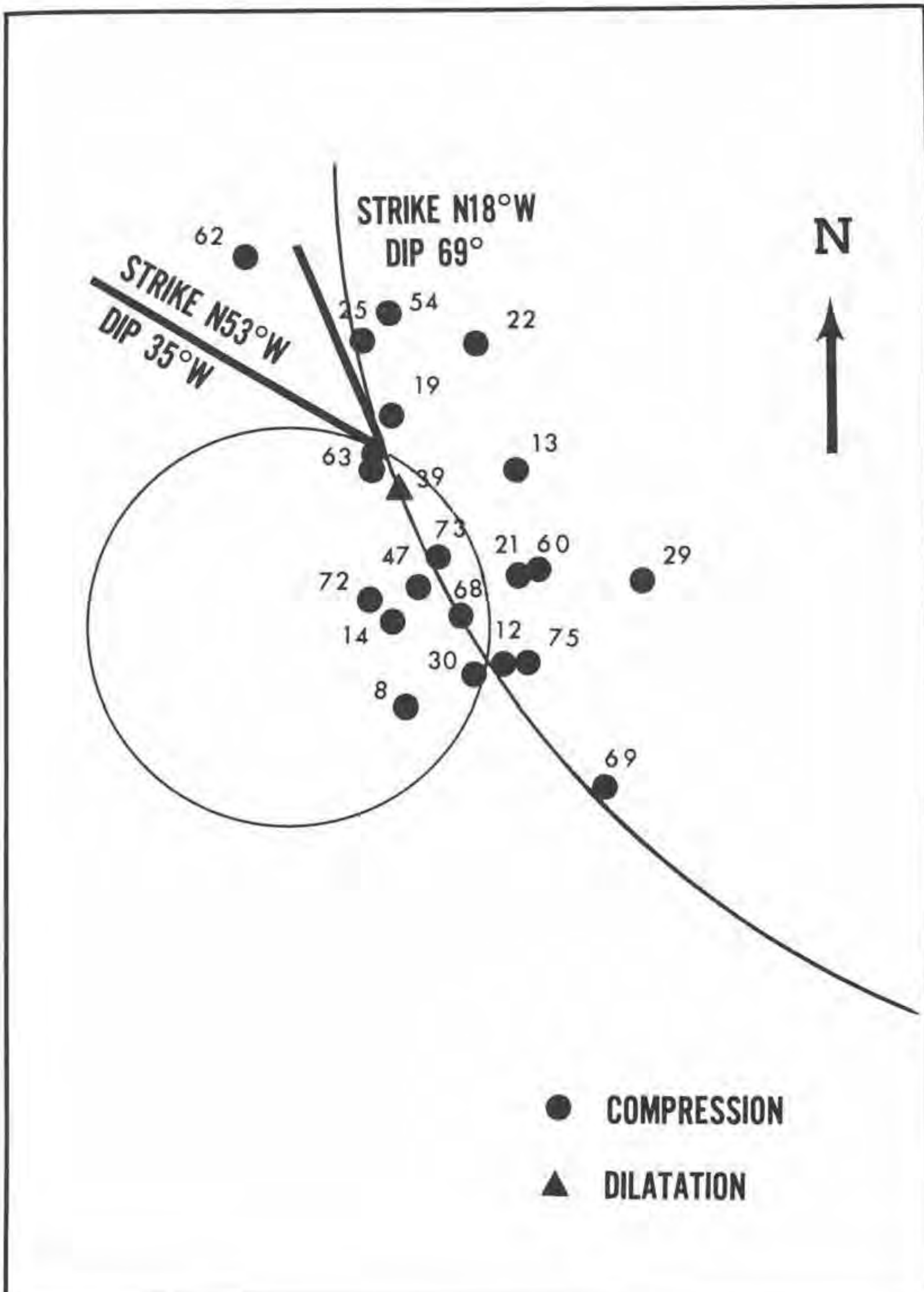

Figure 10.—Stereographic projection showing detail of the fault plane solution.

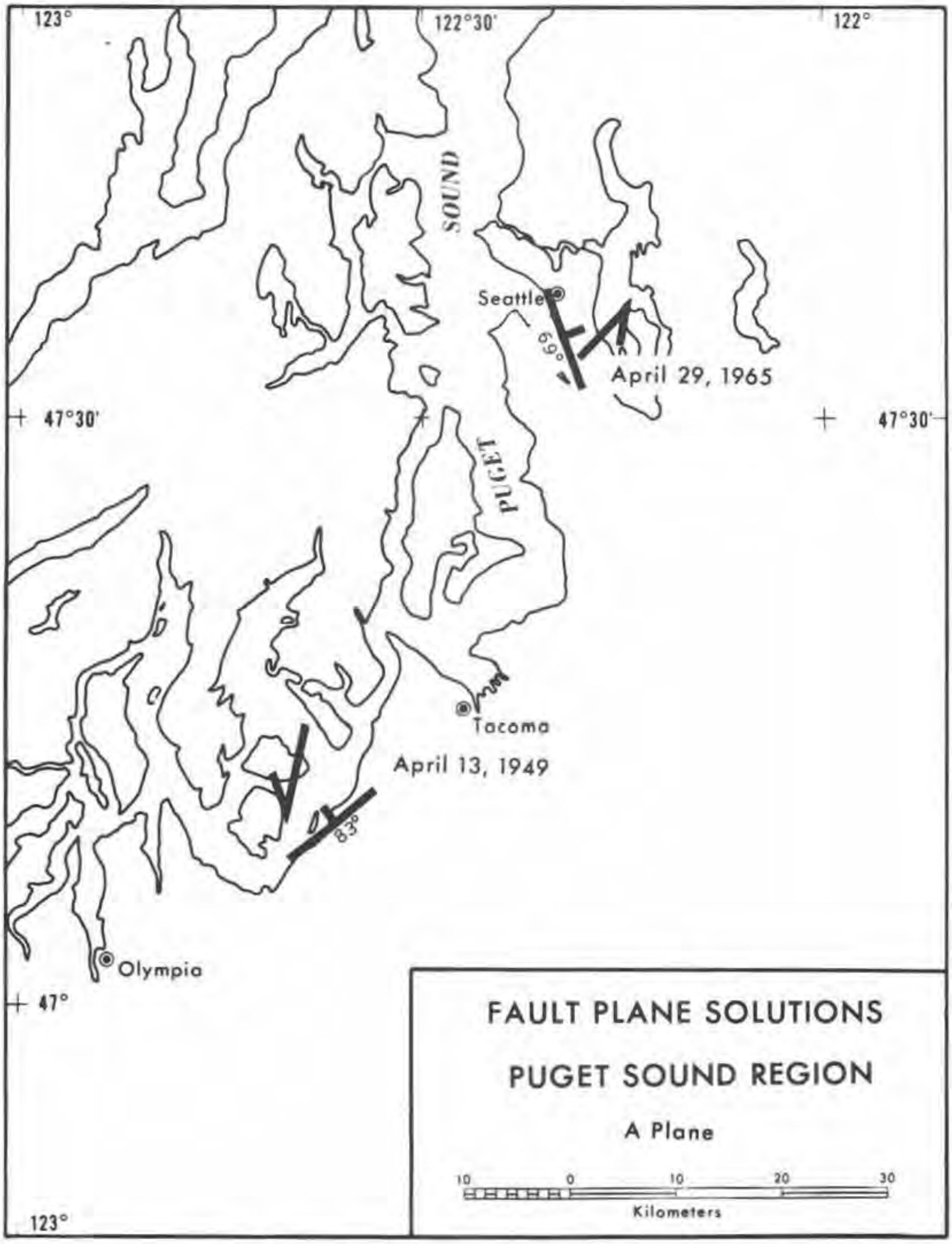

Figure 11.—Comparison of fault plane solutions of the April 29, 1965 and April 13, 1949 earthquakes: A plane.

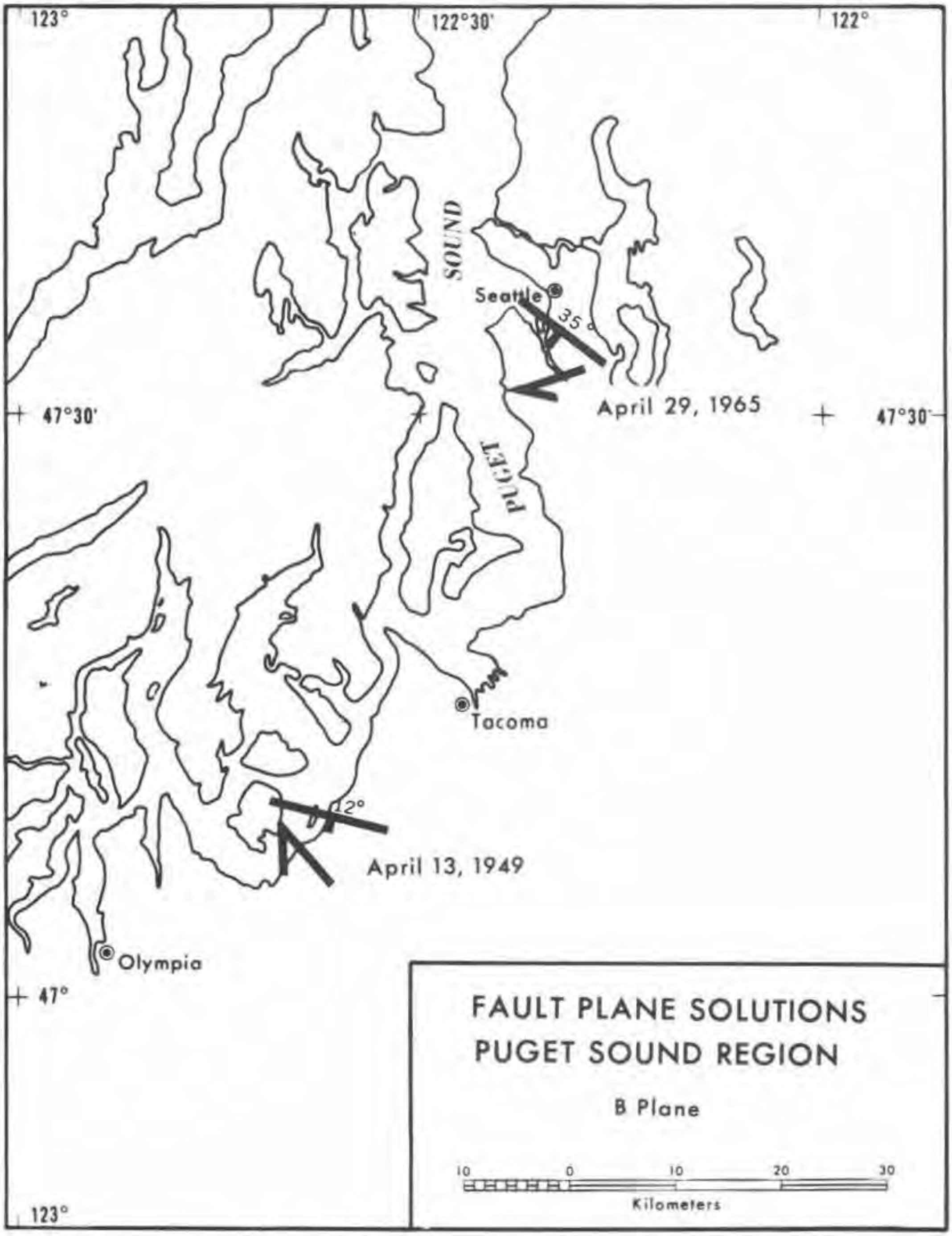

Figure 12.—Comparison of fault plane solutions of the April 29, 1965 and April 13, 1949 earthquakes: B plane.

TABLE 7.—*Character of First Motion*

Station	First Motion: Short Period	First Motion: Long Period	Station	First Motion: Short Period	First Motion: Long Period
1. Akureyri	C*		39. Klamath Falls	(D)*	
2. Anchorage	D*		40. *Kongsberg*	(C)*	(D)
3. Ann Arbor	C*	C	41. La Paz	(D)*	D
4. Arequipa	D*	D	42. Longmire	D*	D
5. Atlanta	C*	C	43. Manila	—	D*
6. Athens	D*	D	44. Mould Bay	D*	D
7. Baguio City	D*	D	45. *Moxa*	D*	
8. Bellingham	C*		46. New Delhi	—	C*
9. *Beograd*	C*		47. *North Reno*	C*	
10. Blacksburg	C*	C	48. Ogdensburg	C*	C
11. Bogota	(D)	C*	49. Ottawa	C*	C
12. Boulder City	C*		50. Oxford	C*	C
13. Bozeman	C*		51. Palisades	C*	C
14. Byerly	—	C*	52. Penticton	C*	C
15. Caracas	C*	C	53. Ponta Delgada		C*
16. College	D*	D	54. *Portland*	C*	
17. Copenhagen	—	D*	55. Port Moresby	D	D*
18. Copper Mine	—	C*	56. *Porto*	D*	
19. Corvallis	C*		57. *Pruhonice*	D*	
20. Dallas	C*	C	58. Rabaul	(D)	D
21. Dugway	C*		59. Resolute	—	C
22. *Edmonton*	C*		60. Salt Lake City	C*	
23. Eskdalemuir	C*	C	61. Seattle	(D)	
24. Florissant		C*	62. Sitka	(C)*	
25. Fort St. James	—	C*	63. *Spokane*	C*	
26. *Frobisher Bay*	D*		64. *State College*	C*	
27. Georgetown	C*	C	65. Stuttgart	(D)	D
28. Godhavn	C*	C	66. *Teheran*	D*	
29. Golden	C*	C	67. *Toledo*	C*	
30. Goldstone	C*	C	68. *Tonopah*	C*	
31. Guam	—	D	69. Tucson	C*	C
32. Helwan	—	D*	70. *Tulsa*	C*	
33. *Hong Kong*	D*		71. Tumwater	D	
34. Honiara	—	D	72. Ukiah	C*	
35. *Istanbul*	D*		73. *Unionville*	C*	
36. *Kap Tobin*	C*		74. Valentia	C*	C
37. *Kastamonu*	C*		75. *Victoria*	C*	
38. Kirkenes	C*		76. Yellow Knife	(D)	C*

Italic is first motion reported by station.
*First motion used in solution.
—Signal not readable.
( ) Questionable reading.

CONCLUSIONS

The Puget Sound area is a part of a moderately active zone of seismicity extending from the vicinity of Portland, Oregon to Vancouver Island. The level of seismic activity in the Puget Sound area has greatly increased in the last quarter of a century, the most severe shock occurring on April 13, 1949. The large shocks in this region have been followed by a relatively small number of aftershocks. The April 29, 1965 earthquake follows this pattern as evidenced by the fact that aftershock activity in the month following the earthquake was practically non-existent. Consideration of the fault plane solution for the April 29, 1965 earthquake shows that no matter which plane is taken as the fault plane, the fault is of the gravity type with northwest strike.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of C. J. Langer and B. J. Morrill of the Coast and Geodetic Survey in gathering intensity information, and Norman Rasmussen of the University of Washington for his cooperation throughout this investigation.

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PRELIMINARY ENGINEERING REPORT

by

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and

William K. Cloud

INTRODUCTION

Seattle, Tacoma, Olympia and neighboring cities in the State of Washington were damaged as the result of an earthquake which occurred at 8:29 a.m., Pacific Daylight Saving Time. The m_b magnitude as given by the Coast and Geodetic Survey is 6.5, and the earthquake's epicenter has been placed at 13 miles southeast of downtown Seattle. The 1965 earthquake had a smaller Richter magnitude than did the last major earthquake in the same area which occurred on April 13, 1949 and had a 7.1 magnitude. The 1949 shock had its epicenter between Tacoma and Olympia and was therefore located somewhat southwest of the 1965 earthquake.

The damage pattern from the 1965 earthquake resembled that of the 1949 shock, with preliminary damage surveys indicating that the 1949 shock was the more destructive of the two.

The focal depth of the 1965 earthquake has been tentatively placed at about 36 miles. The focal depth of the 1949 shock was reported in USC&GS Serial 748 to be "slightly greater than normal." In view of the 10 mile focal depth commonly given for the majority of California earthquakes, the deeper focal depth in these two shocks in Washington suggests a somewhat more moderate surface intensity over a wider area than comparable magnitude but shallower California earthquakes. A general view of the 1965 preliminary damage data tends to confirm this observation.

DESCRIPTION AND ANALYSIS OF DAMAGE

Property loss in the 1965 shock has been estimated at $12,500,000 by the Washington State Civil Defense Department, with much of this loss being in Seattle and in King County. Reliable sources report $500,000 to $1,000,000 loss to the Boeing Company facilities and $1,500,000 damage to Seattle public schools. All of these estimates, made so shortly after the earthquake, are subject to considerable revision as more thoroughly developed data become available. However, in view of the billions of dollars in property value in the affected area, the overall property loss from the earthquake must be considered to be slight.

Three persons were killed from falling debris, three died apparently from heart attacks, and numerous injuries occurred. Figures 13 through 19 are typical of the life hazard from falling masonry.

Building damage was generally light, although it was spectacular in many cases. Total collapses did not occur as far as is known to the authors. In general, damage patterns repeated those of the 1949 shock. Buildings which apparently had been damaged in 1949 often sustained additional damage in 1965. This reoccurring earthquake damage was sometimes intermixed with pre-earthquake settlement cracks which opened wider or caused failure in the 1965 earthquake.

Figure 13.—Failure of an unreinforced brick gable in Seattle. The masonry fell on a parked car, injuring occupant (see Figure 14). (Photo by Seattle Fire Department.)

Figure 14.—Rescuing man injured in automobile due to collapse of gable (see Figure 13). (Photo by Ken Harris, Seattle Post-Intelligencer.)

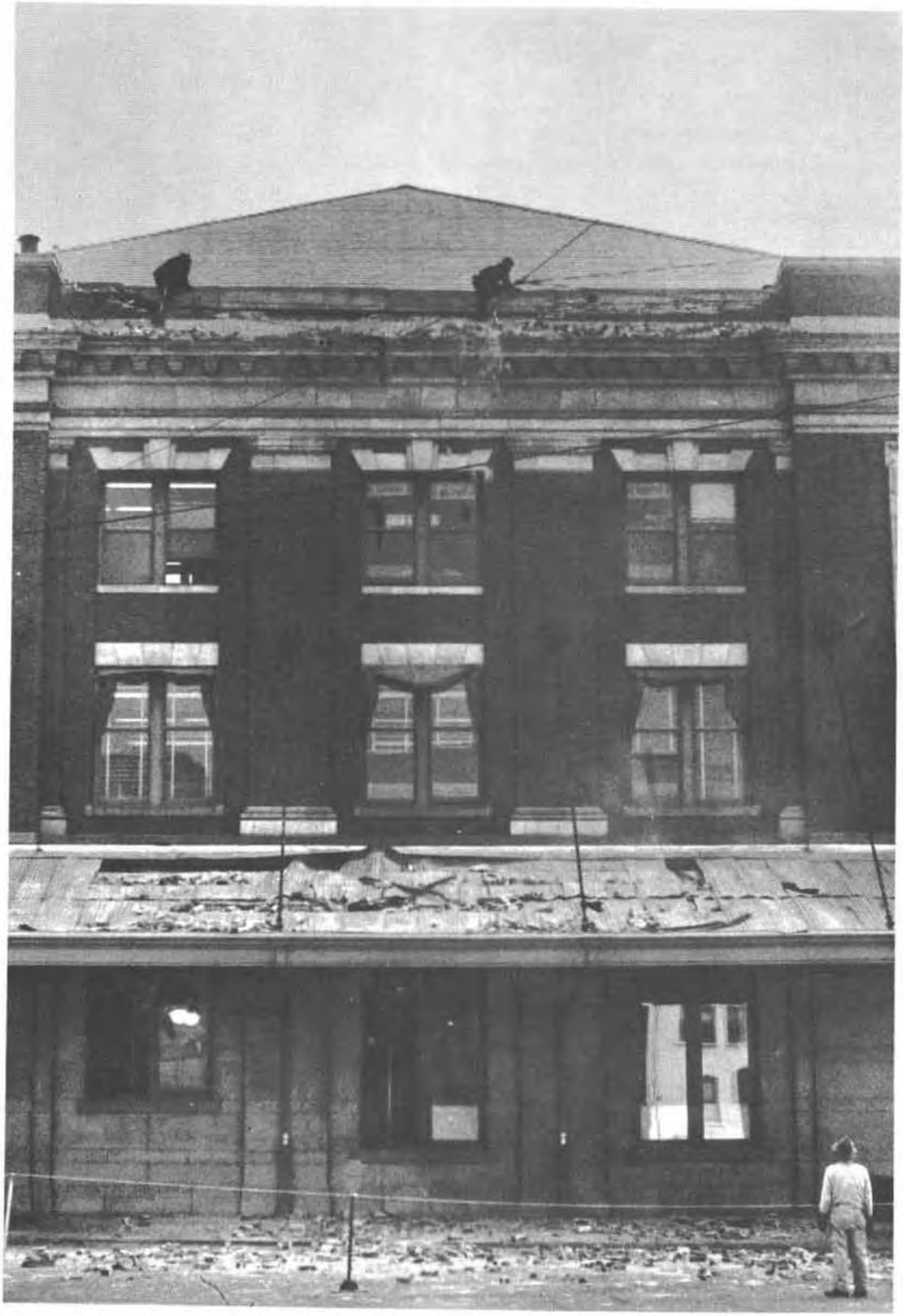

Figure 15.—King Street Railroad Station in Seattle. (Photo by Seattle Fire Department.)

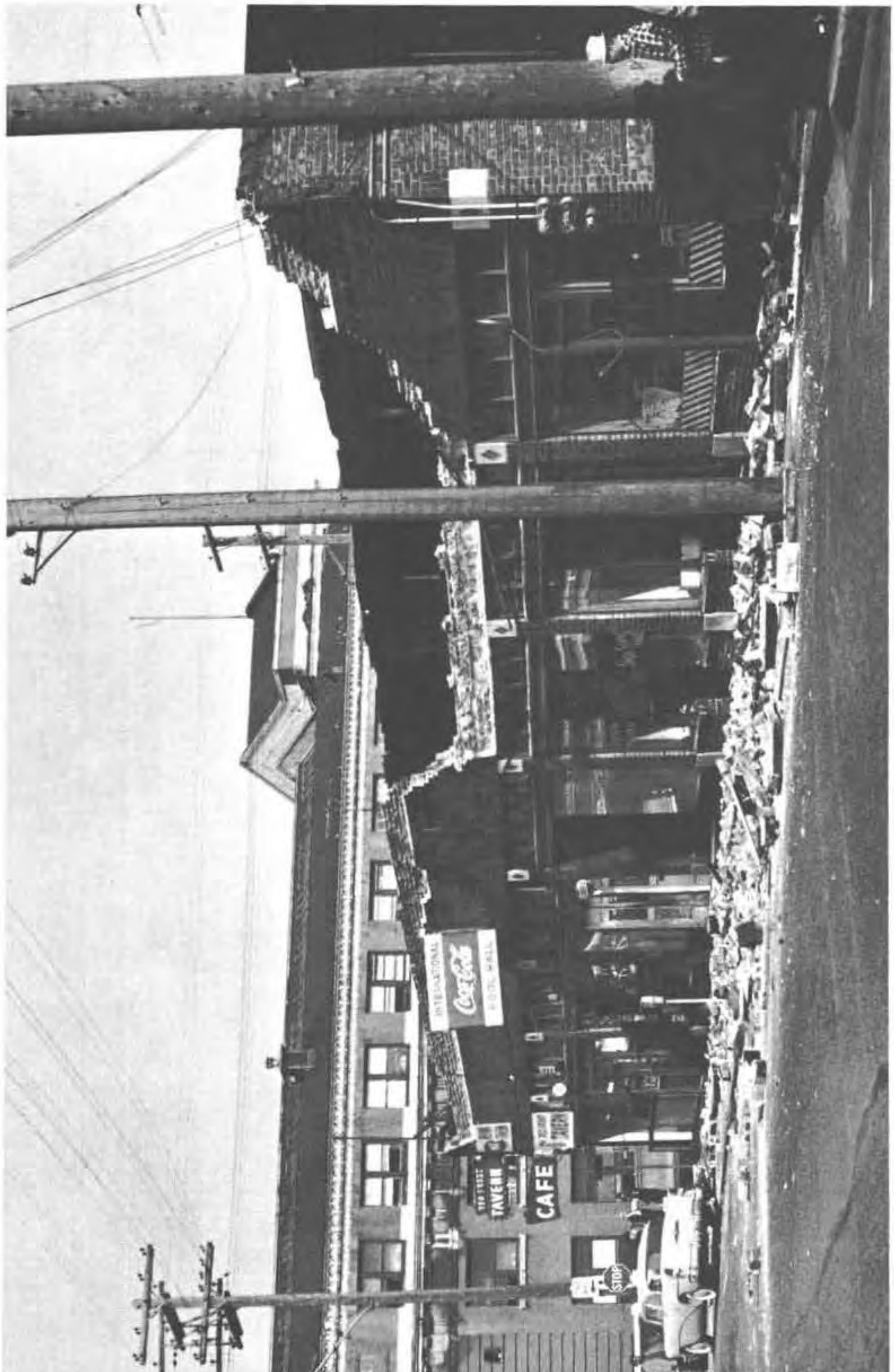

Figure 16.—Failure of unreinforced brick parapet wall in Seattle. (Photo by Seattle Fire Department.)

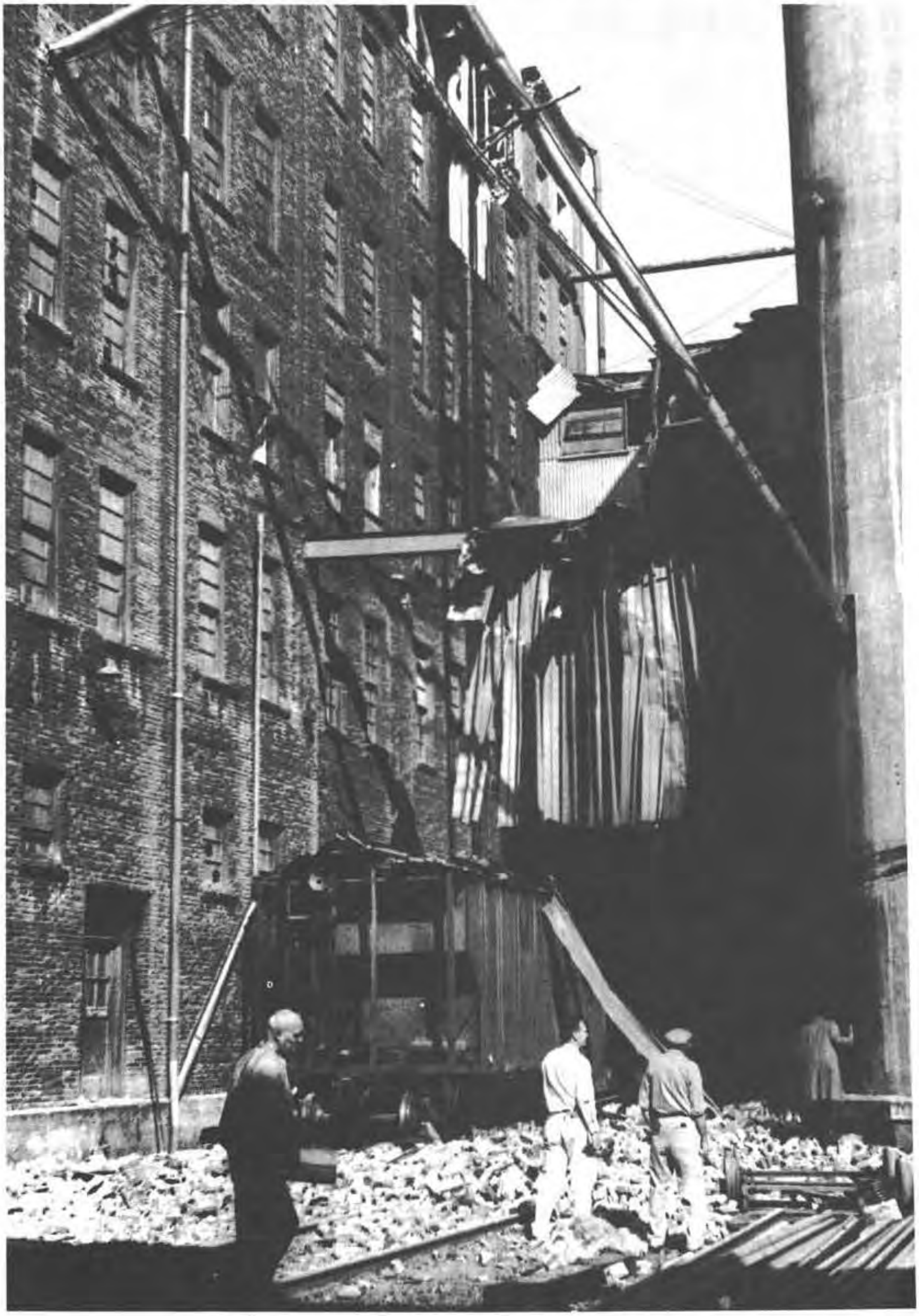

Figure 17.—Unreinforced brick fell from top story at Fisher Flouring Mills, Seattle. (Photo by John Vallentyne, Seattle Post-Intelligencer.)

Figure 18.—The 60-foot brick chimney at the Alki Elementary School in Seattle collapsed on the one-story boiler room, severely damaging it. (Photo by Cory Tolman, Seattle Post-Intelligencer.)

Figure 19.—Hole in the roof due to the collapse of the chimney shown in Figure 18. (Photo by Karl V. Steinbrugge.)

Single family dwellings in the affected areas are generally of wood frame construction, and are rarely more than two stories high. Chimneys are usually brick masonry. Interior partitions are generally plaster or gypsumboard on wood studs. Performance of the wool frame dwellings was almost always excellent, and when damage occurred it was confined to plaster cracking and to unreinforced brick chimney failure at, or above, the roof line as shown in Figures 20 and 21. By no means was the dwelling damage uniform throughout the city. For example, pockets of intense chimney damage to dwellings were found in Seattle (notably in the West Seattle section) while nearby areas of similar construction had no chimney damage. The damage pattern would sometimes change radically within several city blocks. As a rule, wood frame dwelling damage rarely approached as much as 5% of building value.

One exception to the foregoing rule was unit masonry veneered wood frame structures, particularly brick veneer. Four-inch brick veneer peeled off of a number of wood frame structures even though the veneer was anchored to the wood backing wall with galvanized metal anchors. The anchors usually remained nailed to the wood frame when the brick peeled off, and an examination of the mortar indicated that the mortar could be crushed by hand. This type of veneer damage has been noted in many previous earthquakes, and the anchorage certainly demands more careful engineering supervision than is normally given to it. Typical veneer damage is shown in Figure 22.

Multistory buildings generally had slight or no damage, with the damage reported to new and to old structures. Plaster cracking and other non-structural damage was found in multistory buildings in Seattle as well as in Tacoma (these cities being about 30 miles apart). The spectacular damage reported by the press to a 10 story building in Tacoma may have been entirely confined to exterior window

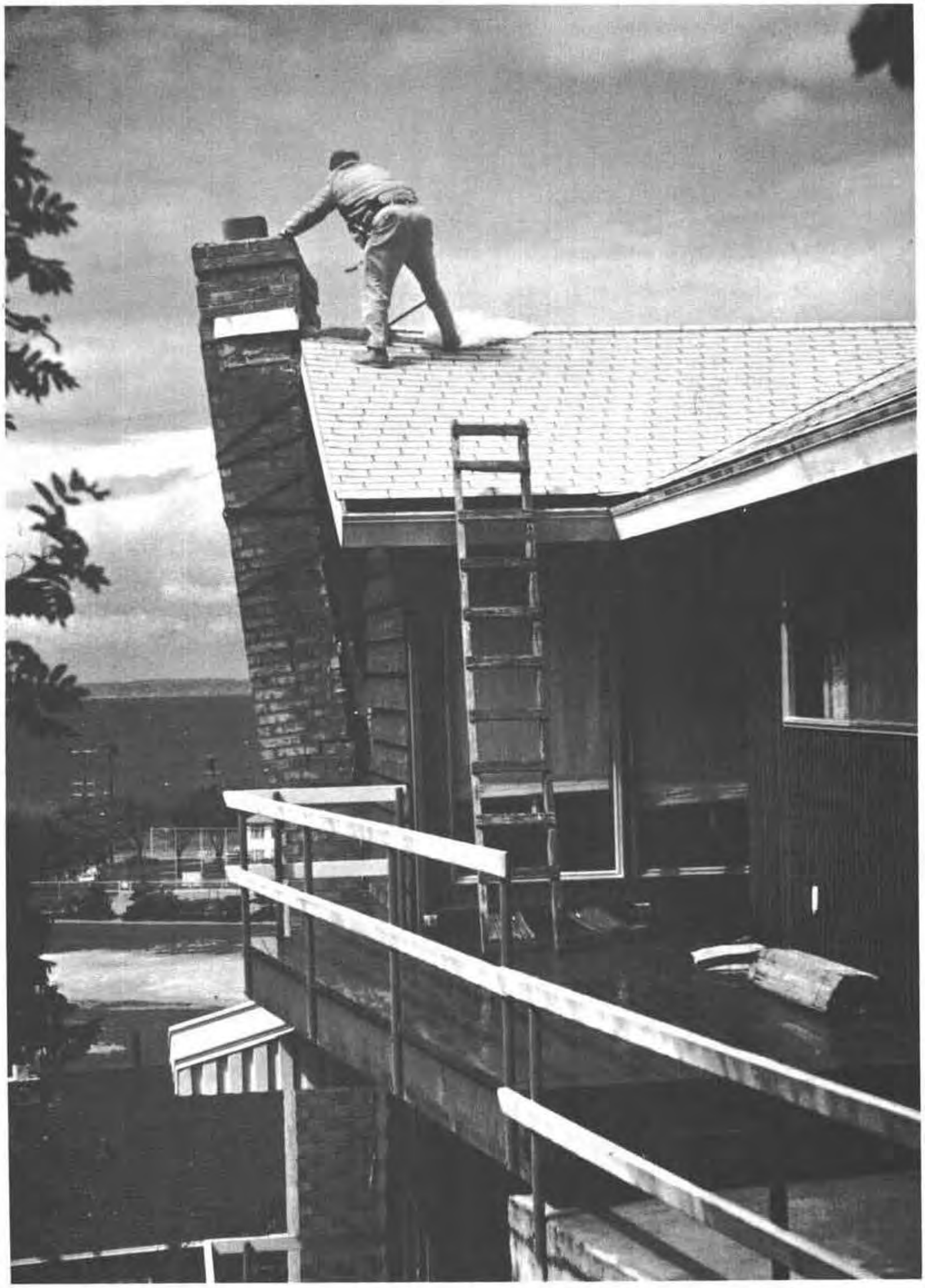

Figure 20.—Chimney damage in West Seattle. (Photo by Karl V. Steinbrugge.)

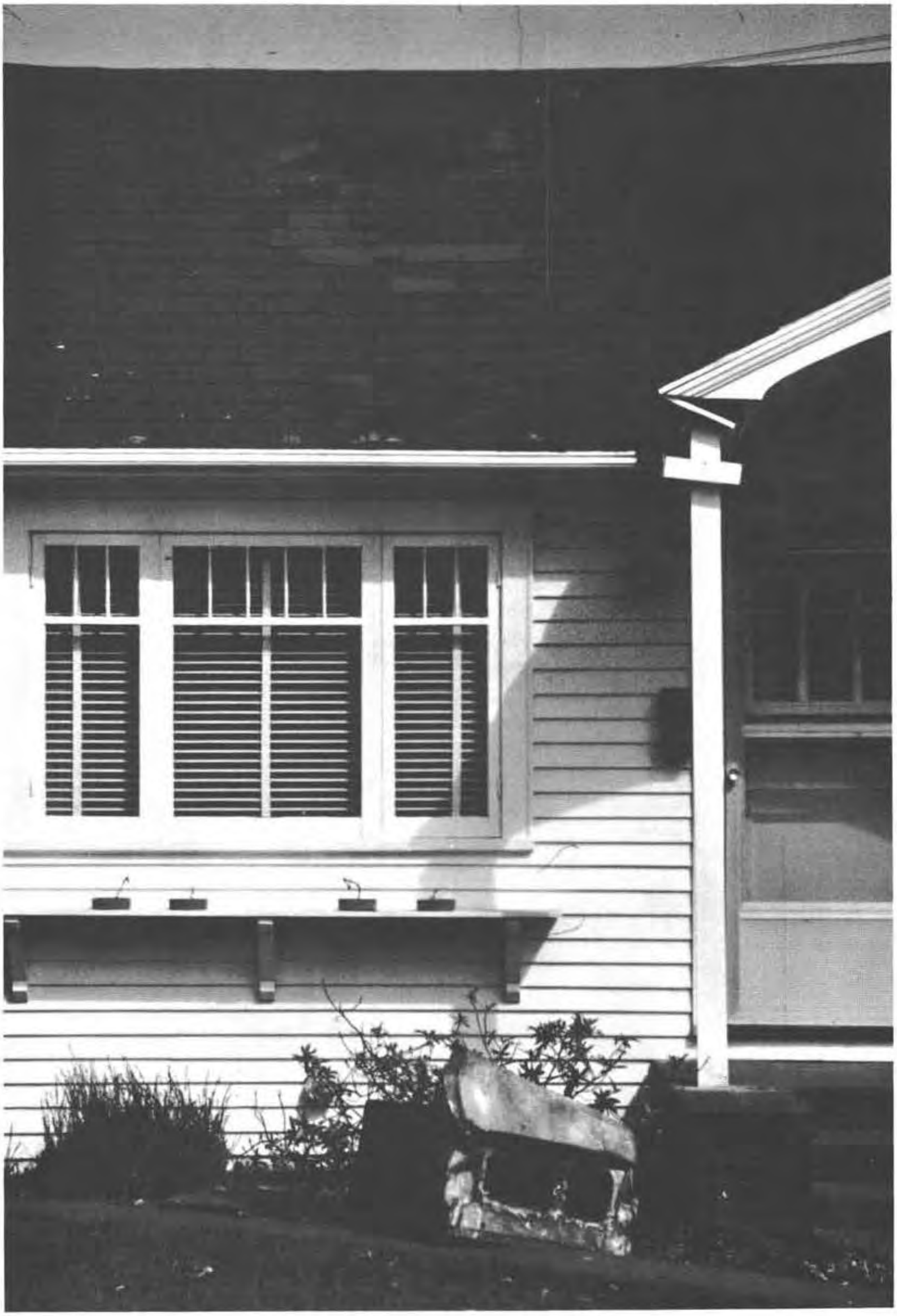

Figure 21.—Chimney damage in West Seattle. (Photo by Karl V. Steinbrugge.)

Figure 22.—Four-inch thick brick veneer peeled off of this wood frame structure in Seattle. The galvanized metal anchors were imbedded in a bed of low strength motar. (Photo by Karl V. Steinbrugge.)

Figure 23.—Glass windows broke on three sides of this 10 story building in Tacoma. The fourth side had no wall openings. (Photo by B. J. Morrill.)

glass in a structure having essentially all glass on 3 sides, with the fourth side solid. (See Figure 23.) Landslide damage to a roadbed in Olympia is shown in Figure 24.

Unreinforced brick bearing wall buildings with sand-lime mortar, as usual, bore the brunt of the damage. This type of building generally has wood roofs and wood supported floors, and is not earthquake resistive in any sense. Numerous instances of parapet and gable failure occurred, and death and injury resulted from this type of damage. As previously mentioned, some of this could be associated with 1949 earthquake damage as well as with settlement damage which was not related to earthquakes. The photographs accompanying this report are typical examples of this type of damage in Seattle.

A classic case of cumulative damage was found on the mud flats of Tacoma. A two-story brick bearing wall building was significantly damaged in the 1949 shock and the second story was subsequently removed. It was apparent when inspected after the 1965 shock that differential settlements also had been occurring, and the 1965 shock found a building which had been weakened by both previous earthquake and settlement. The high apparent intensity at this location requires careful attention before being taken at face value.

Modern buildings which were designed and constructed to be earthquake resistive performed well, as indeed they should in a moderate earthquake. Not all modern structures performed well and four exceptions warrant mention. A one-story warehouse, having a precast prestressed reinforced concrete roof and precast concrete tilt-up walls with poured in place pilasters, had no anchorage between the roof diaphragm and its end shear wall. The roof moved back and forth over the end shear wall, damaging the side walls. A second instance of damage to a building presumably intended to be earthquake resistive occurred at a one-story market in which the steel angle earthquake x-bracing

Figure 24.—Landslide damage to a roadbed in Olympia. (Photo by Karl V. Steinbrugge.)

was embedded in a hollow concrete block wall; the relative rigidities of the elements were such that the hollow concrete block had to fail before the steel x-bracing could function. Additionally, the x-bracing was so located as to cut in two most of the wall reinforcement. A third instance of note was a large manufacturing facility having a very large floor area; the second story precast reinforced concrete panels appeared to have worked loose from their supporting frame. The fourth example was a four story hollow concrete block apartment house in which the block shattered at several locations, and a remarkable absence of vertical reinforcing steel was noted. The mere enactment of earthquake bracing laws does not automatically insure safe construction as was also shown in the 1964 Anchorage, Alaska earthquake.

Eight Seattle public schools, housing 8,800 pupils, were closed until their safety could be established. Of these schools, the West Alki school was the most severely hit and may not be worth repairing. Its 60 foot brick stack fell into the boiler room (see Figures 18 and 19); x-cracks were found in the unreinforced sand-lime mortar brickwork in the 1914 wing; stairs shifted; the north wall of the new wing moved outward; however, not everything fell from the shelves. It should be added that the West Alki school was located in a pocket of high earthquake intensity.

Pockets of high earthquake intensity, as typified by damage such as fallen chimneys, could almost always be associated with the local geology. Damage was the most pronounced in what is commonly termed "poor ground" areas. These pockets were distributed over a large region, with the areas around these pockets having damage so slight that it was difficult to find it. In Seattle, a particularly noticeable damage pocket was the Alki Beach section of West Seattle where virtually every chimney was down. Reportedly, similar intensified damage also occurred here in 1949. Additionally, the low lying and filled areas along the Duwamish River and its mouth settled and were the locations of considerable building damage.

Harbor Island at the mouth of the Duwamish River was a special high damage location. Much, if not all, of this island was man-made, perhaps 50 or more years ago. Some of the structural damage to a newly built precast reinforced concrete building on Harbor Island is shown in Figure 25. The soils are not seismically stable by any standard. On this island are located a number of major industrial facilities and it is of interest to discuss two damage examples of those known to have occurred.

For one example, the Fisher Flouring Mills had extensive damage to its various buildings. A 50,000 gallon wood roof tank on top of a 15-story structure fell seven stories onto the concrete roof of a grain bin, breaking the grain bin roof and spilling water onto the grain. Elsewhere, portions of the unreinforced brick walls fell from the sixth story as may be seen in Figure 17. An examination of this structure showed pre-1965 cracks in the brick walls, some of which apparently opened further in this earthquake. Underground piping around the plant also broke. Equipment in the building shifted and was out of line, and several days were required to put it back into alignment. This plant reportedly had $50,000 damage in the 1949 shock, and the damage in 1965 appears to be greater.

A second instance of damage on Harbor Island occurred at Piers #15 and #16 as shown in Figure 26. These piers shifted toward the water by about one foot due to the soil losing much or all of its strength, or partially liquifying, and pushing the dock toward the water. An exception was the northern extension of the pier which was under construction and did not yet have its soil backfill.

Fire following the earthquake was not a serious problem. In Seattle, one house shifted and this shifting apparently resulted in an electrical short, with fire en-

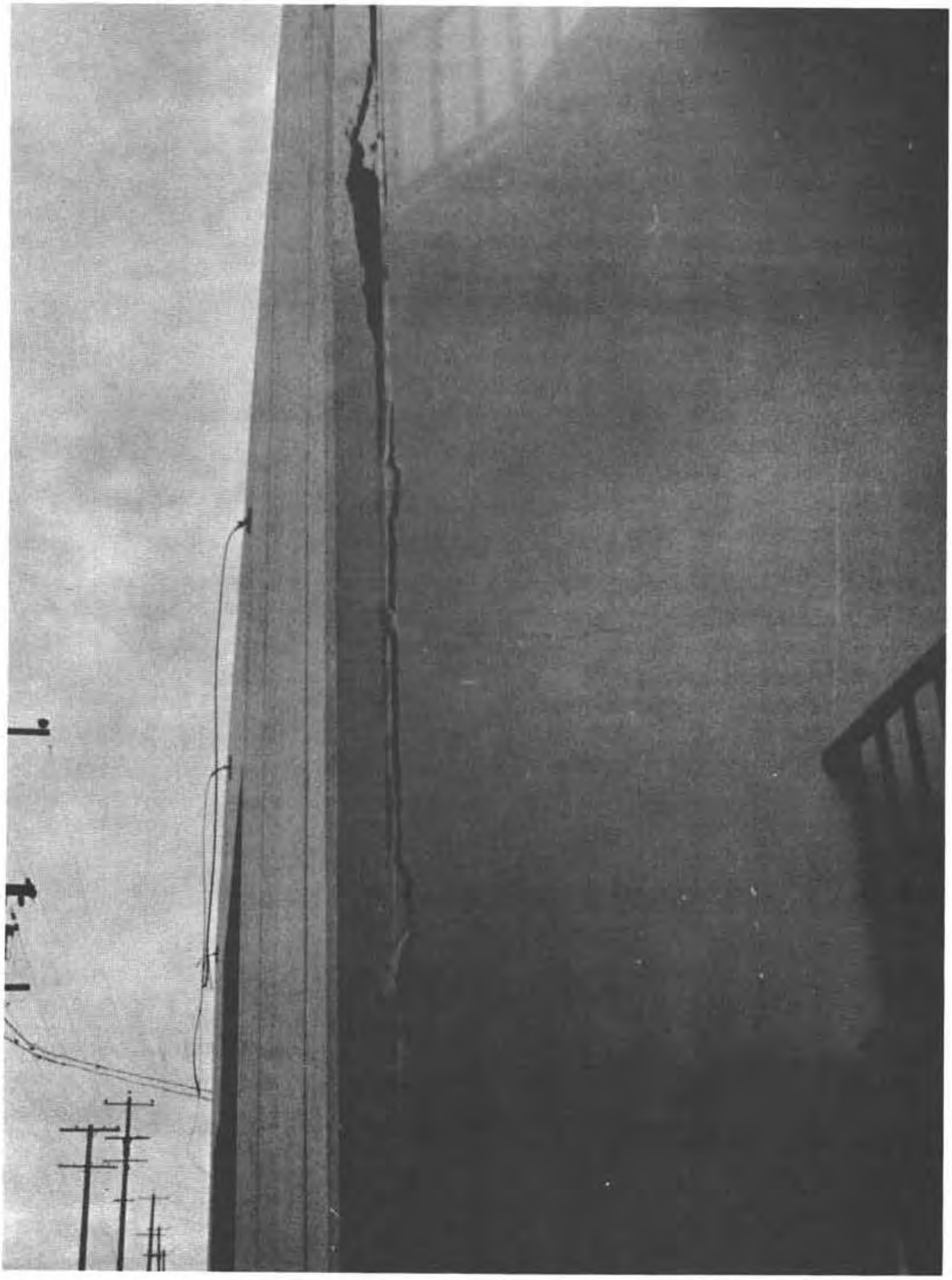

Figure 25.—Some of the structural damage to a newly built precast reinforced concrete building on Harbor Island in Seattle. (Photo by B. J. Morrill.)

Figure 26.—Ground dropped due to the pier at the left shifting toward the water. Location is Harbor Island in Seattle. (Photo by Karl V. Steinbrugge.)

suing. The fire alarm system remained in operation. During the day the Seattle Fire Department had several hundred calls regarding loose chimneys and similar problems. Olympia had no fires although seven alarms were turned in.

Utility damage was not severe. (See Figures 27 and 28.) An excellent summary was prepared by the Washington Surveying and Rating Bureau:

> "Service from the various public utilities was, on the whole, uninterrupted. Damage at the Spokane Street substation of Seattle City Light interrupted service for a few hours in a small area. The Washington Natural Gas Company reported one minor break in the Puyallup area. The Seattle Water Department had one break in a 12-inch main in the Harbor Island area and minor breaks in small pipes in residential areas of unstable ground. Four days after the earthquake, a break in a 20-inch main on Western Avenue at Spring Street resulted in water supply impairment for about one day to four sprinklered buildings supplied off this main.

"In Everett, two of the three 48-inch main supply conduits to the city failed. These failures occurred where the lines are carried on trestles over Ebey Slough. Industrial supply to the large consuming pulp mills was then shut down, the mills either closing down or going to river pumps. With the 50 m.g.d. supply from the remaining line plus 10 m.g.d. from the 28-inch line No. 1 from Lake Chaplain and reservoir storage, normal fire flows were maintained available throughout the city. Full service was restored the following day. One other break was reported in a 4-inch line in a residential district.

"A number of breaks occurred in underground mains on plant sites and to overhead sprinkler piping. These were mainly to those properties located on artificial fills in the southern

Figure 27.—Woodland Park Standpipe, Seattle. Typical damage to anchor bolts may be seen in next figure. (Photo by Washington Surveying and Rating Bureau.)

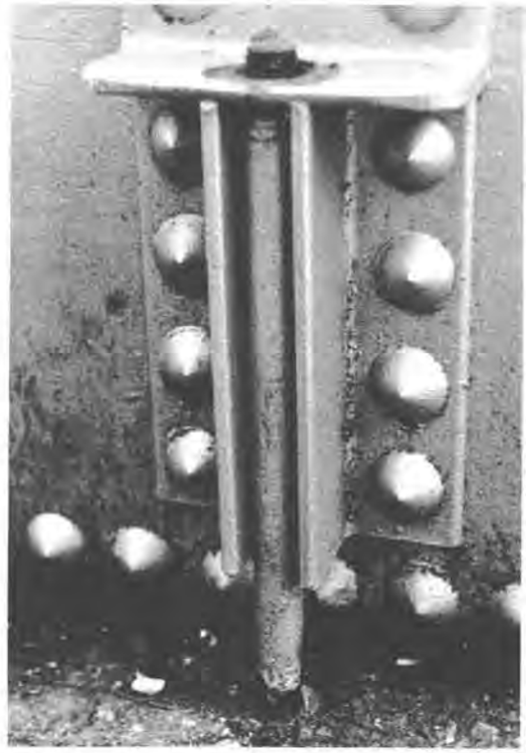

Figure 28.—Typical anchor bolt damage at Woodland Park Standpipe, Seattle. Note that the anchor bolt has necked where it meets the concrete and that the bolt failed in the threads. (Photo by Washington Surveying and Rating Bureau.)

part of Seattle, particularly Harbor Island, resulting in varying periods of impairment with some not yet being restored. Damage to overhead sprinkler piping was mainly to older systems without earthquake bracing and flexible couplings. An exception was to a number of newer systems in buildings located on artificial fill where suspended ceilings and light fixtures damaged sprinkler heads and piping."

A damage survey of the city of Seattle is in its closing stages at this writing. The following is quoted, in part, from a letter report written by Fire Chief Gordon Vickery.

"In the day or two following the earthquake, it became evident that the Fire Department, working in conjunction with the Building Department, might be in a position to render valuable service by conducting a building-by-building survey, to more accurately assess the extent of damage from the quake. The effort was coordinated between the Fire Department, Building Department, and representatives of the U.S. Army Corps of Engineers. On May 3, four days after the earthquake struck, our personnel were out in force actually conducting this survey.

"In developing the mechanics of the program, it was decided that in those buildings where Fire Department inspectors found evidence of possible serious structural damage, the reports would be forwarded to the Building Department for re-survey by teams of qualified experts.

"One survey was conducted on a continuous basis from May 3 through

May 21. During this time, a total of 1,440 man hours were expended, and 1,405 buildings were surveyed from roof to basement. As a result of the survey, 91 buildings were found to have sustained apparent serious or extensive damage, and were recommended to the Building Department for re-survey by experts as rapidly as possible. One hundred and thirteen buildings were found to have sustained apparent moderate damage, and were recommended for re-survey as time and personnel would permit. Two hundred and fifty buildings were found to have sustained superficial or light damage only. In this group there was no apparent need for a follow-up survey, as damage consisted of plaster cracks, missing chimney bricks, and things of this nature. The remaining 951 buildings were either found to have suffered no apparent damage, or damage was so slight that it could not be readily recognized.

"As of this time, May 24, 1965, the re-survey teams are approximately two-thirds complete with the list of 91 buildings in the serious damage category."

STRONG MOTION MEASUREMENTS

Within the felt area of the Puget Sound, Washington earthquake of April 29, 1965, there were six strong motion seismographs of the Coast and Geodetic Survey network. All six of the instruments were triggered into operation by the earthquake. Copies of the records from Olympia, Tacoma and Seattle are shown in Figures 29 through 31.

At the time of the previous major earthquake in the Puget Sound area (April 13, 1949), there were strong motion instruments only at Olympia and Seattle. Records obtained in 1949 from these instruments are shown in Figures 32 and 33.

As the Olympia instrument was the same and was in the same location during both earthquakes, the records can be used for comparison of the two shocks at this site. Figure 34, which shows the number of times acceleration reached various levels in 1949 and 1965, indicates that the 1949 shock was the stronger of the two at Olympia.

Response spectra from the April 29 records are being prepared, but at this time only rough acceleration, displacement, and period estimates based on preliminary scaling of records are available. These data are given in Tables 8 and 9. Similar data for the 1949 earthquake can be found in the publication *United States Earthquakes 1949*.

ACKNOWLEDGMENTS

The authors would like to acknowledge the valuable field assistance given to them by B. J. Morrill and by the Seattle Fire Department personnel (Fire Chief Gordon F. Vickery and Fire Marshall S. H. MacPherson).

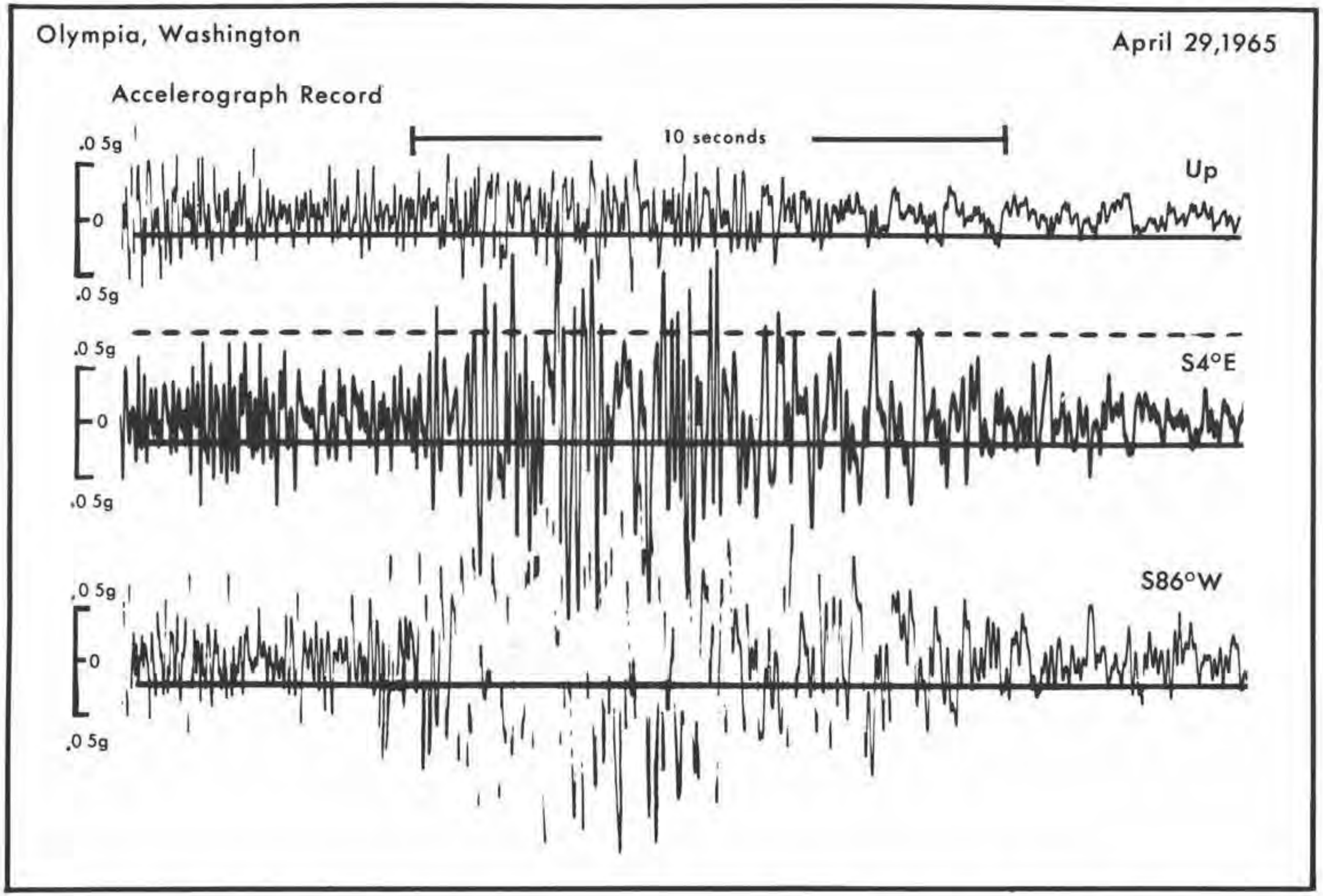

Figure 29.—Reproduction of accelerograph records obtained at Olympia, Washington on April 29, 1965.

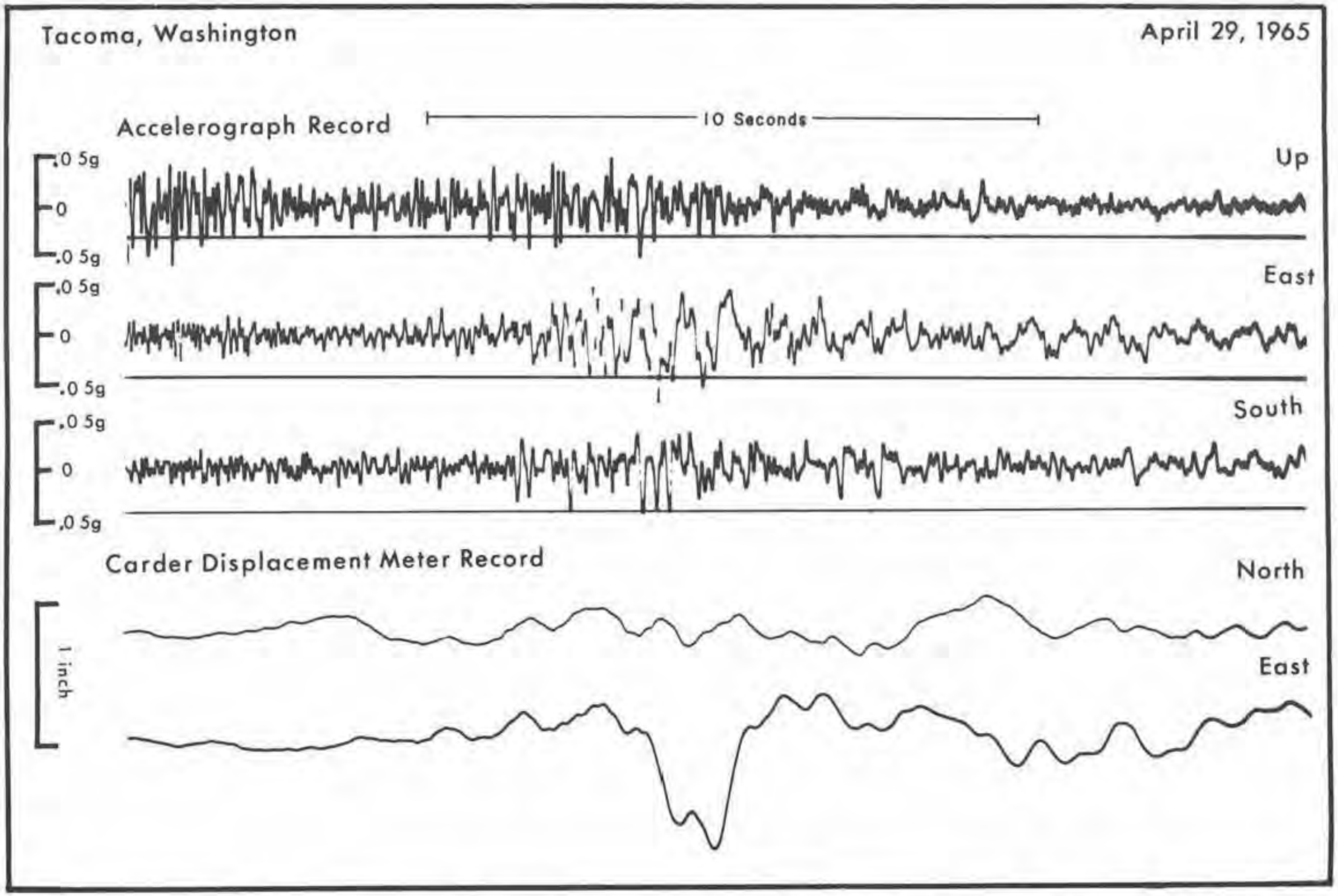

Figure 30.—Reproduction of accelerograph and Carder displacement meter records obtained at Tacoma, Washington on April 29, 1965.

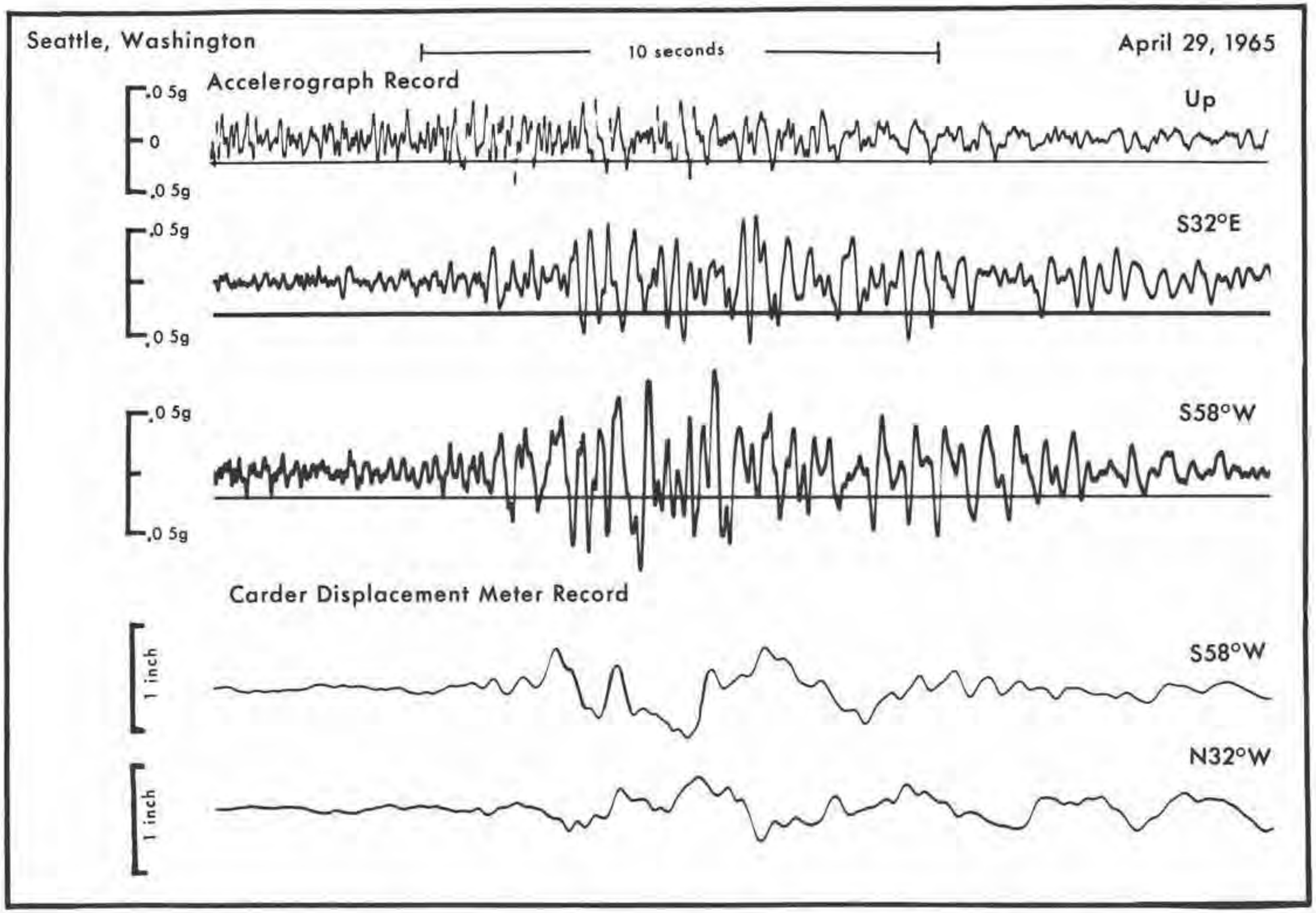

Figure 31.—Reproduction of accelerograph and Carder displacement meter records obtained at Seattle, Washington, on April 29, 1965.

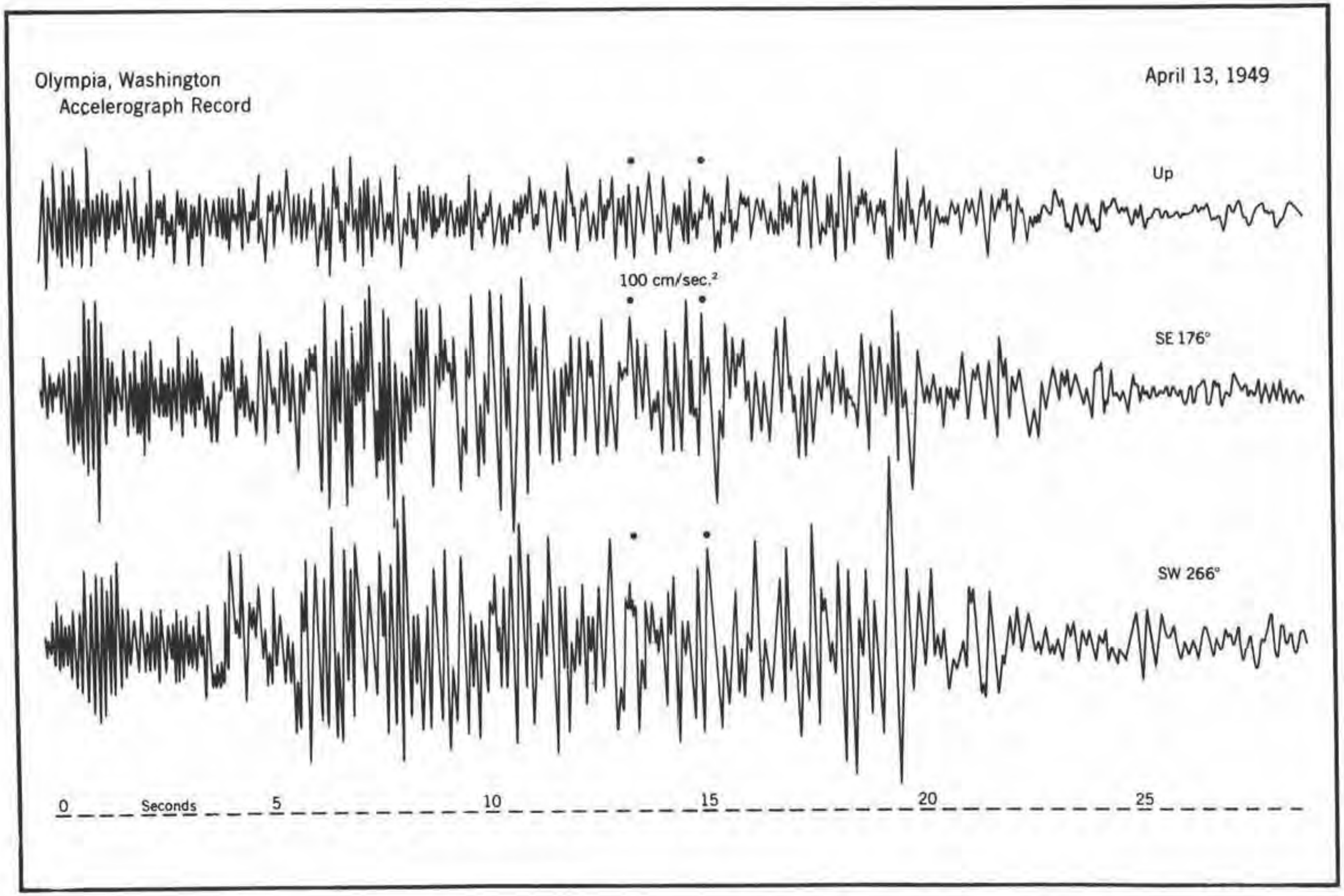

Figure 32.—Tracing of accelerograph record obtained at Olympia, Washington on April 13, 1949.

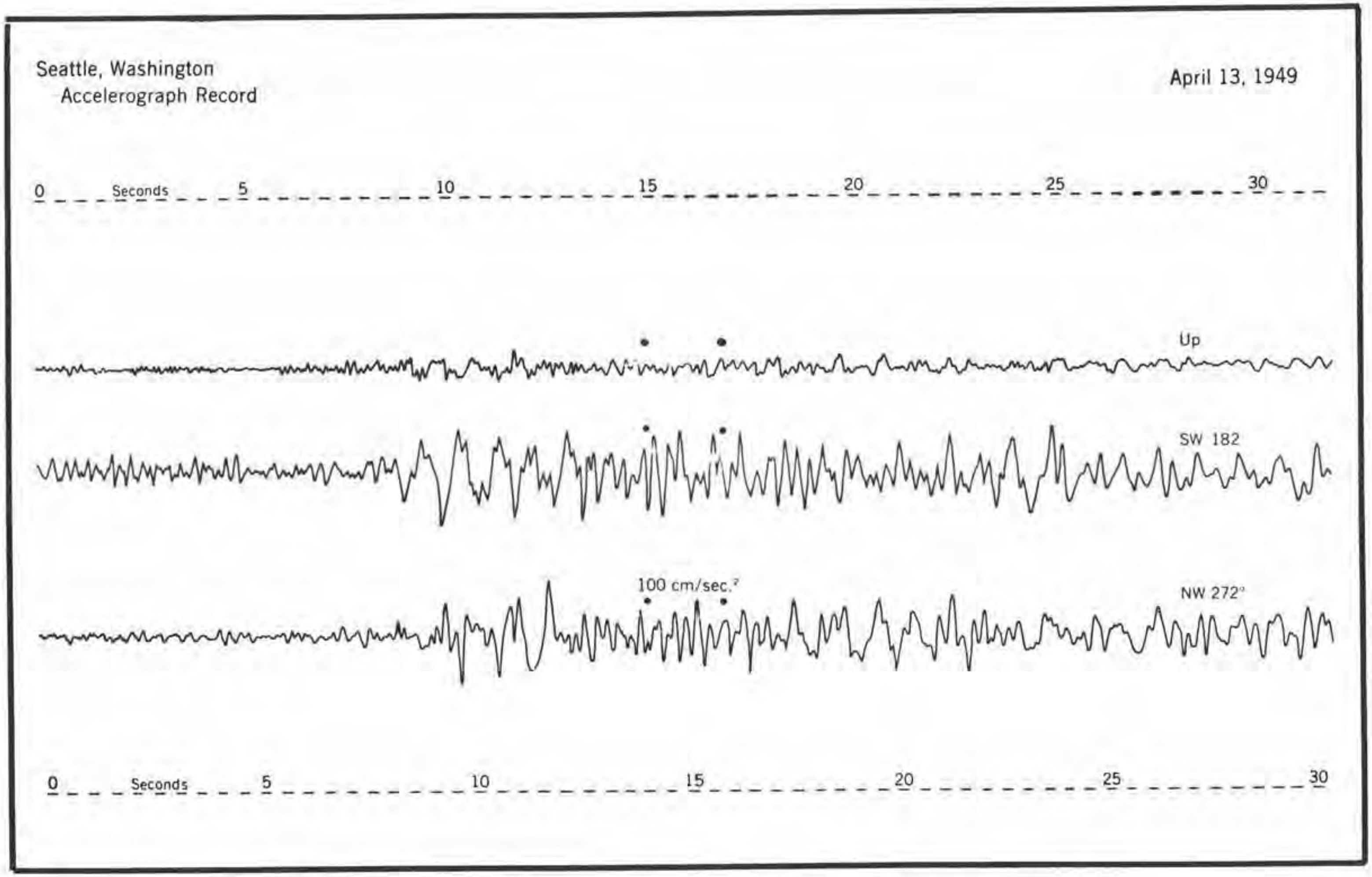

Figure 33.—Tracings of accelerograph records obtained at Seattle, Washington on April 13, 1949.

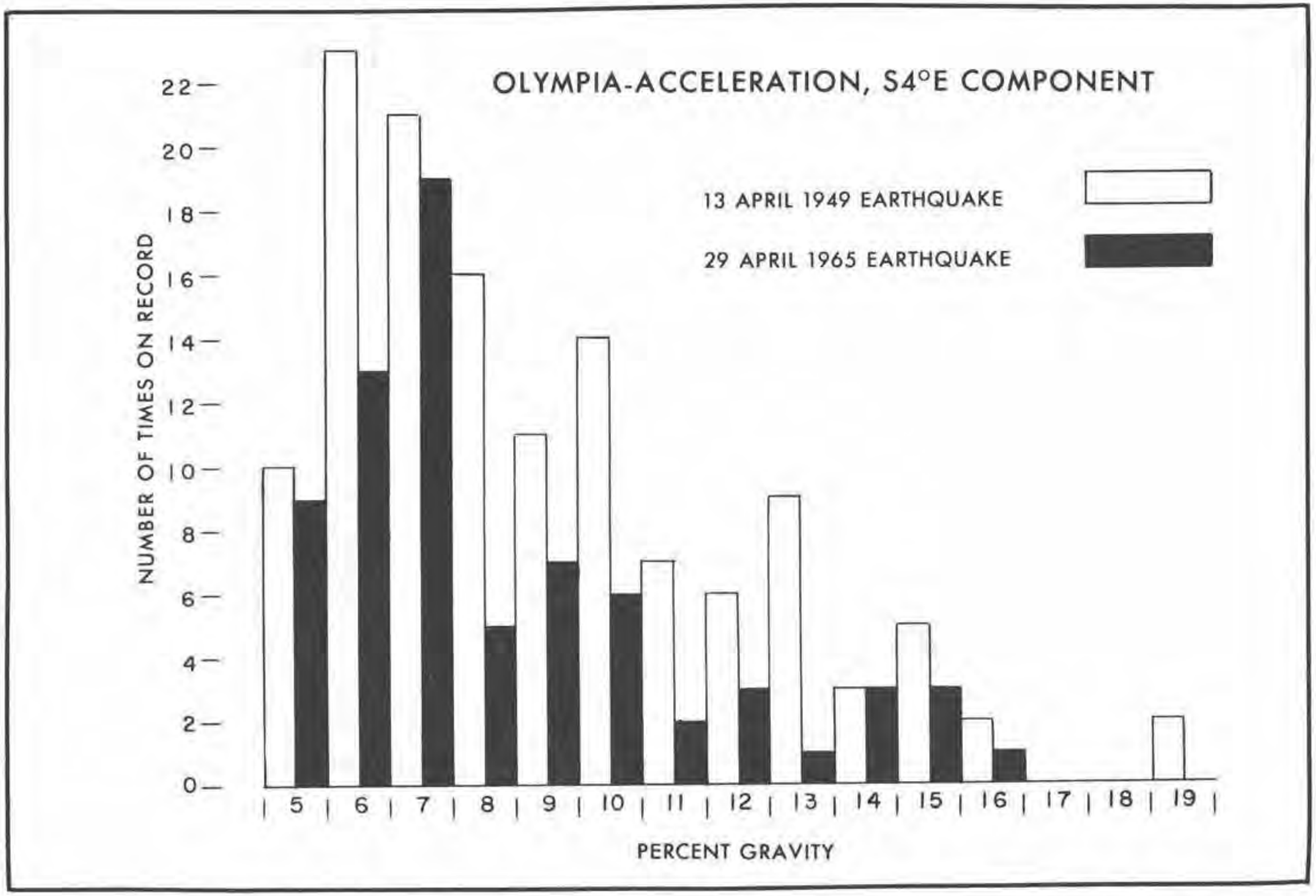

Figure 34.—Comparison of acceleration peaks showing the number of times acceleration reached various levels in the April 29, 1965 and April 13, 1949 earthquakes.

TABLE 8.—*Composite of Strong Motion Instrumental Data (Acceleration)*

Station and Component	Acceleration Constants				Acceleration		Remarks
	Instrument No.	T_0	Sensitivity	ϵ	Maximum	Period	
		sec.	*cm/g.*		*g.*	*sec.*	
Seattle							
Vertical	360	0.084	19.6	10	0.042	0.19	0.1 sec waves modulating 0.2 sec waves.
					0.038	0.27	
					0.035	0.33	
					0.019	0.70	
S32°E	359	0.083	20.3	10	0.058	0.27	0.35 sec waves predominate with 0.1 sec of low amplitude overriding.
					0.054	0.46	
					0.051	0.36	
					0.016	0.74	
S58°W	358	0.084	22.3	11	0.082	0.50	Sinusoidal with overriding 0.1–0.2 sec low amplitude waves.
					0.082	0.36	
					0.074	0.54	
					0.017	0.70	
Tacoma							
Vertical	345	0.078	17.3	10	0.059	0.07	Irregular short period waves.
					0.053	0.22	
					0.038	0.19	
					0.024	0.33	
					0.009	0.057	
East	346	0.078	17.9	8	0.074	0.13	Irregular wave form.
					0.048	0.71	
					0.048	0.67	
South	347	0.076	17.6	10	0.045	0.21	Unbalanced sinusoidal waves.
					0.043	0.11	
					0.017	0.85	
Olympia							
Vertical	307	0.080	18.8	9	0.083	0.046	Sharp spiked and short period waves.
					0.069	0.11	
					0.027	0.93	
S4°E	275	0.081	21.5	8	0.161	0.16	Sinusoidal waves.
					0.135	0.09	
					0.084	0.24	
					0.012	0.83	
S86°W	309	0.080	19.3	10	0.158	0.12	Sinusoidal waves.
					0.197	0.09	
					0.009	0.6	
Ross Dam Crest							
Vertical	S-3	0.082	20.0	11	0.002	0.3	Weak—0.1 sec waves modulating 0.3 sec waves.
S39°E	S-4	0.087	23.3	10	0.004	0.25	Sinusoidal waves.
S51°W	S-1	0.083	21.4	10	0.033	0.3	Sinusoidal waves.
Portland							
Vertical	229	0.082	20.6	10	0.005	0.16	Sinusoidal waves.
N20°E	230	0.084	22.0	9	0.007	0.21	Irregular.
S70°E	231	0.082	20.7	10	0.007	0.23	Irregular.

TABLE 9.—*Composite of Strong Motion Instrumental Data (Displacement)*

Station and Component	Displacement Meter Constants				Displacement		Remarks
	Instrument No.	T_o	Static Magnitude	ϵ	Maximum	Period	
		sec.			*cm.*	*sec.*	
Seattle							
N32°W	12	2.51	0.8	9	0.75	0.5	0.5 sec waves overriding 2.5 sec waves.
					0.73	2.4	
					0.50	4.00	
					0.47	2.60	
S58°W	13	2.45	0.8	10	1.1	3.70	0.7 sec waves modulating 3.7 sec waves.
					0.92	1.40	
					0.3	0.73	
Tacoma							
East	37	3.90	1.0	13	2.0	1.8	A large ½ cycle ground displacement toward the East at 3.0 sec period.
					0.83	4.3	
					1.8	3.0	
					0.35	1.3	
					0.42	4.0	
North	36	4.01	1.0	10	0.67	4.8	
					0.25	1.05	
					0.67	3.8	

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United States Earthquakes
1965

By

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and

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WASHINGTON : 1967

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Los Angeles.—Felt by many and frightened few. Slight damage was reported from the Occidental Center Building where some minor cracks in concrete were observed on the 30th floor. Small objects shifted; hanging objects swung moderately south-north; sharp, jolting shock. Felt by several in the 28-story City Hall where small objects shifted. To observer on the 5th floor, motion seemed undulating in east-west direction. In a building at 3223 West 6th Street, those on 11th floor reported a vigorous north-south sway. On the second floor, a strong jiggling was observed for about 4 seconds. Chandeliers swayed on the 13th floor of the Merchandise Mart. In the Vernon District, felt by many in a 2-story building. Slight, sharp, jolt. Windows, doors, and bookcases rattled slightly. In the Wilshire District, lamps jiggled and dishes rattled.

INTENSITY I–III. Altadena, Culver City, Huntington Park, Inglewood, Long Beach, Maywood, Pacific Palisades, San Gabriel, and Walnut. Reported felt (no details): Baldwin Hills, Inglewood, and Santa Monica.

November 14: 18:02:13.8*. Epicenter 37°44′ north, 122°09′ west, central California, B. Magnitude 2.5. Felt at Berkeley and Oakland.

November 25: 16:58:39*. Epicenter 40.5° north, 125.0° west, off coast of northern California, W. Magnitude 4.0, B. Eureka. Reported as "not felt by all."

December 2: 23:34:58.4*. Epicenter 35.3° north, 118.5° west, south-central California, W. Magnitude 3¾, P. Keene. IV. Felt by many in community. Building creaked slightly. Slow motion of 3 seconds' duration; preceded 2 seconds by moderate earth noises.

December 3: 03:00. Keene. IV. Felt by many in community. Slow motion; lasted 1 second; preceded by faint earth noises.

December 3: 14:49:50.9*. Epicenter 34.2° north, 117.1° west, southern California, W. Magnitude 3.5, P. Felt at San Bernardino.

December 11: 10:09:02*. Epicenter 34.7° north, 118.7° west, south-central California, W. Magnitude 4.2. Keene. V. Felt by all in community. Windows, doors, and dishes rattled; building creaked. Rapid motion in southwest-northeast direction; duration, 4 seconds; moderate earth noises from southwest-northeast.

December 20: 10:30:59.0*. Epicenter 40.7° north, 121.4° west, northern California, W. Magnitude 3.7, B. Felt at Mineral.

WASHINGTON AND OREGON

[120th Meridian or Pacific Standard Time]

April 29: 07:28:43.6*. Epicenter 47.4° north, 122.3° west, northwestern Washington, W. Magnitude 6.5. Felt over an area of approximately 130,000 square miles of the United States and British Columbia, Canada (*see* figs. 6 and 7). Three persons were killed by falling debris—one in downtown Seattle on South King Street, and two on Harbor Island at the Fisher Flouring Mills. The deaths of four elderly women from heart failure in Olympia, Port Townsend, Seattle, and Tacoma were attributed to the earthquake. There were numerous injuries, but most were minor. It was reported that more than 30 persons were treated at hospitals in the Seattle area and dozens suffered minor injuries elsewhere. Damage was estimated at approximately $12.5 million by the State Civil Defense Department, with most of it occurring in King County. Although a maximum intensity of VIII was assigned to some pocket areas of West and South Seattle and at Issaquah, this earthquake is best described as one with a maximum intensity of VII. Some of the more spectacular damage was difficult to evaluate since many buildings in Seattle and other Puget Sound areas had been damaged by previous earthquakes, notably the April 13, 1949, shock. The following paragraphs are excerpts from pages 27–39 of the Preliminary Report, issued by the

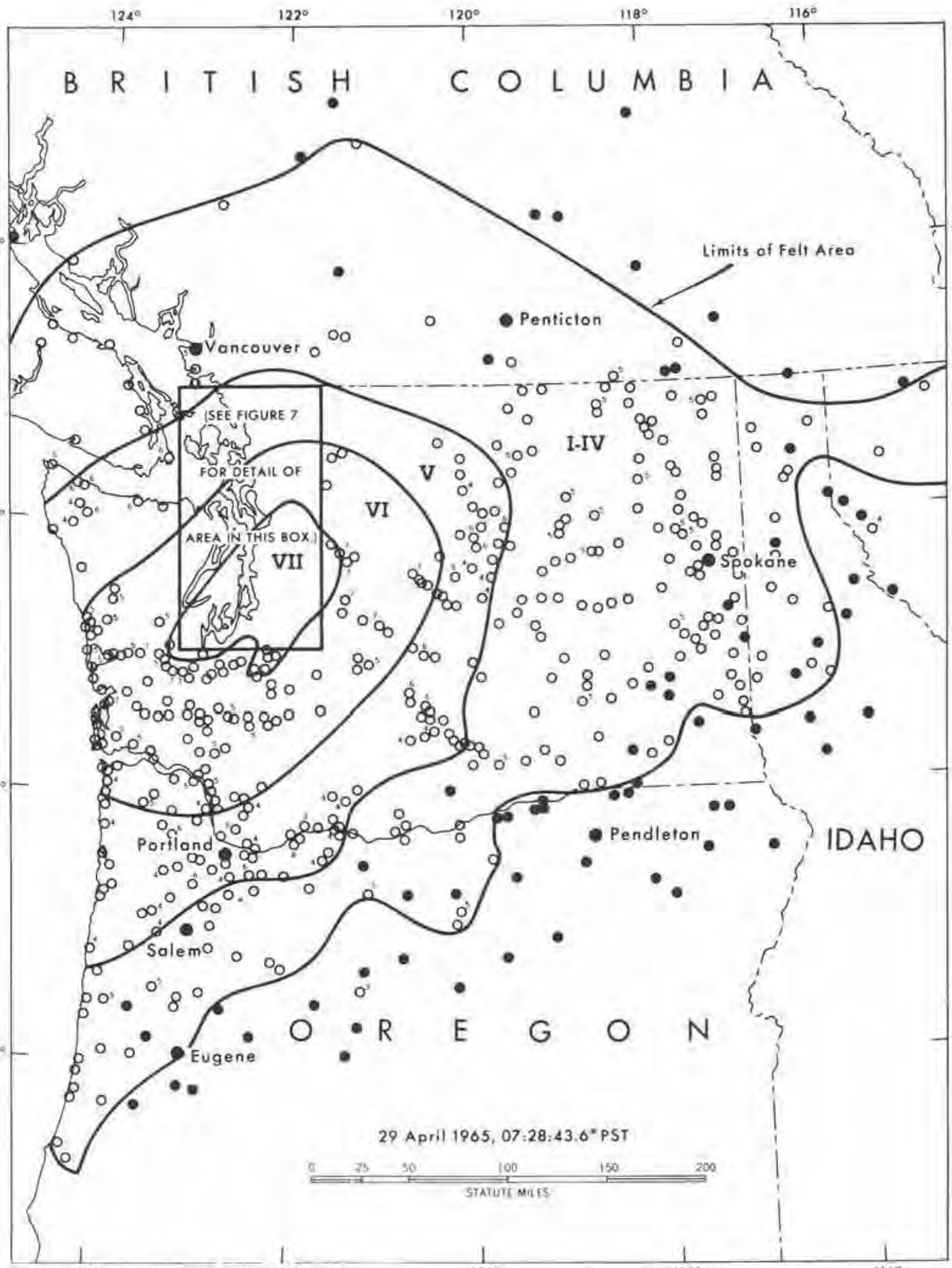


FIGURE 6.—*Area affected by Puget Sound, Wash., earthquake of April 29.*

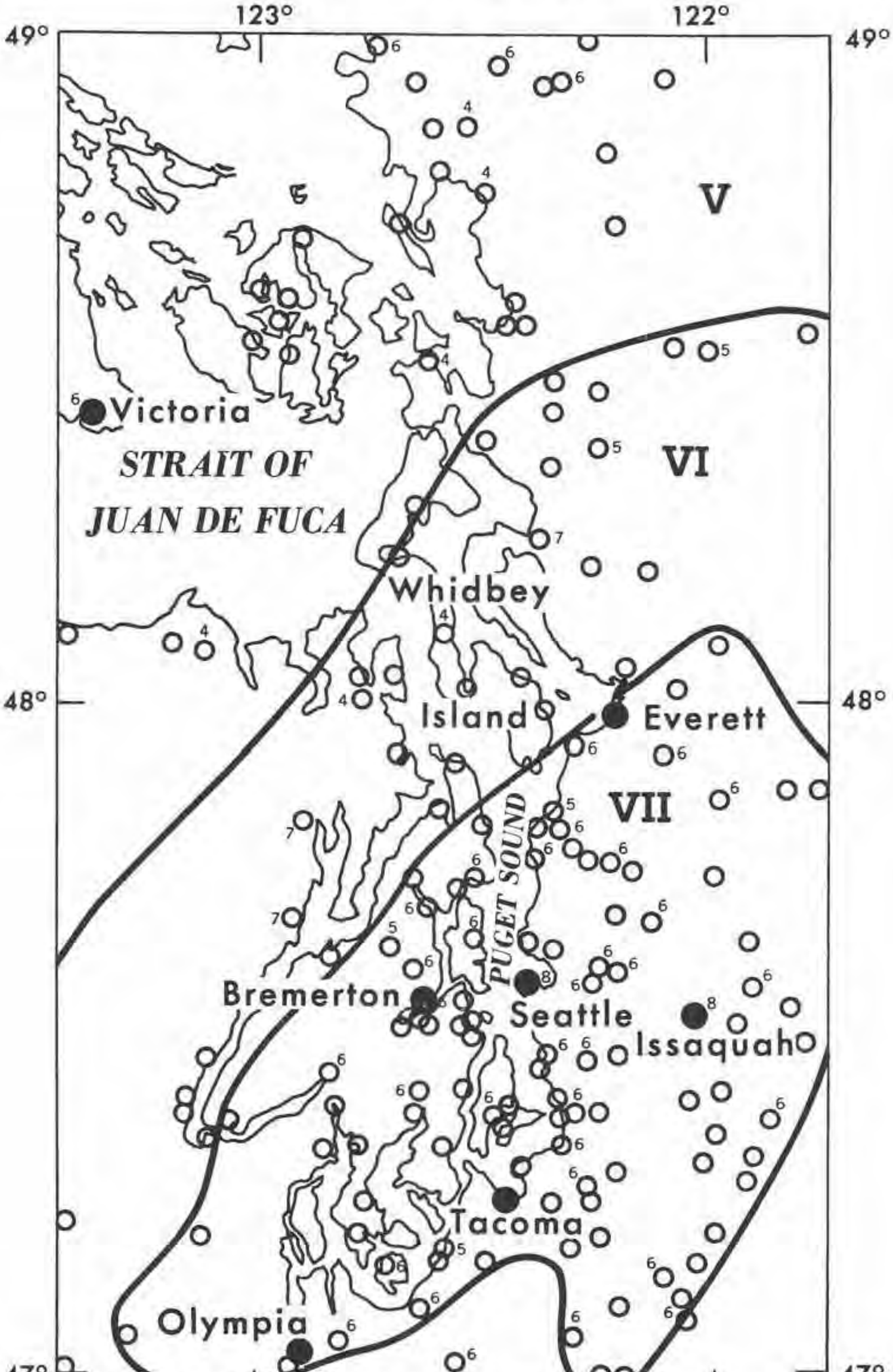


FIGURE 7.—*Epicentral area of Puget Sound, Wash., earthquake of April 29.*

Coast and Geodetic Survey, covering this earthquake.[4]

Building damage was generally light, although it was spectacular in many cases. Total collapses did not occur as far as is known to the authors. In general, damage patterns repeated those of the 1949 shock. Buildings which apparently had been damaged in 1949 often sustained additional damage in 1965. This reoccurring earthquake damage was sometimes intermixed with preearthquake settlement cracks which opened wider or caused failure in the 1965 earthquake.

Single family dwellings in the affected areas are generally of wood-frame construction, and are rarely more than two stories high. Chimneys are usually brick masonry. Interior partitions are generally plaster or gypsumboard on wood studs. Performance of the wood-frame dwellings was almost always excellent, and when damage occurred it was confined to plaster cracking and to unreinforced brick chimney failure at, or above, the roof line. By no means was the dwelling damage uniform throughout the city. For example, pockets of intense chimney damage to dwellings were found in Seattle (notably in the West Seattle section) while nearby areas of similar construction had no chimney damage. The damage pattern would sometimes change radically within several city blocks. As a rule, wood-frame dwelling damage rarely approached as much as 5 percent of building value.

One exception to the foregoing rule was unit masonry veneered wood-frame structures, particularly brick veneer. Four-inch brick veneer peeled off a number of wood-frame structures even though the veneer was anchored to the wood-backing wall with galvanized metal anchors. The anchors usually remained nailed to the wood frame when the brick peeled off, and an examination of the mortar indicated that the mortar could be crushed by hand. This type of veneer damage has been noted in many previous earthquakes . . . .

Multistory buildings generally had slight or no damage, with the damage reported to new and to old structures. Plaster cracking and other nonstructural damage was found in multistory buildings in Seattle as well as in Tacoma (these cities being about 30 miles apart). The spectacular damage reported by the press to a 10-story building in Tacoma may have been entirely confined to exterior window glass in a structure having essentially all glass on three sides, with the fourth side solid.

Unreinforced brick-bearing wall buildings with sand-lime mortar, as usual, bore the brunt of the damage. This type of building generally has wood roofs and wood-supported floors, and is not earthquake resistive in any sense. Numerous instances of parapet and gable failure occurred, and death and injury resulted from this type of damage. As previously mentioned, some of this could be associated with the 1949 earthquake damage as well as with settlement damage which was not related to earthquakes . . . .

A classic case of cumulative damage was found on the mud flats of Tacoma. A two-story brick bearing wall building was significantly damaged in the 1949 shock and the second story was subsequently removed. It was apparent when inspected after the 1965 shock that differential settlements also had been occurring, and the 1965 shock found a building which had been weakened by both previous earthquakes and settlement. The high apparent intensity at this location requires careful attention before being taken at face value.

Modern buildings which were designed and constructed to be earthquake resistive performed well, as indeed they should in a moderate earthquake. Not all modern structures performed well and four exceptions warrant mention. A one-story warehouse, having a precast prestressed reinforced concrete roof and precast concrete tilt-up walls with poured-in-place pilasters, had no anchorage between the roof diaphragm and its end shear wall. The roof moved back and forth over the end shear wall, damaging the side walls. A second instance of damage to a building presumably intended to be earthquake resistive occurred at a one-story market in which the steel angle earthquake X-bracing was embedded in a hollow concrete block wall; the relative rigidities of the elements were such that the hollow concrete block had to fail before the steel X-bracing could function. Additionally, the X-bracing was so located as to cut in two most of the wall reinforcement. A third instance of note was a large manufacturing facility having a very large floor area; the second-story precast reinforced concrete panels appeared to have worked loose from their supporting frame. The fourth example was a four-story hollow concrete-block apartment house in which the block shattered at several locations, and a remarkable absence of vertical reinforcing steel was noted . . . .

Utility damage was not severe. Excerpts (pages 41–42 of the Preliminary Report) of the summary prepared by the Washington Surveying and Rating Bureau follow:

Service from the various public utilities was, on the whole, uninterrupted. Damage at the Spokane Street Substation interrupted service in a small area. The Washington Natural Gas Company reported one minor break in the Puyallup area.

[4] *The Puget Sound, Washington Earthquake of April 29, 1965*, U.S. Department of Commerce, Coast and Geodetic Survey, 51 pages, 1965.

The Seattle Water Department had one break in a 12-inch main in the Harbor Island area and minor breaks in small pipes in residential areas of unstable ground. Four days after the earthquake, a break in a 20-inch main on Western Avenue at Spring Street resulted in water supply impairment for about one day to four sprinklered buildings supplied off this main.

In Everett, two of the three 48-inch main supply conduits to the city failed. These failures occurred where the lines are carried on trestles over Ebey Slough . . . Full service was restored the following day. One other break was reported in a 4-inch line in a residential district.

A number of breaks occurred in underground mains on plant sites and to overhead sprinkler piping. These were mainly to those properties located on artificial fills in the southern part of Seattle, particularly Harbor Island, resulting in varying periods of impairment . . . Damage to overhead sprinkler piping was mainly to older systems without earthquake bracing and flexible couplings. An exception was to a number of newer systems in buildings located on artificial fill where suspended ceilings and light fixtures damaged sprinkler heads and piping.

The following are excerpts from a letter report written by Fire Chief Gordon Vickey (pages 42–43 of the Preliminary Report):

In the day or two following the earthquake, it became evident that the Fire Department, working in conjunction with the Building Department, might be in a position to render valuable service by conducting a building-by-building survey, to more accurately assess the extent of damage from the quake. The effort was coordinated between the Fire Department, Building Department, and representatives of the U.S. Army Corps of Engineers. On May 3, four days after the earthquake struck, our personnel were out in force actually conducting this survey.

One survey was conducted on a continuous basis from May 3 through May 21. During this time, a total of 1,440 man hours were expended, and 1,405 buildings were surveyed from roof to basement. As a result of the survey, 91 buildings were found to have sustained apparent serious or extensive damage, and were recommended to the Building Department for resurvey by experts as rapidly as possible. One hundred and thirteen buildings were found to have sustained apparent moderate damage, and were recommended for resurvey as time and personnel would permit. Two hundred and fifty buildings were found to have sustained superficial or light damage only. In this group there was no apparent need for a follow-up survey, as damage consisted of plaster cracks, missing chimney bricks, and things of this nature. The remaining 951 buildings were either found to have suffered no apparent damage, or damage was so slight that it could not be readily recognized.

Strong-motion earthquake records were obtained from Coast and Geodetic Survey stations located at Olympia, Ross Dam, Seattle, and Tacoma, Wash., and from Portland, Oreg.

Temporary seismograph stations were installed by the Coast and Geodetic Survey at Bremerton, Issaquah, Seattle, Pacific, and Enumclaw to record aftershocks. During the 14 days of operation of the temporary seismograph stations, only one aftershock was recorded at a sufficient number of stations to permit an epicentral location. Twenty-seven aftershocks were reported but could not be located because of insufficient data. No aftershocks were reported felt.

INTENSITY VIII:

Issaquah (about 15 miles southeast of Seattle).—Felt by and frightened all in community. Brick garage partially collapsed. Both of the old, 2- and 3-story, brick junior high schools were extensively damaged. There were long jagged cracks in exterior and interior walls. Daylight could be seen through some of the cracks. At ground level, there were long, broken separations in concrete walkways. Light fixtures were tilted and askew. Chimney damage was very prevalent in the area and extensive damage was reported to liquor stock in stores. Rapid motion in north-south direction; loud earth noises.

Seattle.—Felt by all and frightened many in community. Extensive damage to chimneys was noted in West Seattle. In 188 city blocks, it was found that 1,712 chimneys of the 5,005 were damaged. Two schools in West Seattle were also extensively damaged. Slumping was observed along a steep slope adjacent to 36th Avenue S.W., near Admiral Way. Eight Seattle public schools were closed until their safety could be established. Of these schools, the West Alki School was the most severely damaged. Its 60-foot brick stack fell into the boiler room; X-cracks were found in the unreinforced sand-lime mortar brickwork in the 1914 wing; stairs shifted; and the north wall of the new wing moved outward. However, not everything fell from the shelves. (This school was located in a pocket of high earthquake intensity.)

In Seattle, a particularly noticeable damage pocket was the Alki Beach section of West Seattle where virtually every chimney was down. Similar intensified damage reportedly occurred here in 1949. The low-lying filled areas along the Duwamish River and its mouth settled and were the locations of considerable building damages.

Harbor Island, at the mouth of the Duwamish River, was a special high-damage location. Much, if not all, of this island was man-made, perhaps 50 or more years ago. The soils were not seismically stable by any standard. A newly built pre-cast reinforced concrete building was structurally damaged. On this island were located a number of major industrial facilities. The Fisher Flouring Mills had extensive damage to its various buildings. One instance was a 50,000-gallon wood-roof tank on top of a 15-story structure which fell seven stories onto the roof of a grain bin, breaking the grain bin roof and spilling water onto the grain. Elsewhere, portions of the unreinforced brick walls fell from the sixth story. An examination of this structure showed pre-1965 cracks in the brick walls, some of which apparently opened further in this earthquake. Underground piping around the plant also broke and equipment in the building shifted and was out of alinement. This plant reportedly had $50,000 damage in the 1949 shock, and it appears to be even greater in 1965.

Piers 15 and 16 on Harbor Island shifted toward the water by about 1 foot due to the soil losing much or all of its strength, or partially liquifying and pushing the dock toward the water. An exception was the northern extension of the pier which was under construction and did not yet have its soil backfill.

Seattle (from press reports).—Port of Seattle damages were estimated at $200,000-$250,000. Much of this damage occurred to facilities where construction was in progress. Nearly every waterfront facility was damaged to some extent. Pier 5, where construction projects were underway, was hardest hit. The bulkhead and the fill behind it settled, the fill dropping 6 inches to 2 feet for a width of 25 to 40 feet. The bulkhead was reported to be 6 to 8 inches out of line. Several Port piers suffered similar damage. Pier 20 at the East Waterway Terminal settled. At Pier 36, light fixtures were torn loose in the 5-story, concrete Engineers' Headquarters Building. File cabinets tipped over and the library was a mess. At the Naval Supply Depot, damage was reported to Pier 90 waterline and a Pier 91 steamline. Several heavy light fixtures in the Depot offices were shaken down; others dangled precariously.

A number of bridges were closed temporarily due to slight damage. A major span on the Spokane Street viaduct could not be opened for boat traffic because of bent interlocking pins. The 14th Avenue South drawbridge across the Duwamish River had some pier damage. Navy officials closed the Magnolia Bridge to traffic because of damage to the underside of the structure. Both of the Southwest Spokane Street bridges were jammed shut when the shock threw them out of line. Shipping up the Duwamish Waterway was halted. East-bound lanes of a drawbridge across the Duwamish Waterway were closed to all traffic except transit coaches because of a drop in the road level.

At Carkeek Park, South Seattle areas, an earthslide uncovered an underground stream that overflowed the creek and broke a water main. At Green Lake and vicinity in North Seattle, the lake sloshed under the force of the shock, crinkling blacktop around the Aqua Theater and opening zig-zag fissures in the ground. A concrete wall buckled at the junior crew house at the Aqua Theater, wrecking it possibly beyond repair. Other Park buildings suffered minor cracks and small patches of dislodged plaster. Water spurted 15 feet in the Lower Woodland baseball field due to a water main break. Another smaller main split at Evans Pool at Green Lake, but the pool remained open. Maplewood Place S.W., near Three Tree Point, settled. The following building damage was reported by the press:

Art's Food Center (9999 Holman Road N.W.).—Gaping holes in four concrete walls. Merchandise fell from shelves.

Ballard City Hall (Ballard Avenue N.W. and 22nd Avenue N.W.).—Sidewalks adjacent to the old Ballard City Hall were barricaded due to bricks falling from the old structure.

Boeing Aircraft Company facilities.—Many windows broke in the south side of the Boeing Administration Building and the adjoining Engineering Building. Minor damage was reported in Plant No. 2, mostly broken windows and cracked walls. Some damage was reported at other Boeing facilities, including the Development Center, south of Plant No. 2. There were no reports of injuries other than scratches and bruises.

Federal Office Building.—Extensive damage was reported to the upper floors of the 10-story building. Employees above the third floor were sent home.

First Avenue S.—Sidewalks south of Yesler Way were littered with bricks cracked loose from the tops of older buildings. At 2716 - 60th Avenue S.W., an entire chimney and front wall fell, leaving the living area exposed.

Medical Dental Building (509 Olive Way).—An 8-pound piece of cornice fell on the sidewalk on the Fifth Avenue side of the building. Small chunks of masonry fell from the front of the 16-story building, but were prevented by ledges from reaching the sidewalk. At the Frederick & Nelson Store, minor damage was reported to the store and stock. Some walls were cracked and mannequins toppled. A spokesman reported: "Our building and the adjoining Medical Dental Building teetered apart a bit, then came back together with a loud clap."

Trans-World Airlines Building (opposite the Olympic Hotel).—Severe damage on ground floor. The middle of one ground wall was severely cracked. A front panel window, about 8 by 12 feet, slipped away from its casement.

Union Pacific Railroad Station.—A section of heavy cornice atop the west side of the station fell and crashed through the sidewalk. The third floor sagged, and walls and ceilings were cracked. The station was evacuated.

Press reported the following school damage:

Ballard High School.—Damage was confined to the auditorium, where a ceiling arch was bent and a study wall twisted.

Broadview Elementary School.—Part of the east, brick-exterior wall fell at the old section of Broadview's plant.

Colman Elementary School.—Chimney damage; part of the masonry gables at the entrance fell; front wall damaged.

Franklin High School.—Parts of cornices on four corners of the building fell; lunchroom ceiling cracked; hallway and stairwell were damaged. All fire alarms were short-circuited and activated.

Gatewood Elementary School.—Gables fell.

Leschi Elementary School.—Gables fell.

Madison Junior High School.—Chimney collapsed and masonry fell at the entrance. Several cracks occurred in upstairs rooms at the Administrative and Service Center. Waterline was broken also.

Queen Anne High School. — Walls cracked.

St. Joseph's School.—Pieces of cornices fell from front of building.

University of Washington.—New cracks appeared in partitions of the Mechanical Engineering Building, under repair since early in the year. Three large planks were bolted to the cement-block wall of a second-floor classroom after inspection. Damage to the structure was reported as minor. In the crew house, the section where the new sleeping quarters adjoined the older section was cracked about an inch. Minor cracks on the fourth floor of the new library were observed. Electric cable broke in the Mechanical Engineering Buildings. It was reported that the tops of 60-foot trees swayed 3–4 feet, and that a fissure opened in the practice field at the University. Underground pressure from the shock sent sand spurting in a 100-foot-long zig-zag stretch on the lower football field. Behind the men's pool, areas of the ground dropped as much as a foot. Dirt floor sections in the Hec Edmondson Pavilion also sank slightly. At the Wesley Foundation, a car was badly damaged by falling bricks from a chimney.

West Seattle High School.—Severe cracking of walls throughout the school. Both exterior and interior walls of the auditorium were cracked.

Whittier Elementary School.—Pupils were evacuated from second floor due to structural damage.

Additional press reports of minor damage are as follows:

Bayview Manor Retirement Home.—Doors jammed. Elevator inoperative. Large crack in ceramic mural.

Blessed Sacrament Church (9th Avenue N.E. and 50th Street N.E.).—Possibly serious damage to the tower.

Bon Marche Store.—Major damage occurred to china. "You can see where the sky bridge (connecting the Bon Marche and the Third and Stewart parking garage) moved about 2 inches out of line."

King County Court House.—Considerable plaster damage, particularly in the middle floors.

Providence Hospital.—Many interior wall cracks. The sixth-floor surgery department was closed for two hours due to plaster dust in the operating rooms. Two doctors were trapped when an elevator jammed after dropping from the sixth to the third floor.

St. James Cathedral.—Low-hanging chandeliers swayed violently. Priest left the sanctuary when he was showered by falling debris. Minor damage.

Seattle Times Building.—This 2-story concrete building shook "like an electric vibrator." Plaster sifted down in rooms and teletype printers stopped work briefly.

Smith Tower.—Woman in penthouse on top the tower reported she was rocked out of bed. Extensive cracks and plaster damage were reported on the 33rd floor.

Substation at 4th Avenue S. and South Spokane Street.—City Light Company reported damage at its substation cut off service to some industrial plants, including the Seattle Foundry.

Todds Shipyards Corporation (1801 - 16th Avenue S.W.).—Bricks from fallen chimney damaged parked automobiles and broke a second-floor window.

INTENSITY VII:

Allyn.—Felt by and frightened all in community. Damage to brick, masonry, and concrete. Chimneys twisted and fell. Plaster, chimneys, and ground cracked. Dishes broke. Furnishings shifted; small objects overturned. Person outdoors saw the house sway north-south "about 2 feet each way." Rapid motion in northeast direction; loud noises from north heard.

Auburn.—Felt by all; awakened and frightened many in community. Damage slight. Few chimneys twisted and fell. Few dishes and windows broke. Plaster, windows, and chimneys cracked. Knickknacks fell. Small objects shifted and overturned. Press reported Auburn schools were closed until buildings were checked. The city hall was closed for an hour until inspectors declared the building safe; plaster fell from ceilings. Chimneys and window damage was reported throughout the area. Slides were reported on the Lake Holm Road east of Auburn. Motion slow; duration, 10 seconds.

Black Diamond.—Felt by all; awakened and frightened many in community. Damage slight to considerable in wood and brick. Chimneys twisted and fell. Dishes, windows, and furniture broke. Plaster, windows, and chimneys cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Hanging objects swung north. Rapid motion in east-west direction; duration, 45 seconds; loud earth noises from east-west 5 seconds before shock.

Brinnon.—Felt by all, awakened few, and frightened many in community. Damage slight to masonry and concrete. Chimneys twisted and fell. Dishes and windows broke. Plaster, windows, walls, and chimneys cracked. Knickknacks, books, and pictures fell. "Center beam moved 1/4 inch and split. Lots of cracks in pumice walls and concrete floor. Dumped the stock on shelves to the floor." Hanging objects swung north-south. Rapid motion in north-south (?) direction; duration, 30–60 seconds; preceded 2 seconds by moderate earth noises.

Buckley.—Felt by and frightened all in community. Damage considerable. Chimneys, columns, and monuments twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, windows, walls, and chimneys cracked. Small objects shifted; vases overturned. Trees and bushes shaken strongly. Slow, rolling motion in southwest direction; duration, 30 seconds; loud earth noises from southwest.

Carnation.—Felt by and frightened all in community. Damage considerable. Chimneys twisted. Windows broke. Walls and chimneys cracked. Small objects overturned; furnishings shifted. Trees and bushes shaken strongly. Hanging objects swung north-south. Rapid motion in north-south direction; duration, 1 minute; preceded 3 seconds by loud earth noises from north.

Cumberland.—Felt by and frightened all in community. Damage considerable to brick and concrete. Chimneys, columns, and monuments twisted and fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, windows, walls, chimneys, and ground cracked. Vases, small objects, and furniture overturned; small objects and furnishings shifted. Trees and bushes shaken strongly. Rapid motion; duration, 1 minute; preceded few seconds by loud earth noises from north.

Dash Point (about 7 miles north of Tacoma).—Felt by and frightened all in community. Damage considerable. Chimneys, columns, and monuments twisted and fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Walls, chimneys, and ground cracked. "There is a crack across Sound View Drive." Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Pendulum clock, facing south, started. Hanging objects swung west-east. Rapid motion in west-east direction; duration, 45 seconds; moderate earth noises from west-east.

Des Moines.—Felt by all in community; frightened few. Damage slight. Some dishes and windows broke. Plaster cracked and fell. Knickknacks and books fell. Small objects shifted; vases and small objects overturned. Trees and bushes shaken strongly. Rapid motion; preceded few seconds by loud earth noises.

Dockton.—Felt by all; awakened and frightened many in community. Damage slight. Chimneys twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, and plaster fell. Plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases and small objects overturned. Trees and bushes shaken strongly. Motion rapid; loud earth noises.

Duvall.—Felt by all and frightened many in community. Damage slight to wood, brick, masonry, and concrete. One chimney fell. Plaster and chimneys cracked. Knickknacks, books, and pictures fell; small objects shifted; vases and small objects overturned. Hanging objects swung east-west. Rapid motion in east-west direction; duration, 1 minute.

Eatonville.—Felt by and frightened all. Damage slight. Plaster and walls fell. Dishes, windows, and furniture broke. Plaster, windows, walls, chimneys, and ground cracked. Knickknacks, books, and pictures fell; small objects and furnishings shifted; vases, small objects, and furniture overturned. Pendulum clock stopped. Slow motion in north direction.

Elbe and vicinity.—Felt by all and frightened many in community. Damage slight to brick. Chimneys cracked, twisted, and fell. Knickknacks and pictures fell. Furnishings shifted. Trees and bushes were shaken strongly. "Some people seemed to think that the motion was in several directions. Parked cars jumped up and down. Dishes did not fall from east-west facing cupboards. Two people reported feeling a light tremor on April 30, about 9:10 a.m." Motion rapid; duration, 1 minute; moderate rumbling.

Electron (near Orting).—Felt by and frightened all in community. Damage to masonry. Chimneys, columns, and monuments twisted and fell. Dishes, windows, and furniture broke; walls fell. Ground cracked. Trees and bushes shaken strongly. Rapid motion in northeast direction; duration, 10 seconds.

Enumclaw.—Felt by all and frightened many in community. Damage considerable to brick. Chimneys twisted and fell; dishes and windows broke; pictures and plaster fell. Furniture shifted; small objects overturned. Rapid motion in east-west direction; duration, 1 minute; preceded by moderate earth noises.

Everett.—Felt by and frightened all in community. According to press reports a State Patrol radio tower toppled and streets buckled. A water main broke between Everett and East Everett. Chimney damage and downed power lines were reported from various areas. The Bonneville Power Administration reported three major lines went out of operation. Two 230,000-volt lines from Chief Joseph Dam to the Snohomish substation near Everett were toppled. Another 300,000-volt line from Grand Coulee Dam to Olympia was broken. Other observers reported: Plaster and chimneys cracked. Knickknacks and books fell; small objects shifted and overturned. Motion rapid; duration, 45 seconds; preceded 5 seconds by moderate earth noises.

The following is an excerpt from a report by the Washington Surveying and Rating Bureau:

> In Everett, two of the three 48-inch main supply conduits to the city failed. These failures occurred where the lines are carried on trestles over Ebey Slough. Industrial supply to the large consuming pulp mills was then shut down, the mills either closing down or going to river pumps. Full service was restored the following day. One other break was reported in a 4-inch line in a residential district.

Gate.—Felt by many and awakened few. Damage slight. Chimneys cracked, twisted, and fell. Small objects shifted and overturned. Slow motion north-south; preceded several seconds by loud earth noises.

Gig Harbor (Kitsap Peninsula).—Press reported a part of Crescent Lake Road, west of Gig Harbor, sank out of sight and was covered with water.

Gold Bar.—Felt by all and frightened many in community. Damage moderate. Chimneys twisted and fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Motion rapid; duration, 45 seconds to 1 minute; loud earth noises.

Gorst.–Felt by all and frightened many in community. Damage considerable. Chimneys twisted. Dishes broke. Small objects and furnishings shifted; vases and small objects overturned; knickknacks, books, and pictures fell. Motion rapid; duration, 40 seconds; preceded 40 seconds by moderate earth noises.

Granite Falls.–Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell. Dishes broke. Small objects shifted; knickknacks, books, pictures, and plaster fell. Trees and bushes shaken strongly. Hanging objects swung east-west. Duration, 45 seconds; east-west direction; moderate earth noises.

Grapeview.–Felt by and frightened all in community. Damage to brick, masonry, and concrete. Dishes broke. Plaster, chimneys, and ground cracked. Knickknacks, books, and pictures fell. Small objects and furnishings shifted; vases, small objects and furniture overturned. Trees and bushes shaken strongly. Rapid motion in north-south direction; duration, 40 seconds.

Grotto.–Felt by and frightened all in community. Damage slight to brick and masonry. Chimneys twisted and fell. Plaster and chimneys cracked. Small objects and furnishings shifted, including piano; small objects overturned. Pendulum clock, facing south, stopped. Motion rapid; duration, 1 minute; faint earth noises.

Hobart.–Felt by all in community. Chimneys fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and wall fell. Plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Duration, 45 seconds; east-west direction; earth noises from east-west.

Kapowsin.–Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell. Windows broke. Plaster, windows, and chimneys cracked. Knickknacks, books, and pictures fell. Small objects shifted; vases and small objects overturned. Trees and bushes shaken strongly. Motion rapid; duration, about 1 minute; loud earth noises from north.

Kenmore.–Felt by all in community; frightened few. Damage considerable to masonry. Some chimneys, columns, and monuments fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Some plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Hanging objects swung east-west. Rapid motion in east-west direction; duration, 45 seconds; moderate earth noises.

Kent.–Felt by all and frightened few in community. Press reported general building and window damage. Bricks fell off the old Armory onto parked cars, but no one was injured. One water main broke and several wires snapped. Plaster and walls cracked. Furnishings shifted; vases, small objects, and furniture overturned. Hanging objects swung east-west. Motion slow; preceded 10 seconds by loud earth noises from east-west.

Kingston.–Felt by and frightened all in community. Damage considerable. Chimneys twisted and fell. Dishes and windows broke. Plaster, windows, walls, chimneys, and ground cracked. Knickknacks and pictures fell. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees and bushes shaken strongly. Rapid motion in north direction; duration, 1 minute; loud earth noises from north. Press reported the roadway 2 miles west of Kingston on Highway 104, near the Wolfe School, was damaged, but not closed.

Kirkland.–Felt by all and frightened many in community. Damage slight to brick, masonry, and concrete. Chimneys twisted and fell. Dishes and windows broke; windows cracked. Knickknacks, books, and pictures fell. Motion slow; duration, about 30 seconds; moderate earth noises.

La Grande.–Felt by and frightened all in community. Damage considerable. Chimneys twisted and fell. Shelves in store fell both north-south and east-west. Dishes broke. Knickknacks, books, pictures, and plaster fell. Plaster, walls, chimneys, and ground cracked. Earth cracks along canyon of the Nisqually River; slides into rivers and onto roads. Small objects and furnishings shifted; small objects overturned. Cars outdoors rocked north-south. Trees and bushes shaken strongly. Pendulum clock facing east stopped. Rapid, sharp motion in north-south direction; duration, nearly 1 minute; loud earth noises at beginning of shock.

Lakebay.–Felt by all and frightened many in community. Damage slight to brick. Chimneys twisted and fell. Small objects overturned; knickknacks fell. Motion slow; duration, 2 minutes; direction north-south; sharp vibration at first; ending with gentle sway; moderate earth noises.

Lake Stevens.–Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell. Plaster and walls cracked. Trees and bushes shaken strongly. Pendulum clock stopped. Hanging objects swung east-west. Slow motion in east-west direction; duration, 50 seconds; preceded 7 seconds by loud earth noises from east.

Lakeview.–Felt by all and frightened many in community. Damage considerable to brick and masonry. Plaster, windows, walls, and chimneys cracked. Dishes and windows broke. Knickknacks, pictures, and plaster fell. Small objects shifted; vases and small objects overturned. Trees and bushes shaken strongly. Slow motion in steady, rolling, north-northwest direction; duration, about 1 minute; preceded 2–4 seconds by moderate-to-loud earth noises from north-northwest.

Leavenworth.–Felt by all and frightened many in community. Damage slight. Chimneys, columns, and monuments fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Motion rapid; moderate earth noises.

Longbranch.–Felt by all and frightened many in community. Damage considerable. Chimneys twisted and fell. Dishes broke. Knickknacks, books, pictures, and plaster fell. Plaster and chimneys cracked. Small objects shifted; vases and small objects overturned. Trees and bushes were shaken strongly. Rapid motion in east direction; duration, 30 seconds; preceded about 12 seconds by moderate earth noises from east. "After shock had quieted down, light fixtures and other hanging objects were swinging east-west."

McCleary.–Felt by and frightened all. Damage slight to masonry and concrete. Chimneys twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, and walls fell. Plaster, windows, walls, and chimneys cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Merchandise fell from store shelves. Light fixtures hanging from ceiling in post office were loosened. "To me, the shake seemed more severe than that of 1949. This time I was in a masonry building; in 1949 I was in a wooden building."

Manchester.–Felt by all and frightened many in community. Damage considerable to brick, masonry, and concrete. Chimneys twisted and fell. Plaster, walls, chimneys, and ground cracked. Knickknacks, books, and pictures fell. Dishes broke. Small objects shifted; furnishings shifted 3 inches; vases and small objects overturned. Rapid, intense motion in east-west direction; moderate earth noises from north-northwest or east.

Maple Valley.—Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell. Plaster, windows, and chimneys cracked. Knickknacks, books, and plaster fell. Dishes and windows broke. Small objects and furnishings shifted; vases and small objects overturned. Trees and bushes shaken strongly. Slow motion in west (?) direction; moderate earth noises from west (?). Press account stated the County Engineer reported fairly extensive damage to the county's South Road District shops. The water system, electrical shop, and service station were hard hit. Damage to the shops was estimated at $10,000 or more. Slides were reported on the Jones Road and Devils Elbow Road near Maple Valley.

Milton.—Felt by all and frightened many in community. Damage slight. Chimneys, columns, and monuments fell. Knickknacks, books, pictures, plaster, and walls fell. Dishes, windows, and furniture broke. Plaster, windows, walls, and chimneys cracked. Small objects and furnishings shifted and overturned. Trees and bushes shaken strongly. Hanging objects swung north. Rapid motion in north direction; duration, 45 seconds; moderate earth noises from north.

Mineral.—Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell. Dishes broke. Chimneys cracked. Knickknacks, books, and pictures fell. Small objects shifted and overturned. Trees, bushes shaken strongly. Slow motion in north-south direction; duration, 50 seconds; moderate earth noises from north-south.

Montesano.—Felt by and frightened all in community. Damage slight. Few chimneys cracked; one fell. Small objects shifted and overturned in few instances. Slow motion in northeast direction; duration, 1 minute; moderate earth noises from northeast.

North Bend.—Felt by all and frightened many in community. Damage considerable to brick, masonry, and concrete. "This shock caused more damage in this area than any shock during the past 50 years." Chimneys twisted and fell. Plaster, windows, walls, and chimneys cracked. Knickknacks, books, pictures, plaster, and walls fell. Dishes, windows, and furniture broke. Small objects and furniture overturned. Trees and bushes shaken strongly. Rapid motion in east direction; duration, 1 minute; preceded 10 seconds by loud earth noises from east. Press reported an extensive slide occurred on the southwest slope of Mount Si near North Bend; heavy damage to liquor stock at North Bend.

Oakville.—Felt by all and frightened few in community. Damage slight to concrete. Chimneys twisted and fell. All chimneys were down on a hill in the northwest corner of town. New fireplace moved 1 inch and chimney broke and twisted. Dishes and windows broke. Plaster, windows, walls, and chimneys cracked. Knickknacks, books, and plaster fell. Small objects overturned. Two shocks about 1 minute apart; preceded by moderate earth noises. Power poles swayed north-south during first shock and east-west during second shock. Several persons at first thought it was a sonic boom.

Olalla.—Felt by and frightened all in community. Chimneys twisted and fell. Chimneys and ground cracked. "Our home on hill next to post office had main chimney knocked down and house pulled away about 3 inches from fireplace chimney (half-way up). House sunk in several places. There are quite a number of chimneys gone in this area." Merchandise fell from shelves in grocery shore; knickknacks, books, and pictures fell. Small objects and furnishings shifted; vases and small objects overturned. Rapid, jerky motion; loud earth noises.

Olympia.—Felt by and frightened all in community. The following is from press reports: The Union Pacific Railway reported a hillside fill slid away from beneath a 400-foot section of a branch line just outside of Olympia. In the Temple of Justice, cracks developed in the walls of the law library; cabinet tipped over; books scattered around the floors; pictures fell from walls. In the Legislative Building, there was a crack about 3 feet long on the inside of the inner dome of the rotunda. The 5-ton chandelier swung on its 110-foot chain, like a pendulum clock, in a 1-foot orbit for half an hour after the shock. There were reports the dome had shifted. The building superintendent reported some stones weighing 25 pounds or more had broken loose. Cracks, due to the 1949 shock, were reopened in the Executive Mansion. Glass from chandeliers in the ballroom cascaded to the floor. Light fixtures were torn out of the ceiling on the top floor of the Health Building. The water-pollution laboratory was a tangled mess of broken bottles and other equipment. The new post office was damaged considerably and ordered closed. A road around Capitol Lake, at the base of the Capitol complex, was damaged, allowing water to flow beneath the road. St. Peter's Hospital reported four persons were treated for minor injuries. Damage to light fixtures and elevator shafts in the Capitol Building was about $200,000; damage to the road and railroad was estimated at the same amount.

The following is from a report by the Washington State Division of Mines and Geology:

> The questionnaires (newspaper canvass) verified our personal observations that the greatest damage occurred in the area between 15th Avenue and 20th Avenue and between Capitol Way and Cherry Street. Damage was rated as none or light (interior plaster cracks and mortar cracks in chimneys) versus moderate to heavy. This latter classification means that chimney bricks were dislodged or chimneys were destroyed and interior plaster cracked and fell. About 15 percent of the Eastside and Westside reported moderate to heavy chimney damage and there were a few reports of plaster damage. Five percent of the Carlyon-Eskridge area reported moderate to heavy chimney damage, and roughly 10 percent reported plaster damage. The Capitol area seemed to have fared considerably worse than the other three areas, at least as far as chimney damage was concerned. About half the responses from this area reported moderate to severe chimney damage. Fifteen percent reported moderate plaster damage. Both north-south and east-west directions of motion were reported.

Other observers in Olympia reported the following: Most objects in the General Administration Building, 3rd floor, fell from shelves facing north-south; east-west facing shelves lost few objects. Files and bookcases shifted up to 3.5 inches. Motion seemed to start abruptly. No aftershocks were felt. No agitation could be seen on the surface of Capitol Lake about 100–150 yards away. At the post office, light fixtures fell. Small objects and furnishings shifted; small objects overturned. Rapid, explosive-like motion in east-west direction; loud earth noises. Four miles south of Olympia (Municipal Airport), felt by many; general alarm. Damage was slight to buildings. Some chimneys cracked and pulled away from houses; a few north-south and vertical cracks in airport building. Slight displacement of hanging electrical fixtures. One jarred loose from ceiling. Many objects were displaced or knocked to the floor throughout the area. Plaster cracked in a few localities, and pieces were thrown down in some instances. "No landslides in this area, but there were some in the surrounding area." Motion bumping, swaying, rapid onset; loud, rumbling earth noises.

Orting.—Felt by all; awakened and frightened many in community. Damage considerable to brick. Chimneys twisted and fell; windows and furniture broke. Plaster, windows, walls, and chimneys cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturne-

Rapid motion in north-south direction; duration, 35 seconds; preceded 2–3 seconds by loud earth noises from north-south.

Pacific.—Felt by and frightened all in community. Chimneys twisted and fell; chimneys cracked. Knickknacks and pictures fell. Furnishings shifted; furniture overturned. Trees, bushes shaken strongly. Slow motion in north-south direction; duration, 2½ minutes; preceded by loud earth noises from north-south.

Palmer.—Felt by all and frightened many in community. Damage slight. Chimneys twisted and fell; chimneys cracked. Knickknacks, books, and pictures fell. Small objects and furnishings shifted; vases, small objects overturned. Trees, bushes shaken strongly. Motion rapid; duration, 30 seconds; loud earth noises.

Peshastin.—Felt by all and awakened few. Damage considerable. Chimneys twisted and fell. Plaster and chimneys cracked. Knickknacks and pictures fell. Small objects shifted and overturned. Motion rapid; duration, 1 minute; moderate earth noises from northwest.

Portage.—Felt by all and frightened many in community. Damage slight. Chimneys fell; chimneys cracked. Dishes broke. Small objects shifted; vases and small objects overturned. Rapid motion in east-west direction; duration, 1 minute; loud earth noises.

Port Orchard.—Felt by all and frightened many in community. Damage considerable in masonry and concrete. Brick chimneys fell. Walls, floors, chimneys, and ground cracked. Windows broke. Telephone service disrupted. "Many homes and businesses reported fallen pictures from walls and broken dishes from cabinets and shelving." Pendulum clock, facing east, stopped. Rapid motion in southwest direction; duration, 45 seconds; preceded about 6 seconds by moderate earth noises from southwest. Press reported the highway a mile east of Port Orchard was cracked.

Poulsbo.—Felt by and frightened all in community. Damage slight. Chimneys twisted and fell. Plaster, walls, and chimneys cracked. Dishes broke. Knickknacks and pictures fell. Small objects and furnishings shifted; vases and small objects overturned. Trees, bushes shaken strongly. Pendulum clock, facing west, stopped. Rapid motion in southerly direction; duration, 45 seconds; moderate earth noises from southerly direction.

Preston.—Felt by all; awakened and frightened many in community. Damage slight to brick. Chimneys fell; chimneys cracked. Dishes broke. Knickknacks and books fell. Small objects shifted and overturned. Trees, bushes shaken strongly. Motion rapid; duration, 45 seconds. "Shock began with several seconds of vibration in north-south direction, rapidly increasing in speed and intensity; then followed heavy shocks of undulating and rocking motion, accompanied by earth noises. Rocking continued for several seconds after rumblings ceased."

Puyallup (about 30 miles south of Seattle).—Felt by and frightened many in community; awakened few. Damage considerable. Chimneys and walls fell. Plaster and chimneys cracked. Dishes and windows broke. Knickknacks, books, and plaster fell. Small objects and furniture overturned. Trees, bushes shaken strongly. Pendulum clock, facing south, stopped. Rapid, rolling motion in north-south direction; loud earth noises from north. The Washington Natural Gas Company reported one minor break in the Puyallup area.

Quilcene.—Frightened all in community; awakened many. Damage considerable. Plaster and walls fell; plaster, windows, walls, chimneys cracked. Dishes, windows, and furniture broke. Knickknacks, books, and pictures fell. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees, bushes shaken strongly. Pendulum clock stopped.

Rocking motion in north-south direction; loud earth noises.

Ravensdale.—Felt by all (except people in cars) and frightened many in community. Damage slight. Chimneys twisted and fell; plaster fell; plaster and chimneys cracked. Knickknacks, books, and pictures fell. Small objects shifted; vases and small objects overturned. Motion slow; duration, 30 seconds; moderate earth noises.

Renton.—Felt by all and frightened many in community. At the Boeing Aircraft Plant (reported by Dr. Gordon B. Oakeshott, California State Division of Mines and Geology), floors settled away from the foundation piling; much interior concrete block cracked; fluorescent light fixtures down; acoustical ceiling tile fell, and concrete tiles fell away from structural steel members. Press reported fireplace collapsed, injuring three members of family. Large boiler broke at the Pacific Car and Foundry Company. Motion rapid; duration, 45–50 seconds; preceded few seconds by loud earth noises.

Retsil.—Felt by all; awakened and frightened many in community. Damage considerable. Chimneys twisted and fell. Dishes, windows, and furniture broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, windows, walls, chimneys, and ground cracked. Small objects and furnishings shifted; vases, small objects, and furniture overturned. Trees, bushes shaken strongly. Rapid motion in north-south direction; moderate earth noises.

Ronald.—Felt by all and frightened many in community. Damage slight to brick and masonry. Chimneys twisted and fell. Windows broke. Plaster and chimneys cracked. "Most damage confined to toppled chimneys and broken windows." Small objects and furnishings shifted; vases, small objects, and furniture overturned. Large rock dump started to slide and cave. Rapid motion in south direction; duration, 5–10 seconds; faint earth noises.

Roslyn.—Awakened and frightened many in community. Damage slight. Chimneys cracked and fell. Pictures fell; small objects and furnishings shifted; vases, small objects, and furniture overturned. First shock fairly light; second, rapid strong shaking in east direction; duration, 45 seconds; accompanied by earth noises.

Shelton.—Felt by many. "Most building damage was to chimneys—fell southwest. Have heard of three cracked walls. Main return line broke on southwest side of my public pool. Objects displaced by jumping." Bumping motion in northwest to south direction; gradual onset; roaring earth noise heard at time of shock.

Skykomish.—Felt by and frightened all in community. Damage slight to brick. Chimneys fell. Walls and chimneys cracked; plaster fell. Vases and small objects overturned. Rapid motion in west-east or east-west direction; duration, 30–45 seconds; moderate earth noises from west-east.

Snoqualmie.—Felt by all and frightened many in community. Damage considerable to brick. Chimneys twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, and plaster fell. Plaster, windows, and chimneys cracked. Small objects and furnishings shifted; vases and small objects overturned. Hanging objects swung northeast. Rapid motion in northeast direction; duration, 30 seconds; moderate earth noises from northeast.

Snoqualmie Falls.—Frightened many in community. Damage considerable. "Many chimneys and fireplaces down or not useable." Walls, chimneys, flues and fireplaces cracked. Dishes and windows broke. Small objects and furnishings shifted. Books out of bookshelves and bookcases; mail out of boxes and everything on floor at post office. Slides on Mount Si. Rapid, rolling motion in east-west direction; moderate earth noises from east west. "It was like being on a small boat on choppy water."

South Bend.—Felt by all and frightened many. Damage slight. Chimneys twisted and fell; chimneys cracked. Knickknacks fell. Small objects shifted; vases and small objects overturned. Motion slow; duration, 1 minute.

South Colby.—Felt by and frightened all in community. Damage considerable to brick and masonry. Chimneys twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, stock on store shelves, and plaster fell. Plaster, windows, walls, and chimneys cracked. Small objects and furnishings shifted; vases and small objects overturned. Hanging objects swung and fell. Rapid motion in north-south direction; duration, 45 seconds; preceded about 4 seconds by loud earth noises.

Stanwood.—Felt by many in community. "One of the heaviest shocks ever felt in this locality." Damage slight. Chimneys twisted and fell; chimneys cracked. Knickknacks, books, and pictures fell. Small objects and furniture shifted; vases and small objects overturned. Moderate motion in northwest direction; duration, 20 seconds.

Sultan.—Felt by and frightened all in community. Chimneys twisted and fell. Dishes and windows broke. Knickknacks, books, pictures, plaster, and walls fell. Plaster, walls, and chimneys cracked. Small objects and furnishings shifted; vases overturned. Trees and bushes were shaken strongly. Pendulum clock stopped. Rapid motion in east-west direction; duration, 35–45 seconds; preceded 3–4 seconds by loud earth noises.

Sumner.—Felt by several and frightened few in community. Damage slight to masonry. Chimneys twisted and fell. Plaster and chimneys cracked. Small objects shifted. Rapid motion in east direction; duration, 45–60 seconds; moderate earth noises.

Suquamish (about 15 miles northwest of Seattle).—Felt by all; awakened and frightened many in community. Damage slight. The press reported the shoreline of Suquamish, in northeast Kitsap County, heaved up 15 feet in places. A 2-story beach house was demolished and trees were uprooted. Fill dirt for a road slid down a 100-foot bank. A nearby resident reported the beach below the bank heaved in a wave-like motion and rolled like a wave toward the bank. The beach close under the bank seemed to sink several feet. "The earthquake left a high beach, most of which was washed out by the high tide." Ground cracked. Books and plaster fell. Trees and bushes were shaken strongly. Rapid motion in northeast direction; duration, 40–50 seconds; preceded 5 seconds by moderate earth noises from the east.

Tacoma.—Felt by and frightened all in community. Damage considerable. Press reported the Union Station was evacuated due to extensive damage. Hugh chunks of concrete fell from the roof. No one was injured, but most activity at the old depot was halted until damage could be determined. Tacoma police said preliminary reports indicated no major damage. About 60 windows were broken at Schoenfeld's Furniture Store, near the depot. Many walls and chimneys throughout the city and suburbs were toppled; many windows shattered; gas and water mains broke. Damage to schools was very light. One of the main downtown streets, Pacific Avenue, was littered with bricks and debris. A cross fell from one church. The Narrows Bridge shook violently for 3–5 minutes, but no serious damage resulted. An official reported bolts on the bridge were sheared and one light pole was down. A cashier at the toll plaza reported vibrating cables scarred concrete blocks, and that light standards shook, dislodging glass fixtures. All glass in the roadway lights was broken. Cables rippled the length of the span. Two liquor stores reported broken merchandise. Rapid motion in west direction; duration, 1 minute; loud earth noises.

Tahuya.—Felt by all. Damage slight to concrete. Chimneys twisted and fell. Ground cracked. Small objects and furnishings shifted; china closet nearly overturned. Trees and bushes shook strongly. Hanging objects swung north-south. Rapid motion in north-south direction, duration, less than 1 minute; preceded 2–3 seconds by loud earth noises. "This earthquake was much stronger than the 1949 shock."

Tumwater (about 2 miles south of Olympia).–Landslide caused breakage of a sewer line and railroad tracks. The Union Pacific Railroad reported that a hillside fill slid away from beneath a 400-foot section of a branch line just outside of Olympia (press). Damage was estimated at about $200,000.

Vashon Island.–Considerable chimney loss, wall cracks, and fallen plaster were reported from practically all parts of the island. The southern and western sections seemed to have been most severely damaged. Press reports stated the Burton-Tahlequah Road settled. Stock was thrown from shelves in markets and bottles broke. Home waterpipe broke. Felt very strongly at Vashon. At Ellisport, east shore, the shock was felt by all, awakened few, and frightened many. Trees and bushes were shaken strongly; hanging objects swung northeast. Rapid motion in northeast direction; duration, 30 seconds to 1 minute; loud earth noises.

Vaughn.–Felt by, awakened, and frightened many. Damage slight. Chimneys twisted and fell; some chimneys cracked. Knickknacks, books, and pictures fell. Trees and bushes were shaken strongly. Slow motion in west-east direction; duration, 45 seconds. This was preceded by loud earth noises from the south.

Wauna.–Felt by all and frightened many in community. Damage considerable to brick and masonry. Chimneys twisted and fell. Knickknacks, books, and pictures fell. Plaster, walls, and chimneys cracked. Small objects shifted and overturned. Trees and bushes were shaken strongly. Pendulum clock stopped. Rapid motion in north-south direction; duration, 45 seconds; moderate earth noises from north-south.

NOTE: Since additional data have been received subsequent to the printing of the report, "*The Puget Sound, Washington Earthquake of April 29, 1965,*" some towns that were listed in the report at lower intensities have been re-evaluated at higher intensities.

INTENSITY VI: Adna, Alder, Algona, Aloha, Amanda Park, Amboy, American River, Anderson Island (47°09.8′ north, 122°42.0′ west), Ardenvior, Arlington, Bainbridge Island, Baring, Bay Center, Beaver, Belfair, Bellevue, Blaine, Bothell, Bremerton, Bridgeport, Brooklyn, Brush Prairie, Bucoda, Burien, Burley, Burlington, Burton, Carbonado, Cashmere, Castle Rock, Cathlamet, Centralia, Chehalis, Chelan, Chelan Falls, Cinebar, Clallam Bay, Clearlake, Cle Elum, Clinton, Concrete, Conway, Copalis Beach, Copalis Crossing, Cosmopolis, Cougar, Coupeville, Darrington, Dryden, Dupont, Easton, Edmonds, Ellensburg, Elma, Ethel, Fall City, Fort Steilacoom, Fox Island, Frances, Freeland, Galvin, Gig Harbor, Glenoma, Gooseprairie, Graham, Hadlock, Hansville, Harper, Hoodsport, Hyak, Ilwaco, Index, Indianola, Joyce, Kelso, Keyport, Kosmos, La Center, Lacey, La Conner, Langley, Lebam, Lester, Lilliwaup, Littlerock, Long Beach, Longview, Lowell, Lyman, Lynden, McKenna, Marblemount, Marysville, Mayfield, Medina, Menlo, Mercer Island, Midway, Monroe, Morton, Mossyrock, Mountlake Terrace, Mount Rainier National Park, Mount Vernon, Mukilteo, Naches, Nahcotta, Napevine, Nooksack, Nordland, Omak, Onalaska, Orondo, Oysterville, Pacific Beach, Packwood, Pe Ell, Porter, Port Gamble, Port Ludlow, Potlatch, Rainer, Randle, Raymond, Redmond, Redondo, Richmond Beach, Rochester, Rollingbay, Roy, Ryderwood, Satsop, Seabeck, Seahurst, Seattle Heights, Sekiu, Selah, Selleck, Shelton, Silvana, Skamokawa, Snohomish, South Cle Elum, South Prairie, Southworth, Startup, Stevens Pass (Mount Persis region), Swift Dam (about 5½ miles east of Cougar), Tokeland, Toledo, Toutle, Tracyton, Tukwila, Union, Vader, Wilkeson, Winlock, Woodinville, Woodland, and Zenith.

INTENSITY VI IN OREGON: Astoria, Birkenfeld, Boring, Buxton, Clatskanie, Clifton, Hammond, Knappa, Newberg, Seaside, and Vernonia.

INTENSITY VI IN BRITISH COLUMBIA, CANADA: Victoria.—Plaster cracked; china broke. Many vacated houses. Piles shifted at the harbor. (Questionnaire canvass by Dr. W. G. Milne, Dominion Astrophysical Observatory, Victoria, B. C.)

INTENSITY V IN WASHINGTON: Aberdeen, Acme, Aeneas, Ajlune, Ariel, Ashford, Big Lake (about 6 miles southeast of Mount Vernon), Blanchard, Bow, Brewster Buena, Bumping Lake, Carlsborg, Carrolls, Chewelah, Chinook, Cliffdell, Colfax, Connell, Cook, Cowiche, Creston, Crewport, Curlew, Curtis, Custer, Decatur Island, Deep River, Deer Harbor, Deming, Doty, East Olympia, Eastsound, Edison, Electric City, Everson, Ferndale, Ford, Friday Harbor, Gardiner, Gifford, Glenwood, Grayland, Grays River, Greenbank, Hamilton, Heisson, Hoquiam, Humptulips, Inchelium area, Kalama, Keller, Kittitas, Lakewood, Lamont, La Push, Loon Lake, Lopez, Lummi Island, Lynnwood, Malaga, Malone, Malott, Maple Falls, Marietta, Matlock, Mazama, Metaline, Methow, Millwood, Moclips, Monitor, Moxee City, Naselle, Neah Bay, Neilton, Nespelem, North Bonneville, Oak Harbor, Ocean City, Ocean Park, Olga, Orcas, Port Angeles, Port Townsend, Prosser, Riverside, Rock Island, Rockport, Rosburg, Salkum, Shaw Island, Silver Creek, Silverdale, Silverlake, Steilacoom, Stevenson, Sumas, Tenino, Thorp, Tumtum, Underwood, Vancouver, Vantage, Waldron, White Salmon, Wiley City, Winthrop, Withrow, Yakima (and 6 miles north of at Gleed), Yelm, and Zillah.

INTENSITY V IN OREGON: Aloha, Beaver, Brightwood, Cannon Beach, Cape Meares Lighthouse (about 8 miles northwest of Tillamook), Fairview, Gales Creek, Hebo, Hillsboro, Jewell, McMinnville, Mayville (3 miles east of), Milwaukie, Monmouth, Mosier (2 miles southeast of), Mount Hood, Odell, Philomath, Portland, Rainier, Sandy, Scappoose, Tidewater, Tigard, Timber, Tygh Valley, Valsetz, Warrenton, and Willamina.

INTENSITY V IN BRITISH COLUMBIA, CANADA: Abbotsford, Grand Forks, and Huntingdon.

INTENSITY IV IN WASHINGTON: Addy, Airway Heights, Albion, Almira, Anacortes, Azwell, Bellingham, Benton City, Beverly, Bingen, Boyds, Brownstown, Camas, Carlton, Chattaroy, Cheney, Clayton, Chimacum, Colbert, Colville, Conconully, Coulee City, Coulee Dam, Cusick, Douglas, Edwall, Elberton, Elmer City, Ewan, Fairfield, Forks, Four Lakes, Fruitland, Grand Coulee, Granger, Harrah, Hartline, Hatton, Hunters, Husum, Ione, Irby (about 10 miles northwest of Odessa), Kahlotus, Kiona, Lamona, Lancaster, Laurel, Laurier, Lincoln, Lind, Loomis, Lyle, Mabton, Malden, Malo, Manson, Marcus, Marlin, Marshall, Maryhill, Medical Lake, Mohler, Molson (10 miles south of, on Dry Gulch Road), Moses Lake, Northport, Odessa, Oroville, Othello, Outlook, Palisades, Pasco, Pateros, Point Roberts, Pullman, Richland (Hanford Project), Roosevelt, Sappho, Schwarder (5 miles south of Yakima), Sequim, Spokane, Steptoe, Stratford, Sunnyside, Synarep, Thornton, Tiger, Tonasket, Touchet, Trout Lake, Twisp, Union Gap, Uniontown, Usk, Valley, Veradale, Walla Walla and vicinity, Warden, Washougal, Washtucna, Waterville, Waukon, Wenatchee, Westport, White Swan, Wilbur, Wilson, and Yacolt.

INTENSITY IV IN OREGON: Arlington, Aurora, Bonneville, Cascade Locks, Cherry Grove (7 miles west of Gaston), Coos Bay, Dallas, Depoe Bay, Detroit (Detroit Ranger Station, 1 miles west of Detroit), Estacada, Gardiner, Gaston, Gearhart, Goble, Government Camp, Hood River, Idanha, Ione, Lebanon, Mapleton, Marquam, Mill City, Mulino, Nehalem, North Powder, Oregon City, Pacific City, Parkdale, Prineville, Rufus, Salem, Scottsburg, Shedd, Sheridan, Sublimity, Tillamook, Walton, Westlake, West Linn, and Woodburn.

INTENSITY IV IN IDAHO: Athol, Bonners Ferry, Bovill, Coeur D'Alene, Elk River, Moscow, Nordman, Potlatch, and Saint Maries.

INTENSITY IV IN MONTANA: Eureka.

INTENSITY IV IN BRITISH COLUMBIA, CANADA: Agassiz, Alberni, Cache Creek, Duncan, Ganges, Hope-Princeton Highway, Ladner, Ladysmith, Oliver, Port Renfrew, Powell River, Shawnigan Lake, Silver Creek (3 miles west of Hope), and Vancouver.

INTENSITY I–III IN WASHINGTON: Benge, Bluecreek, Carson, Cedonia, Clearwater, Colton, Cunningham, Danville, Dayton, Deer Park (2 miles north of), Denison, Entiat, Ephrata, Evans, Farmer, Freeman, Glenwood, Goldendale, Grandview, Kettle Falls, Kewa, Larson Air Force Base (about 8 miles north by west of Moses Lake), Liberty Lake, Locke, Mansfield, Mead, Mica, Metaline Falls, Nine Mile Falls, Okanogan, Orient, Otis Orchards, Pine City, Reardan, Rice, Rosalia (5 miles north and west of), Saint John, Soap Lake, Snake River (5 miles north of), Springdale, Tekoa, Toppenish, Urban (Sinclair Island), Waitsburg, Wallula, Wapato, Wawawai (7 miles north of, on Snake River), Wellpinit, Winchester, Winona, and Wishram.

INTENSITY I–III IN OREGON: Clackamas, Coquille, Culver, Eugene (Mahlon Sweet Field, about 8 miles north-northwest of Eugene), Florence, Fossil, Gresham, Halsey, Saint Helens, Silverton, The Dalles (4 or 5 miles west of), Toledo, Waldport, Winchester Bay, and Yachats.

INTENSITY I–III IN IDAHO: Calder, Coolin, Dover, Harrison, Kootenai, and Sandpoint.

INTENSITY I–III IN MONTANA: Hot Springs, Kalispell, Noxon, Trout Creek, and Whitefish (5½ miles west of Bissel community).

INTENSITY I–III IN BRITISH COLUMBIA, CANADA: Bowser, Castlegar (west side of Columbia River), Denman Island (west-central section), Gabriola (Gabriola Island, northwest section), North Bend, Parksville, Pemberton, Princeton, Ucluelet, and Union Bay.

April 30: 09:10 (about). Elbe, Wash. Light tremor reported felt by two.

October 23: 08:27:59.8*. Epicenter 47.5° north, 122.4° west, Washington, Puget Sound area, W. Magnitude 4.8. Felt at Bremerton, Everett, Olympia, Tacoma, Seattle, and Waterman.

ALASKA

[150th Meridian or Alaska Standard Time]

January 3: 13:13:50.4*. Epicenter 60.2° north, 151.2° west, Kenai Peninsula, depth about 76 km, W. Magnitude 5.3. Felt at Homer.

January 3: 17:41:23*. Epicenter 59.9° north, 153.6° west, southern Alaska, depth about 76 km, W. Magnitude 5.3. Felt at Homer.

January 6: 08:27:36.0*. Epicenter 60.1° north, 151.8° west, Kenai Peninsula, depth about 93 km, W. Magnitude 5.6. Felt at Homer.

January 6: 20:23. Felt at Homer.

January 27: 11:12. Felt on Adak.

February 3: (1) 19:01:21.8*; (2) 21:40:27*. Epicenter (1) 51.3° north, 178.6° east, Rat Islands, Aleutian Islands, depth about 40 km, W. Magnitude 7¾, P; (2) 50.9° north, 177.7° east, Rat Islands, Aleutian Islands, depth about 33 km, W. Magnitude 5.0, W. VI. Buildings cracked and objects fell on Adak and Shemya Islands. Hairline cracks appeared in runways on Attu. The first shock generated a tsunami that was recorded at several tide stations (*see* "Tidal Disturbances of Seismic Origin," page 61). Slight flood-

SELECTED REFERENCES

Edwards, H. H., 1950, Discussion of damage caused by the Pacific Northwest earthquake of April 13, 1949, and recommendations of measures to reduce property damage and public hazards due to future earthquakes: (report to) Seattle Section, American Society of Civil Engineers, 30 p.

The report is essentially the same as the three articles published in "Western Construction" that are reprinted herein.

Hopper, M. G., and others, 1975, A study of earthquake losses in the Puget Sound, Washington, area: U.S. Geological Survey Open File Report 75-375, 298 p.

A study "intended to inform those agencies...of potential hazard to people, structures, and lifeline functions" to facilitate "planning response to earthquake disaster." Simulates two 7.5-magnitude events and what their effects might be in Snohomish, King, Pierce, Kitsap, and Mason Counties.

MacPherson, S. H., (1965), A report of the April 29, 1965 earthquake, Seattle, Washington: Seattle Fire Department, 21 p.

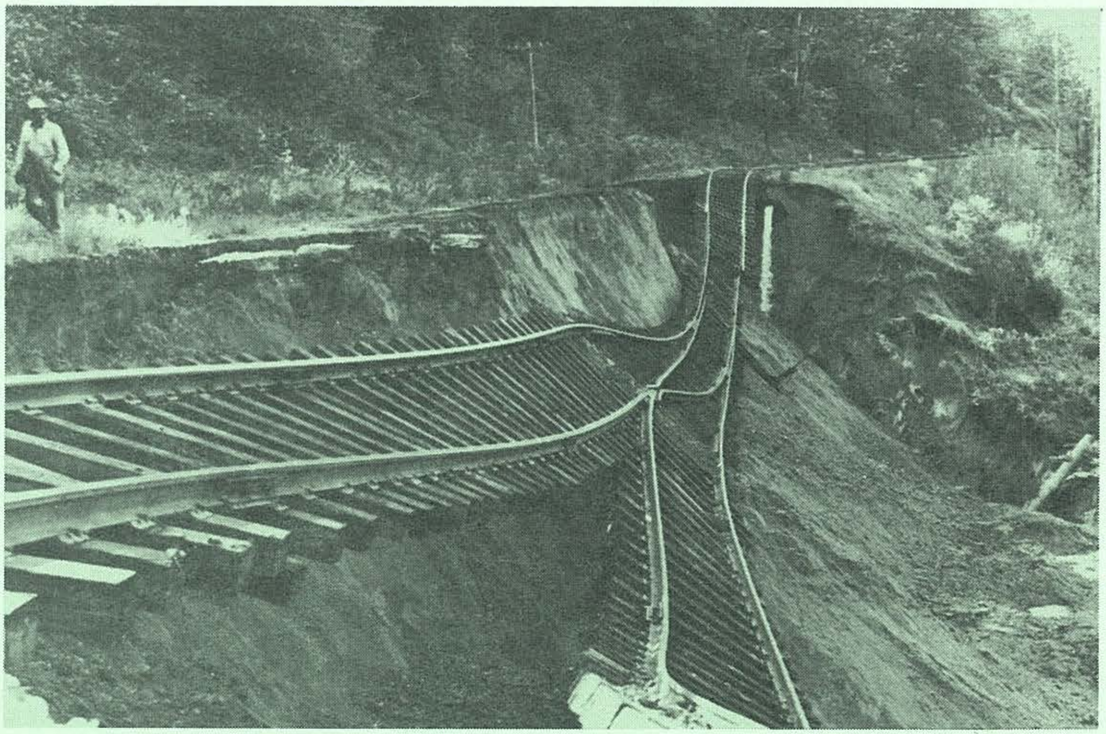
A report about building inspections in Seattle, with five photographs.

Rasmussen, N. H., and others, (1974), Earthquake hazard evaluation of the Puget Sound region, Washington State: Geophysics Program, University of Washington, Seattle, 99 p.

General report that attempts to project damage from future quakes. Includes epicenter maps and list of damaging quakes. Essentially technical; no photographs.

U.S. Army Corps of Engineers, 1949, Report on damage resulting from earthquake of 13 April 1949: Seattle District, 27 p.

An internal, rather detailed report with five photographs, appendice about "soil and foundation rupture", and a list of damage to the Northe Pacific Railway.



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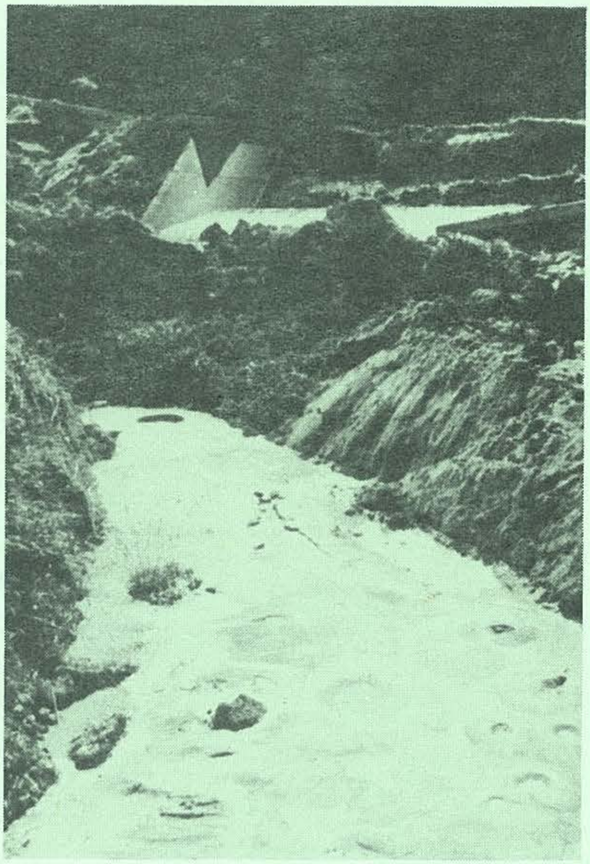

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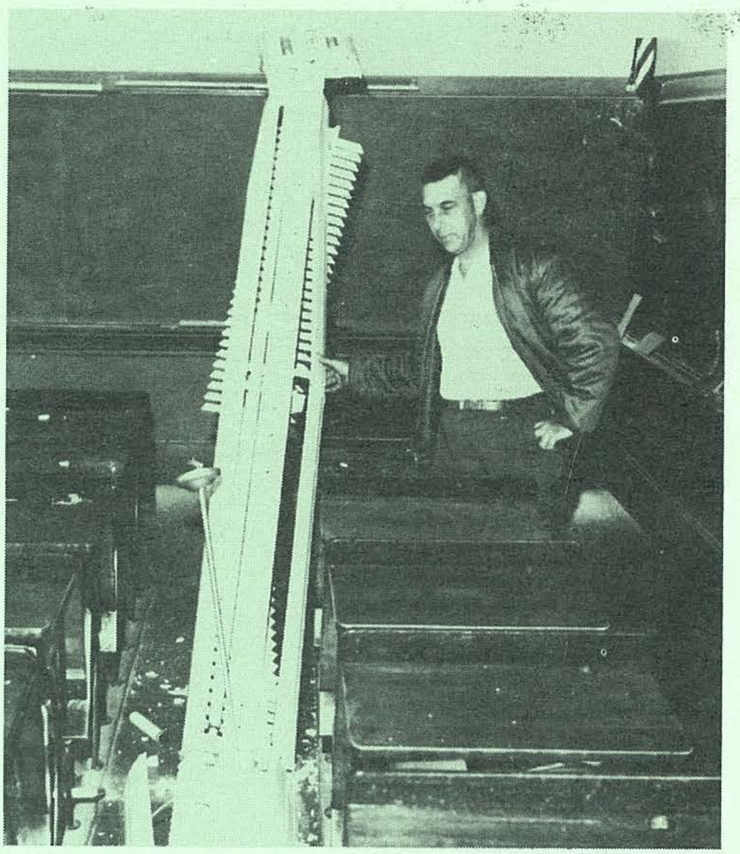

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