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the strong motion seismograph network in western canada, 1970

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Contents

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Abstract. A program to install strong motion seismographs in the active seismic regions in western Canada was initiated in 1961. A total of 14 accelerographs and 48 seismoscopes are now installed along the coast of British Columbia. The seismoscopes and eight of the accelerographs are instruments of United States Coast and Geodetic Survey design manufactured in Canada. The remaining six accelerographs have been purchased in the United States. The strong motion instruments are distributed in buildings on varied geological and local soil formations in a program to determine ground motion and its variation with soil type in the vicinity of earthquake epicentres.

Résumé. Un programme d'installation de séismographes à fortes secousses a été amorcé en 1961 dans les secteurs d'activité séismique prononcée de l'Ouest du Canada. Quatorze accélérographes et quarante-huit séismoscopes sont déjà en place le long de la côte de la Colombie-Britannique. Les séismoscopes et huit des accélérographes ont été fabriqués au Canada selon un modèle mis au point par le *Coast and Geodetic Survey* des États-Unis. Les six autres accélérographes ont été achetés aux États-Unis. Les séismographes à fortes secousses ont été installés dans des bâtiments sur divers genres de sols et de formations géologiques afin de permettre de déterminer le mouvement du sol et ses variations selon le type de sol aux environs de l'épicentre des séismes.

Introduction

Scientists of the United States Coast and Geodetic Survey developed, in the early 1930s, a seismograph system for the study of the response of buildings and different soils to the large accelerations which occur near the epicentres of large earthquakes (Ulrich, 1935). The units have proven successful in producing good records, although the original design has been modified several times. The accelerogram from the United States Coast and Geodetic Survey instrument near the El Centro earthquake of 1942 has been used for many earthquake engineering studies. Many of the early instruments were placed in California, but the most recent list of the United States strong motion seismographs shows that, at the present time, there are new stations being added in all the earthquake zones in the United States. A new series of instruments have appeared on the market to meet the demand. Japanese seismologists have also developed strong motion seismographs. There are many sites in Japan where strong motion instruments are located, and many records have been obtained. New Zealand seismologists have developed instruments for distribution in earthquake zones. Similar programs are in progress in Russia, India, Chile, Mexico and other countries.

In 1961, when Canadian seismologists first took an active interest in engineering seismology, there were no commercial manufacturers of strong motion seismographs in North America. A strong motion seismograph was borrowed from the U.S.C.G.S. site at Tacoma, Washington, and tenders were called for making blueprints and building units similar to it. Fairey Aviation of Victoria was the successful bidder, and have since built eight of the units for use in western Canada. The United Electro Dynamics Corporation of Pasadena, now a Teledyne Company, designed and produced the AR-240, a more compact and up-dated version of a strong motion seismograph. This unit lacks the displacement meters incorporated in the U.S.C.G.S. model, but otherwise retains similar basic instrumental constants. Six of these instruments have been purchased for use in western Canada. The price for one unit of either the Fairey model, or the AR-240 is approximately $4,000. Since these instruments have been purchased, new designs of strong motion instruments have appeared on the market at a greatly reduced price.

Several versions of a low-cost strong motion seismograph have been designed in various countries. The United States model is called the Wilmot-Survey type seismoscope. Fairey Aviation, and United Engineering, both Victoria firms, have each built 25 seismoscopes of this design for the Dominion Observatory. Many of these more limited units can be installed because the cost is low—approximately $200 each.

The aim of the strong motion program on the west coast of Canada is to obtain basic ground motion data on varied geological and soil formations during large earthquakes. In an effort to restrict measurements to that of true ground motion (and not building motion), the instruments have been placed in the basement of buildings. The buildings are low and have a relatively small mass to minimize the influence of the building on the true ground motion. The coastal region of British Columbia is part of the circum-Pacific earthquake zone, and earthquakes may occur throughout the region. Instruments are distributed along the coast from Prince Rupert to Victoria. There is a greater concentration of strong motion instruments in the more heavily populated southern section. In this section, because of the complex recent geological history (Armstrong 1956, 1957; Fyles 1960, 1963), there are areas where instruments may be installed on many different types and thicknesses of soil, relatively close to each other.

Instrumentation

Fairey Aviation strong motion accelerograph (U.S. Coast and Geodetic Survey standard design). Figure 1 is a photograph of an instrument in this series. This unit contains three mutually perpendicular accelerometers, and two displacement meters. Accelerometer and displacement meter response together with time marks are recorded on 12-inch wide photographic paper at a speed of approximately 2 cm/sec. The instrument operates from a 12-volt battery, maintained in fully-

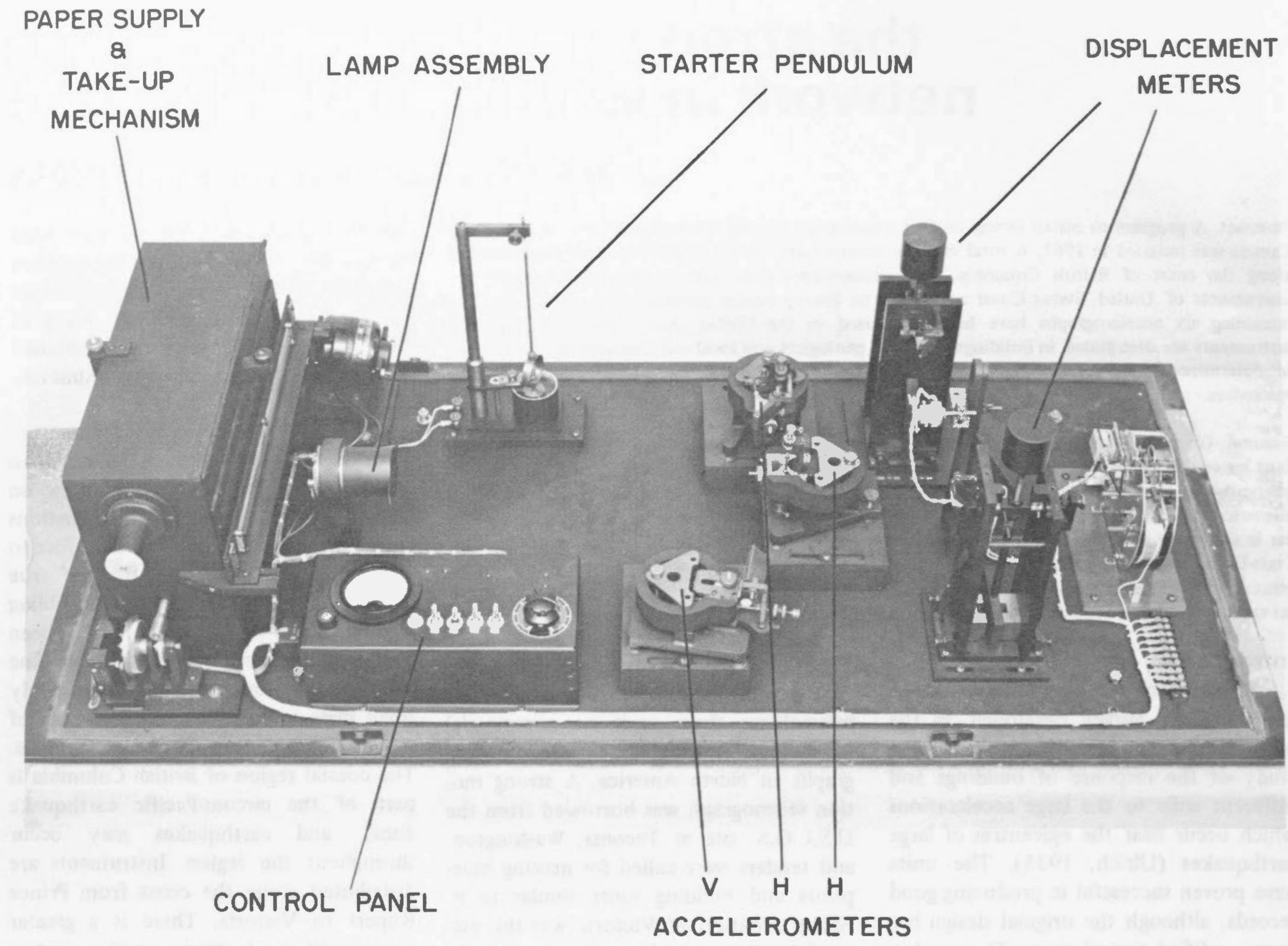

Figure 1. Photograph of accelerograph (U.S.C.G.S. design).

charged condition by a continuous trickle-charge. Recorder operation in the presence of large ground motion is initiated by closure of contacts on a starter pendulum that responds to horizontal ground motion. Sensitivity of the starter is adjustable by varying the spacing of the contacts. This starter pendulum has a natural period of approximately 1 second, and 30 per cent critical damping is obtained with a dash pot of oil. The gap between contacts on the starter is set at 0.6 mm. This will be closed by an earthquake with intensity of IV or greater at the site.

Momentary closure of the starter pendulum contacts de-energizes a holding relay. Release of the holding relay then initiates operation of an 8-day mechanical clock movement to provide half-second time interval marks, turns on the recording lamp and the paper drive motor. Once started, the unit operates for 90 seconds after which it is turned off and the holding relay is again energized. Additional 90-second operation cycles will occur whenever the ground motion is sufficient to produce closure of the starter pendulum contacts. A maximum of 10 such cycles can occur before a final stop switch is closed. The room must be darkened to remove or change the record.

The torsion-pendulum type accelerometers have a natural period of approximately 0.06 second, damping of 60 per cent critical, acceleration magnification of approximately 120, corresponding to a sensitivity of approximately 12 mm trace amplitude for an acceleration of 0.1 gravity. The normalized response curve for an accelerometer is shown in Figure 2 (after U.S.C.G.S.).

The Carder displacement meters have a natural period of approximately 3 seconds, damping of 60 per cent critical (eddy-current damping), and a magnification of 1. The response curve for a displacement meter is shown in Figure 3.

The U.E.D. AR-240 strong motion accelerograph. The AR-240 strong motion accelerograph of the U.E.D. Earth Sciences Division (Figure 4) was marketed in late 1963. The instrument contains three mutually perpendicular accelerometers with a natural period of approximately 0.06 second and 60 per cent critical electromagnetic damping. These torsion seismometers have a sensitivity of 7.6 mm trace amplitude for 0.1 gravity

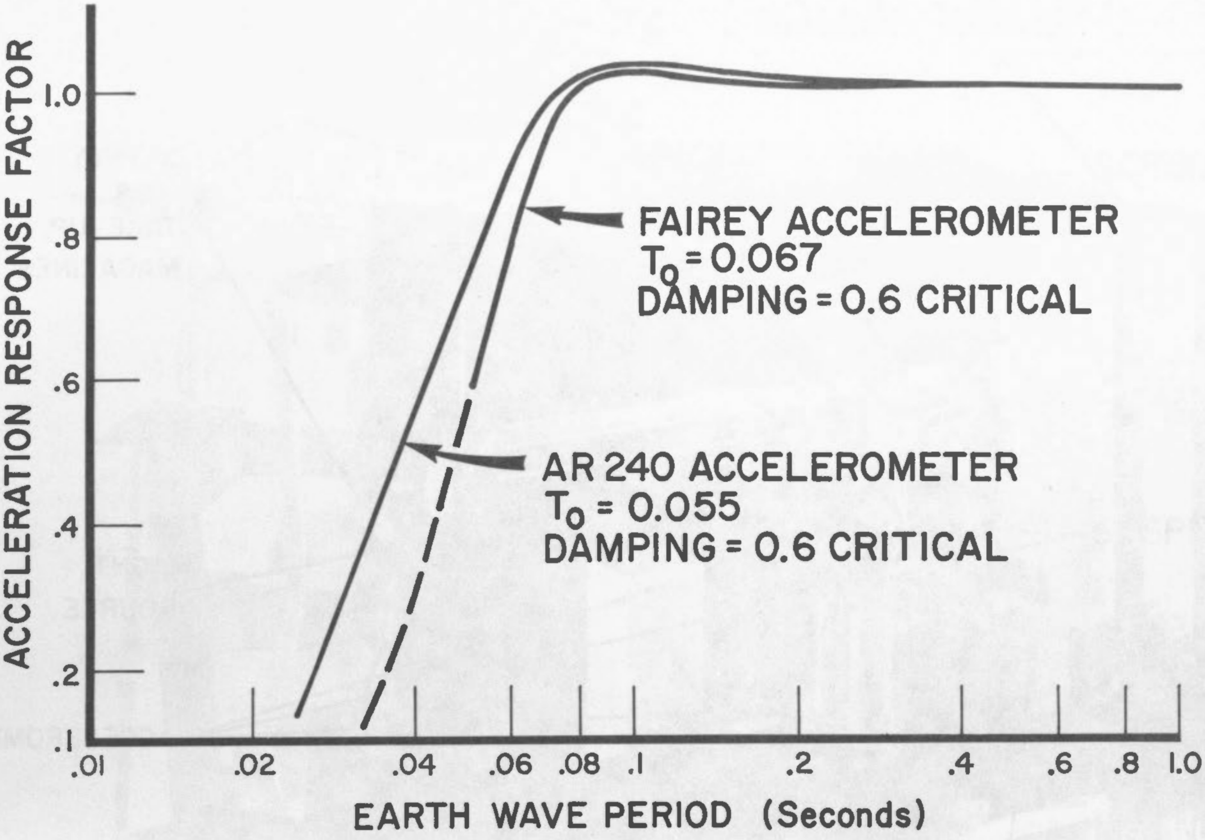

Figure 2. Response curve of accelerometers.

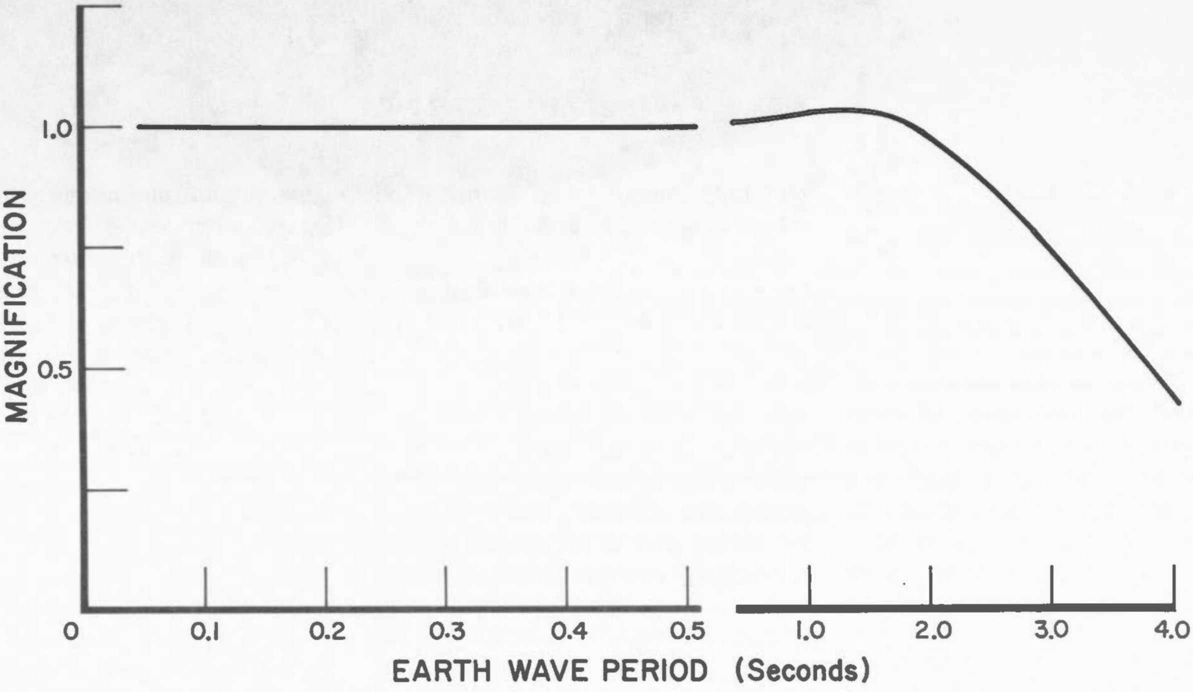

Figure 3. Response curve of Carder-type displacement meter.

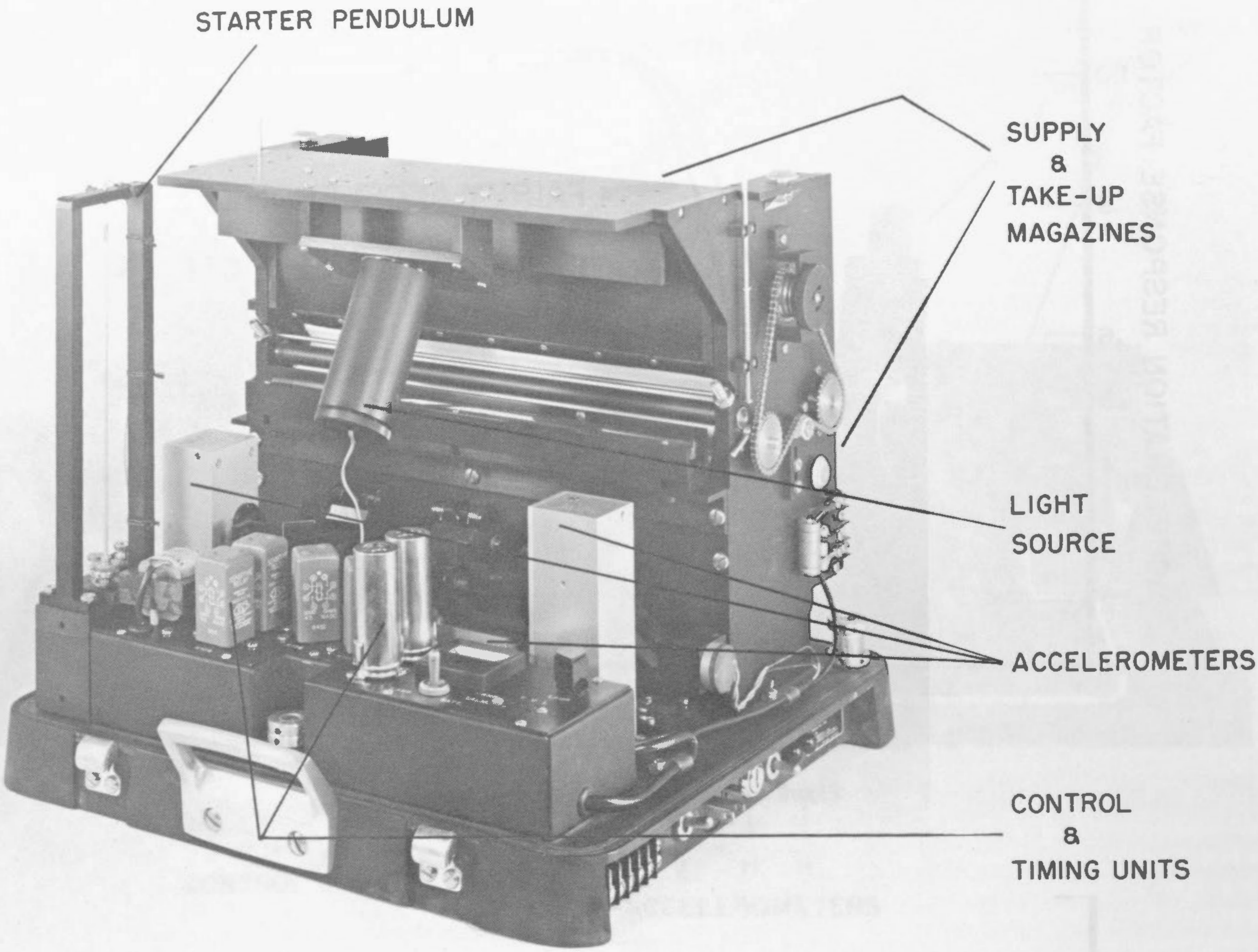

Figure 4. Photograph of U.E.D. AR-240.

acceleration. Their response curve is shown in Figure 2.

The AR-240 is self-triggering with a critically magnetic damped starter pendulum that has a natural period of one second and is sensitive to horizontal motion. The gap between contacts is set to 0.6 mm. The unit shuts off seven seconds after the last contact closure of the starter pendulum and is ready for a new operation. The recording is done on 12-inch-wide photographic paper at a speed of 2 cm. per second. Recording paper is carried in magazines which can be changed without darkening the room. Time marks are controlled by an electronic timing module and are put on the record every half second. The unit is operated from a 12-volt battery that is kept fully charged by an internal trickle charger connected to available A.C.

Fairey Aviation and United Engineering seismoscopes (Wilmot Survey type). The seismoscope (Figure 5) is a conical pendulum that includes a smoked glass plate upon which a scriber rides. The instrument does not measure either the displacement or the acceleration of the ground, but provides a direct record on the smoked glass of the velocity response of an average structure to ground motion. That is, it records a particular point, defined by its period and damping, on the velocity response spectrum (Hudson 1956).

The seismoscopes made by Fairey Aviation and United Engineering have the same physical dimensions as the Wilmot Survey instrument (Cloud and Hudson 1961) with slight alterations to the scriber support and damping magnets. They have a period of approximately 0.75 second and variable eddy-current damping. The Fairey instruments have a maximum damping of about 5 per cent critical at one centimetre amplitude.

A deflection of 1 cm at 5 per cent damping is the equivalent to a maximum velocity response of 0.45 ft/sec for a structure with 10 per cent damping and period of 0.75 sec. Because of their more powerful magnets, the United Engineering instruments have a wider range of damping values available and have been set at approximately 10 per cent critical for 1 cm of deflection. With this series of

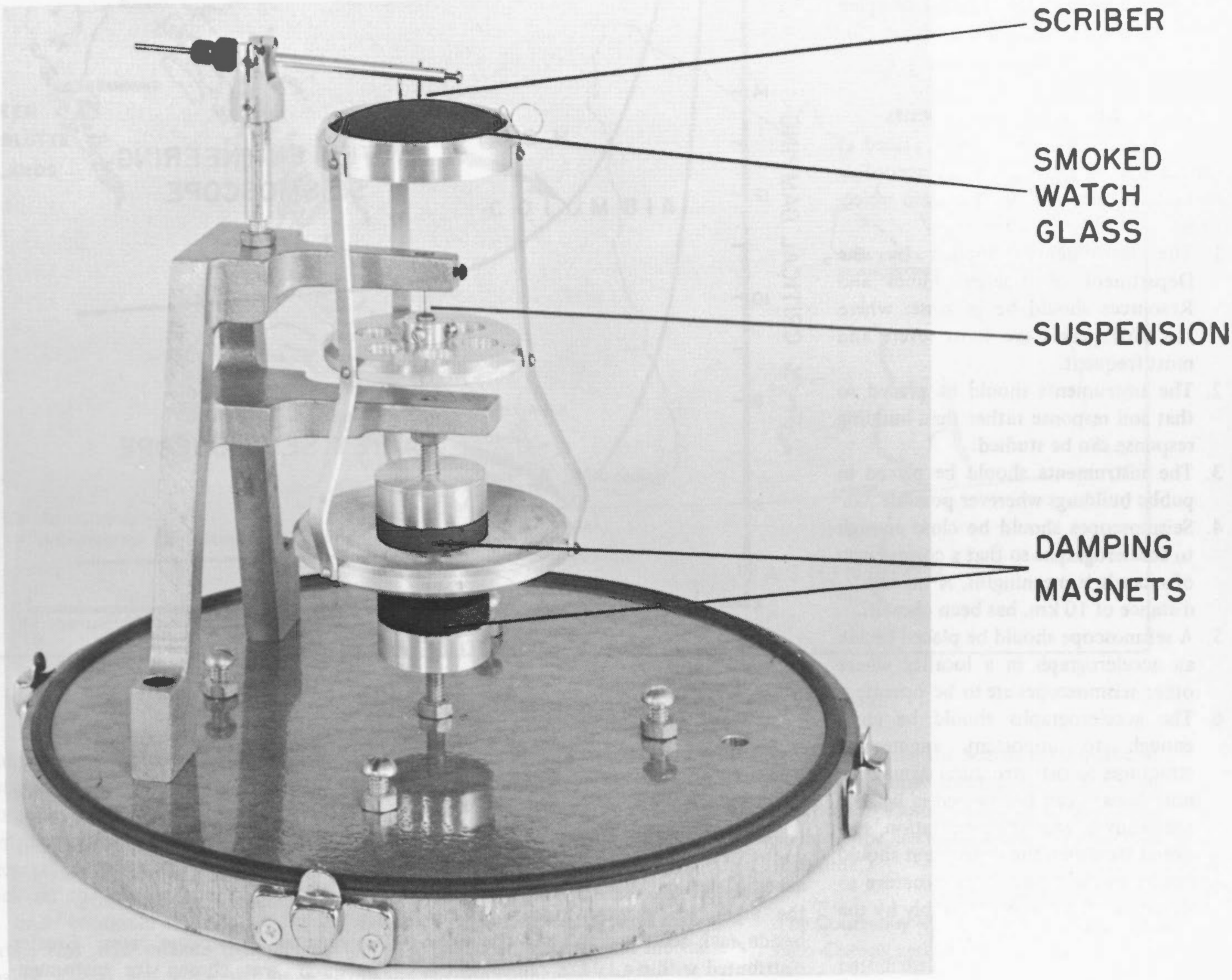

Figure 5. Photograph of seismoscope (Wilmot Survey type).

instruments, a deflection of 1 cm at 10 per cent damping is the equivalent to a maximum velocity response of 0.64 ft/sec for a structure with 10 per cent damping and period of 0.75 sec. Typical damping versus amplitude curves are shown for each model in Figure 6.

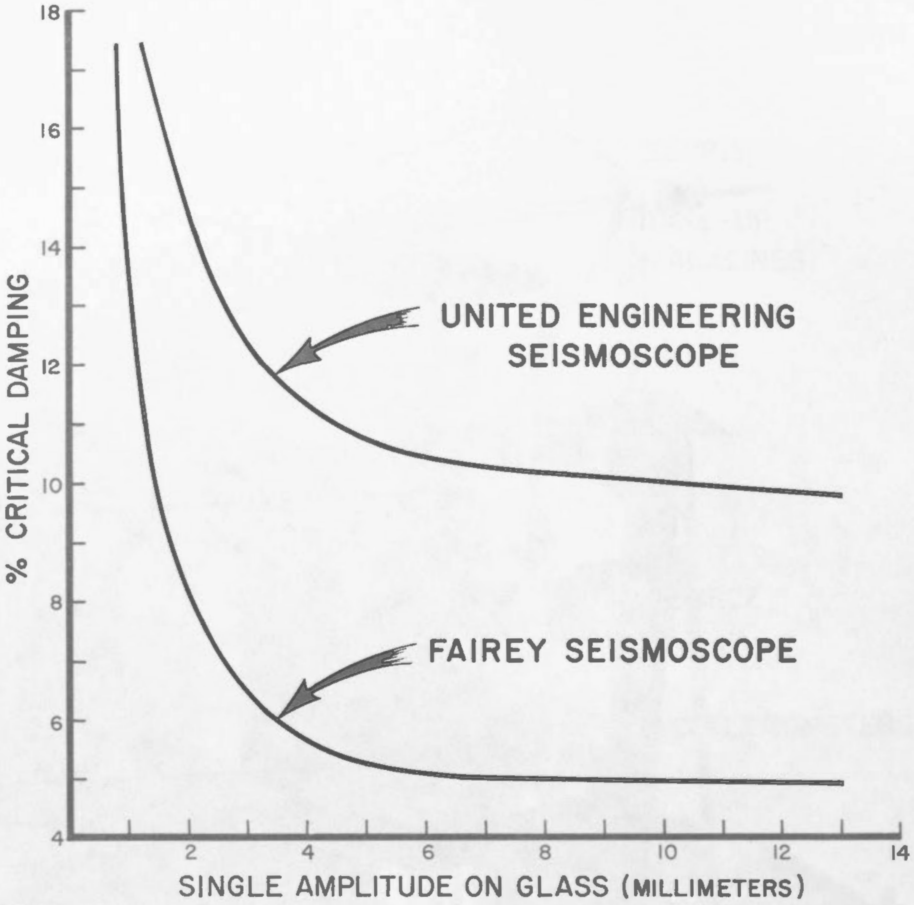

Figure 6. Seismoscope damping versus amplitude.

The distribution of instruments

The instruments have been placed at various sites in western Canada according to certain rules and with certain objectives:

1. The instruments supplied by the Department of Energy, Mines and Resources should be in zones where the earthquakes are most severe and most frequent.
2. The instruments should be placed so that soil response rather than building response can be studied.
3. The instruments should be placed in public buildings wherever possible.
4. Seismoscopes should be close enough to accelerographs so that a comparison of records is meaningful. A maximum distance of 10 km. has been chosen.
5. A seismoscope should be placed beside an accelerograph in a locality where other seismoscopes are to be operated.
6. The accelerographs should be close enough to important engineering structures so that structural damage or non damage can be assessed in light of the known ground acceleration recorded. However, the instrument should not be so close to a large structure so that it is influenced appreciably by the motion of the structure itself.

The 14 accelerographs are distributed as shown in Figure 7. Their distribution is a compromise between nearness to previous earthquake epicentres (Figure 8) and nearness to population centres where information gained can be most usefully applied. Several accelerographs have been located by themselves with the major factor in their site selection being proximity to a possible epicentre. The remaining accelerographs are accompanied by networks of seismoscopes and are located in and around population areas where construction on different types of foundation conditions is common. The seismoscopes are distributed so as to measure the response of these different conditions.

Presently there are four areas of the west coast where the accelerographs are accompanied by seismoscopes. In each of the areas, one seismoscope is located beside each accelerograph and the others distributed within a 10-km radius. In this way the records of all the seismoscopes can be compared more readily to the three component acceleration record by observing the record on the adjacent seismoscope. Also, in each area, one seismoscope is located on bedrock. This distribution provides a basis with which to compare areas and to form intensity interpretations of different microzones in a particular area.

Most of the seismoscopes have been located in schools. In this manner, by consulting with a single authority in an area, installation arrangements have been simplified and the coverage of many different types of soils and foundation conditions in that area have been made possible. Also, the school buildings are usually one or two storey structures minimizing any serious interaction between the building and the soil condition.

The greater Vancouver area. Greater Vancouver was chosen for instrumentation because it is the major city on the west coast of Canada, and most of the industry and major buildings of the west coast are located there. The original network inside the city limits has been expanded and is still under expansion outwards from Vancouver because of the different types of soils in the area. The deposits of three glaciations, intervening marine and glaciofluvial deposits, plus the deposits of the Fraser River and its large delta, offer many varying foundation conditions. The area is sufficiently industrialized so that there are buildings on almost every type of soil available.

Figure 7. Distribution of strong motion instruments in western Canada.

The instrument network presently consists of five accelerographs and 26 seismoscopes as shown in Figure 9. Two lines of instrument sites, A and B, appear as a general pattern. The A line begins on bedrock on the north shore of Burrard Inlet, and continues south to Point Roberts. This line crosses the varying depths of glacial and glacio-marine deposits upon which the city of Vancouver stands. It then crosses the Fraser River delta and ends upon glacial till at its southern end. The B line begins on the deep interglacial sandy deposits of Point Gray, and proceeds east across Vancouver to where it meets the silts of the Fraser River. It is planned to extend this line eastward to Abbotsford across the varying depths of marine, glacio-marine, and glaciofluvial deposits that have not been preloaded by glacial ice.

The one exception to the soil response study orientation of this strong motion program is in the 21 storey B.C. Hydro Building in Vancouver. During the Seattle earthquake (April 1965), motions that were imperceptible at ground level and did not trigger the strong motion unit located in the basement, caused a considerable amount of alarm on the upper floors of the building. A unit has now been installed on the roof and the starters of the two are connected together.

The greater Victoria area. The Victoria area was chosen for instrumentation because it is the second largest city on the Canadian west coast, and because it is the nearest city in Canada to epicentres located in the Puget Sound region. The major factor in choosing the distribution of sites in and around the city was the existence of an exact drilling record of soil information to bedrock. The network consists of two accelerographs and 11 seismoscopes distributed as shown in Figure 10. The accelerograph located on deep soil on the University of Victoria campus was triggered during the Seattle earthquake of 1965. The unit located on bedrock in downtown Victoria did not trigger. (The seismoscope network was not in place at that time.)

The Courtenay–Comox area. The Courtenay–Comox area was chosen for instrumentation because of its proximity to the large earthquake of 1946 (Hodgson 1946). The present network consists of one accelerograph and six seismoscopes distributed as shown in Figure 11.

The Alberni area. The Alberni Valley was chosen for instrumentation because in this area earthquakes throughout the region are experienced with a greater intensity than might be expected. The fluvial deposits of the Somass River intersect with the glacial and marine deposits of the area giving a variety of soil conditions on which construction exists. The present network consists of one

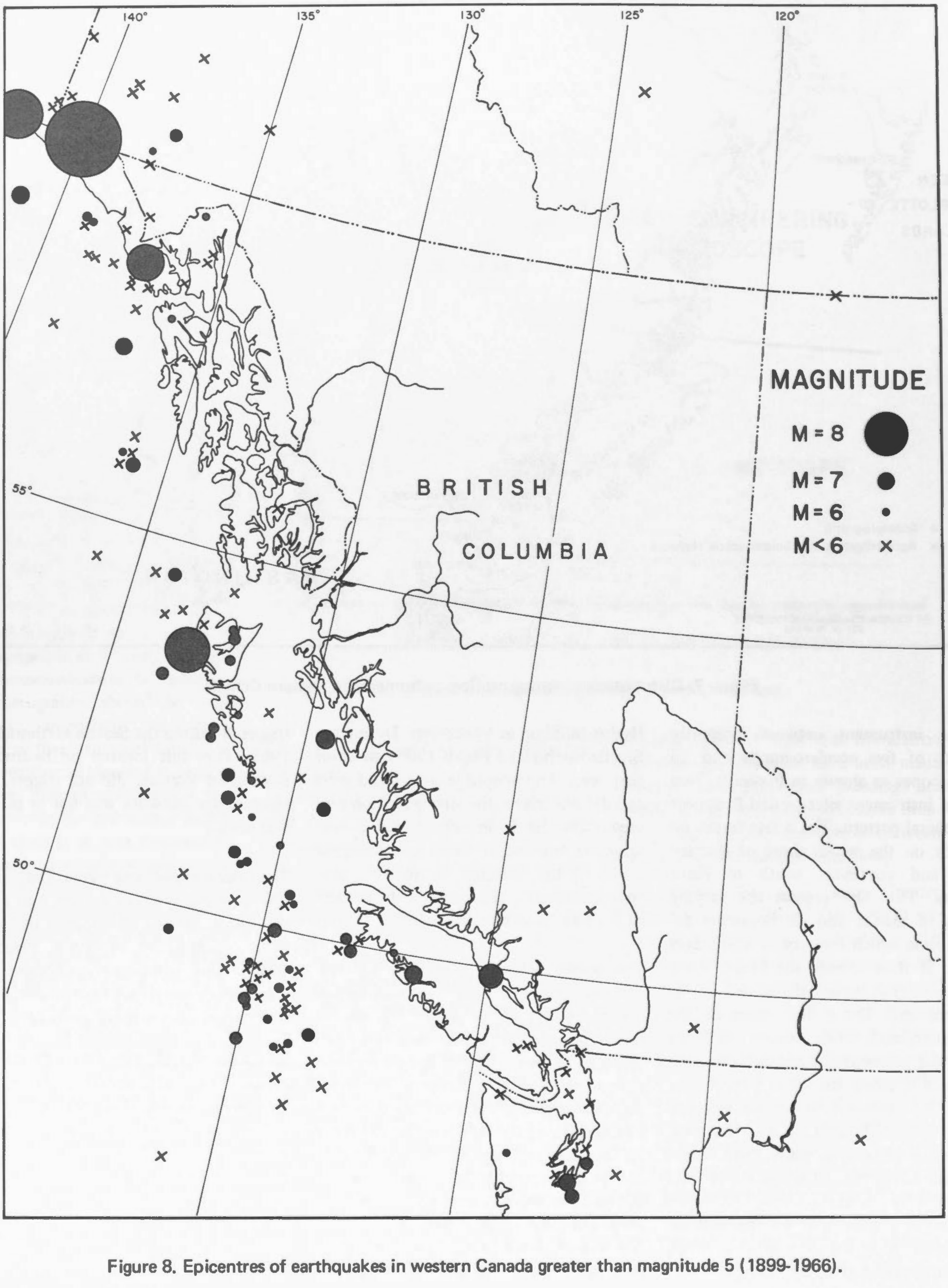

Figure 8. Epicentres of earthquakes in western Canada greater than magnitude 5 (1899-1966).

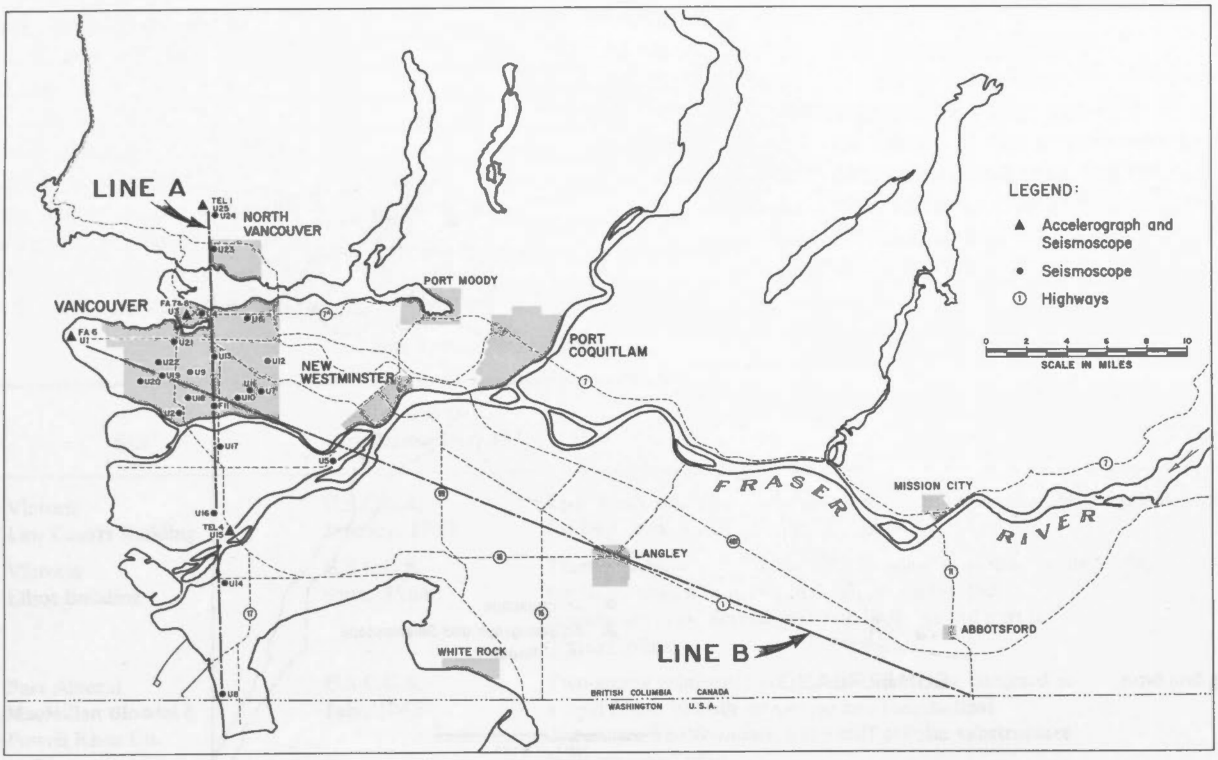

Figure 9. Distribution of strong motion instruments in the Vancouver area.

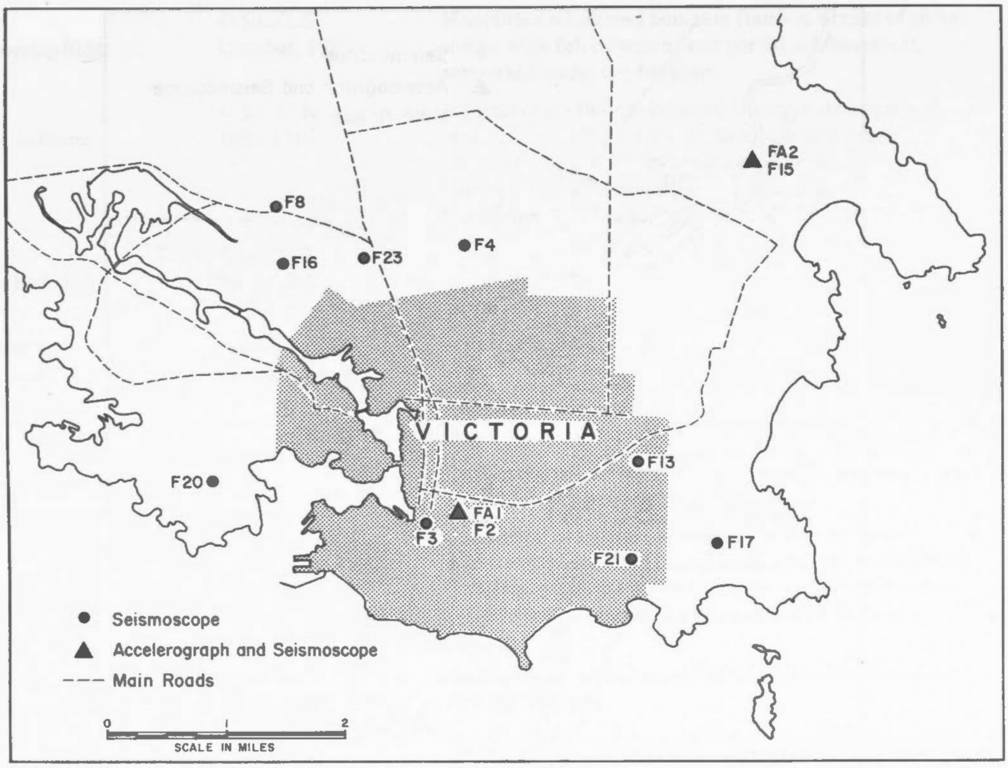

Figure 10. Distribution of strong motion instruments in the Victoria area.

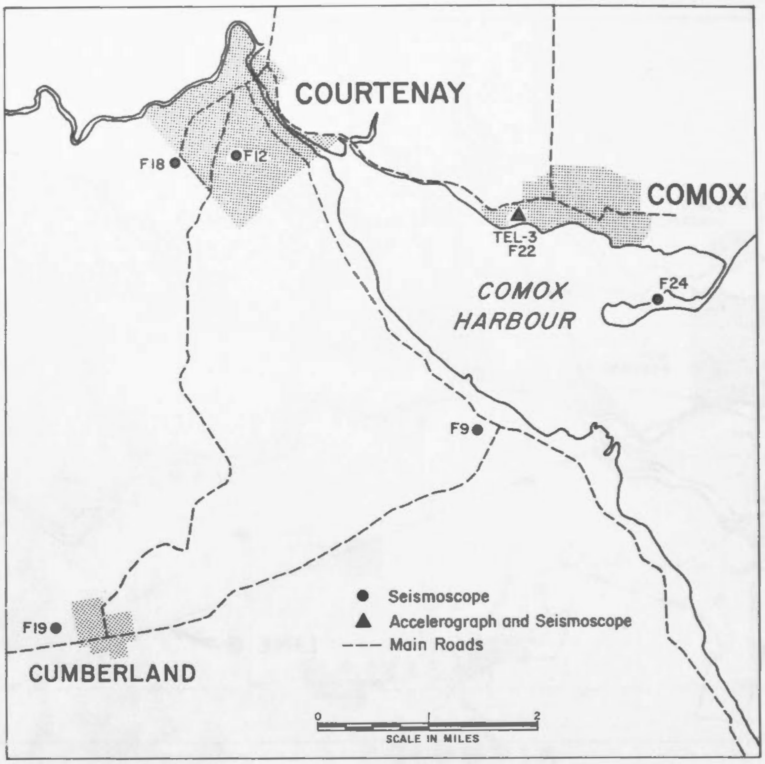

Figure 11. Distribution of strong motion instruments in the Courtenay-Comox area.

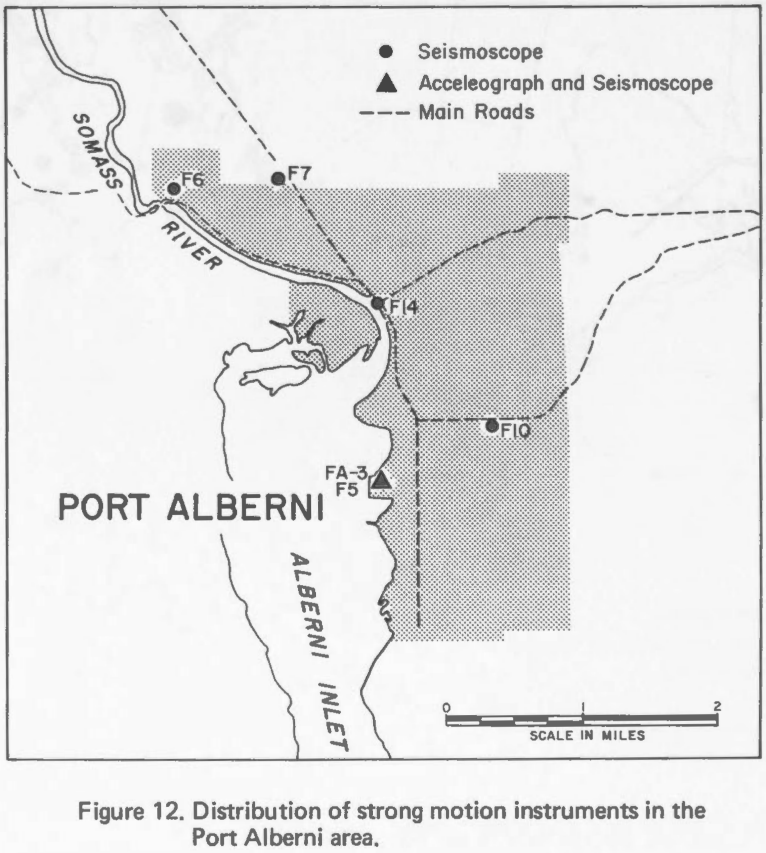

Figure 12. Distribution of strong motion instruments in the Port Alberni area.

accelerograph and five seismoscopes distributed as shown in Figure 12.

The strong motion network of western Canada is intended to be a continuing and growing network. It now consists of 14 accelerographs and 48 seismoscopes. The present policy is to continue this project as far and as rapidly as funds will permit. It is expected that private funds will permit the instrumenting of specific buildings or projects within this network. As far as possible, seismologists of the Earth Physics Branch will assist with the installation and maintenance of any private site provided any records obtained are in the public domain for earthquake engineering purposes. An example of this is the two seismoscopes which have been placed at positions near the Mica Creek Damsite by B.C. Hydro and Caseco Consultants.

Table I provides the details of the accelerograph sites and Table II provides the details of the seismoscope sites. The plans of the buildings, and the soil conditions as far as they are known are on file for each strong motion site for possible use in the future.

Table I. Information on accelerograph sites

Number	Site	Instrument and Installation Date	Building Description	Soil Type
FA-1	Victoria Law Courts Building	U.S.C.G.S. January, 1963	Five-storey reinforced concrete building with shear walls for transmission of horizontal forces.	granitic rock
FA-2	Victoria Elliot Building	U.S.C.G.S. Sept., 1964	Three-storey reinforced concrete building with shear walls for transmission of horizontal forces. Part of the foundation is reinforced concrete footings and part is 'Franki' piles.	clay
FA-3	Port Alberni MacMillan Bloedel & Powell River Co.	U.S.C.G.S. July, 1965	Two-storey reinforced concrete construction designed as a rigid frame in both transverse and longitudinal directions. The foundation is a stiff cellular substructure built on wood piles.	sand and gravel
FA-4	Campbell River Ladore Dam	U.S.C.G.S. July, 1965	A concrete gravity dam, 140 feet high.	granitic rock
FA-5	Port Hardy Seismic Vault	U.S.C.G.S. March, 1968	The instrument is on a pier in a standard underground seismic vault.	granitic rock
FA-6	Vancouver Civil Engineering Bldg.	U.S.C.G.S. October, 1965	Monolithic reinforced concrete frame structure of three stories with full basement and partial sub-basement, supported on spread footings.	sand and gravel
FA-7	Vancouver B.C. Hydro Building	U.S.C.G.S. July, 1963	A twenty-two floor reinforced concrete structure with the central core as the main structural element resisting horizontal forces. There are cross walls in the two basements to achieve complete hull action of the basements. The foundation is a modified raft design.	sandstone
FA-8	Vancouver B.C. Hydro Building (penthouse)	U.S.C.G.S. July, 1966	as above	as above
TEL-1	North Vancouver Cleveland Dam	AR-240 January, 1968	A concrete gravity dam, 300 feet high.	granitic rock
TEL-2	Duncan North Cowichan Hospital	AR-240 October, 1967	Reinforced concrete shear wall structure varying from one to six stories. Foundations are spread footings.	sand
TEL-3	Comox St. Joseph's Hospital	AR-240 August, 1967	Reinforced concrete shear wall structure four stories high. Foundations are spread footings.	glacial till
TEL-4	Richmond Massey Tunnel	AR-240 September, 1967	The tunnel has a cross section of 78 ft × 24 ft and is composed of six 344-ft reinforced concrete sections held together by clamps and rubber gaskets. It rests on a 4-ft bed of sand in a partial trench dredged in the river bottom.	sand and silt
TEL-5	Sandspit Airport Terminal Bldg.	AR-240 September, 1967	Single storey wood frame building. Foundations are a poured concrete.	sandy gravel
TEL-6	Prince Rupert Columbia Cellulose	AR-240 July, 1967	A 60-ft high two-storey steel box frame building with a concrete basement.	gravel

FA – Fairey Aviation strong motion accelerograph.

TEL – U.E.D. AR-240 strong motion accelerograph.

Table II. Information on seismoscope sites

Number	Site	Date	Soil Type
U1	Vancouver Civil Engineering Bldg., U.B.C.	October, 1965	sand and gravel
U2	Vancouver Lloyd George Elementary School	July, 1967	glacial till
U3	Vancouver B.C. Hydro Building	September, 1966	sandstone
U4	Vancouver Vancouver Vocational Institute	July, 1967	shale
U5	Richmond Hamilton Elementary School	October, 1967	boggy peat and sand
U6	Vancouver Templeton Junior Secondary School	September, 1966	glacial till
U7	Vancouver Killarney Secondary School	September, 1966	glacial till
U8	Delta English Bluff Elementary School	October, 1967	glacial till
U9	Vancouver Eric Hamber Secondary School	September, 1966	glacial till
U10	Vancouver David Thompson Secondary School	September, 1966	glacial till
U11	Vancouver Waverley Elementary School	July, 1967	muskeg
U12	Vancouver Windermere Secondary School	July, 1967	glacial till
U13	Vancouver Sir Charles Tupper Secondary	September, 1966	silt and gravel
U14	Delta Delta Secondary School	October, 1967	soft wet sand
U15	Richmond Massey Tunnel	September, 1967	sand and silt
U16	Richmond Daniel Woodard Elementary School	October, 1967	clay
U17	Richmond Mitchell Elementary School	October, 1967	clay
U18	Vancouver Churchill Secondary School	September, 1966	glacial till
U19	Vancouver Point Grey Jr. Secondary School	September, 1966	dense sand and silt
U20	Vancouver Kerrisdale Elementary Annex	September, 1966	sand, gravel and clay
U21	Vancouver School Board Administration Bldg.	September, 1966	glacial till
U22	Vancouver Prince of Wales Secondary School	July, 1967	bedrock
U23	North Vancouver Prince Charles School	October, 1967	glacial till
U24	North Vancouver Canyon Heights Elementary School	October, 1967	glacial till
U25	North Vancouver Cleveland Dam	January, 1968	bedrock
F2	Victoria Law Courts	September, 1965	bedrock

Table II. Information on seismoscopes sites (cont'd)

Number	Site	Date	Soil Type
F3	Victoria Bus Depot	October, 1967	clay and silt
F4	Victoria Cloverdale School	September, 1965	bedrock
F5	Port Alberni M.B. & P.R. Pulp Mill	May, 1965	sand and gravel
F6	Port Alberni River Bend Elementary School	September, 1969	firm sandy soil
F7	Port Alberni Seismic Station	February, 1968	bedrock
F8	Victoria Colquitz School	September, 1965	stiff brown clay
F9	Royston Royston Elementary School	September, 1967	gravel
F10	Port Alberni Calgary Elementary School	September, 1969	glacial till
F11	Vancouver Moberley Elementary Annex "A"	October, 1967	glacial till
F12	Courtenay Courtenay Elementary School	September, 1967	strongly bedded shale
F13	Victoria Bank Street School	September, 1965	dense glacial till
F14	Port Alberni Regional District of Alberni-Clayoquot office	November, 1969	sand and silt
F15	Victoria Elliot Building, Univ. of Victoria	September, 1965	clay
F16	Victoria Tillicum School	September, 1965	stiff brown clay
F17	Victoria Monterey School	September, 1965	stiff brown clay
F18	Courtenay Lake Trail Jr. Secondary School	September, 1967	sandy loam
F19	Cumberland Cumberland Junior Secondary School	September, 1967	sandstone
F20	Victoria McCauley School	September, 1965	stiff brown clay
F21	Victoria Margaret Jenkins School	September, 1965	stiff brown clay
F22	Comox St. Joseph's Hospital	August, 1967	glacial till
F23	Victoria Tolmie School	September, 1965	stiff brown clay
F24	Comox Goose Spit	November, 1968	sand

U – United Engineering seismoscopes.

F – Fairey Aviation seismoscopes.

Record of the earthquake of April 29, 1965. The Fairey accelerograph at the University of Victoria was triggered by this Seattle earthquake. The epicentre was 170 kms. from this site; the magnitude of the earthquake was 6.5 and the depth of focus was 57 kms. Intensities in Victoria varied from IV to V. A copy of the record is shown in Figure 13. Maximum acceleration is approximately 0.03 g. Dr. S. Cherry, at the University of British Columbia, produced the Fourier spectra curve for us which is shown in Figure 14. The response curve peaks at frequencies of 0.2 Hz and 3 Hz.

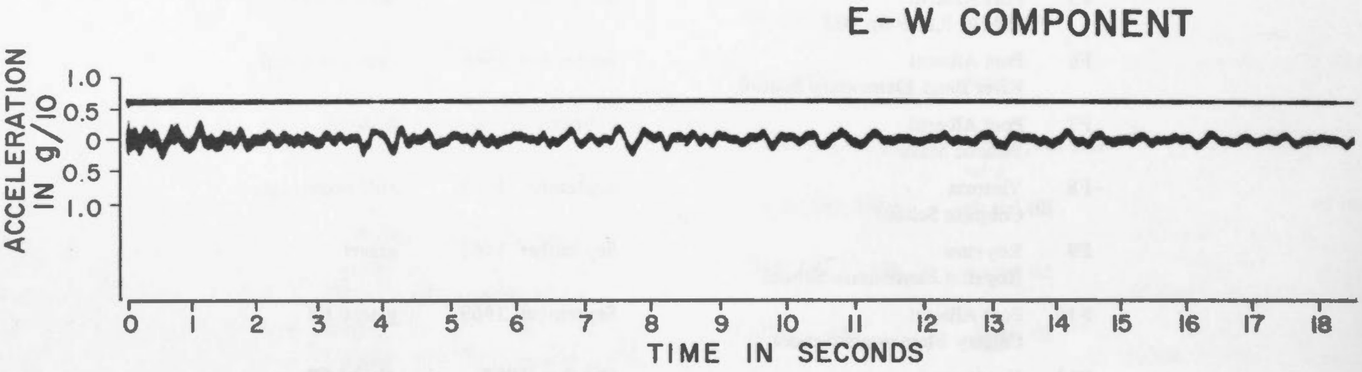

Figure 13. Record of April 29, 1965 earthquake.

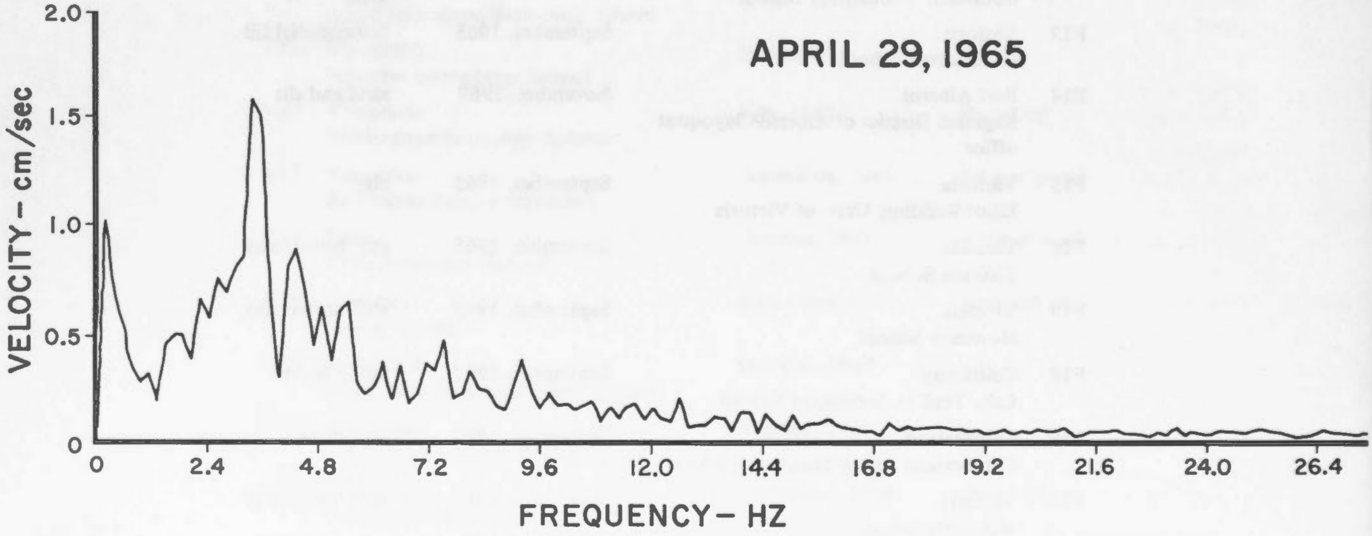

Figure 14. Spectra of April 29, 1965 earthquake.

Acknowledgments

The United States Coast and Geodetic Survey generously loaned one of their instruments for copying in order to get the program started. William K. Cloud of their San Francisco office has been most helpful. A. Camelford of the former Sidney office of Fairey Aviation is responsible for much of the effort to make the first Canadian instrument. There have been many suggestions from private individuals concerning engineering and geological details of sites. Those who have been especially helpful are H. Nasmith of R.C Thurber and Associates of Victoria, and Reid, Jones and Christofersen of Vancouver. Dr. S. Cherry of the Civil Engineering Department, U.B.C and D.A. Matheson of the Vancouver City Building Department have made many suggestions concerning sites in greater Vancouver.

The following organizations have permitted the installation of instruments at their respective sites, and have been very helpful in supplying many details of their structures:

University of Victoria and Public Works Dept. of B.C. – Elliot Building.

Public Works Department of British Columbia – Law Courts in Victoria.

Canadian Pacific Hotels – bus depot in Victoria.

School Board of District 61 – Greater Victoria.

Cowichan District Hospital – Duncan.

MacMillan, Bloedell, and Powell River Company – Alberni.

School Board of District 70 – Alberni.

St. Joseph's Hospital – Comox.

School Board of District 71 – Courtenay.

B.C. Hydro and Power Authority – Ladore Dam and Administration Building.

Department of Transport – Airport Manager – Sandspit.

Columbia Cellulose – Prince Rupert.

School Board of District 39 – Vancouver.

School Board of District 38 – Richmond.

School Board of District 37 – Delta.

School Board of District 44 – North Vancouver.

Greater Vancouver Water District.

University of British Columbia.

Department of Highways of British Columbia.

Department of National Defence – H.M.C.S. Quadra.

City of Port Alberni – Regional District of Alberni-Clayoquot Office.

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