A SURVEY OF THE CANADIAN STRONG MOTION SEISMOGRAPH NETWORK

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ABSTRACT

At the end of 1974 there were forty-five accelerographs and seventy-five seismoscopes deployed in Canada for the purpose of measuring strong earthquake ground motion. The Department of Energy, Mines and Resources and the National Research Council have installed most of the instruments but one quarter of them are privately owned.

About three quarters of the instruments are located near the west coast with the next largest concentration in the St. Lawrence Valley region. There is one instrument in the Arctic. The majority have been deployed to measure ground motion in populated areas but a few have been deployed in areas of higher seismicity remote from population centers. In western Canada particular emphasis has been placed on measuring the response of different soil types and soil depths. The only major structures in the country that have been instrumented are two large dams. More than two thirds of the accelerographs now in place record on seventy millimeter film. Because of the declining cost of accelerographs in recent years the trend has been away from the installation of seismoscopes.

INTRODUCTION

The strong motion seismology instrumentation program in Canada started in 1962 when a strong motion seismograph was borrowed from the United States Coast and Geodetic Survey (USCGS). At that time there were no commercially manufactured strong motion seismographs so tenders were called to manufacture instruments in Canada similar to the USCGS design. The first of these was installed in Victoria in January of 1963. Since that time forty-five accelerographs and eighty-two seismoscopes and other non-powered devices have been installed to measure strong earthquake ground motion. The main purpose of this paper is to present descriptive information on all the accelerograph sites in Canada and to discuss the instrumentation programs presently underway.

INSTRUMENTATION

The strong motion instruments deployed in Canada at the end of 1974 are listed in Table 1. There are two main types. The more complex are the accelerographs which are battery operated, self-triggering devices that record three components of acceleration. The simpler type are seismoscopes which are conical pendulum devices that record the earth's motion with a scriber tracing on smoked glass (Cloud and Hudson 1961). The accelerographs give a time history of ground acceleration and enable an accurate picture of ground motion to be recovered in the band-width from about 25 to 0.1 hertz. Seismoscopes respond only to seismic energy near their natural period which is about three quarters of a second.

Another type of strong motion instrument deployed in Canada is the peak recording accelerograph. This, like the seismoscope, is a lower cost device designed to supplement the regular accelerograph. It records only the maximum acceleration in each of three components and is perhaps best suited for deployment near regular accelerographs in structural response studies, and has been widely used in the instrumentation of nuclear power facilities in the United States. Since few structures in Canada have been instrumented to study their structural response, few peak recording accelerographs have been deployed. The only ones presently in place are in the Mica Creek dam in British Columbia.

Strong motion instrument networks in both eastern and western Canada started as mixed groups of accelerographs and seismoscopes. The seismoscopes were deployed at the accelerograph sites as backup instruments and in nearby areas as a low cost supplement to the accelerographs. However, the cost of accelerographs has dropped from about $4000 in the early

1960's to less than $1500, while the cost of seismoscopes has almost doubled. This has changed the cost ratio between the two types of instruments from about thirty to one in the early 1960's to about six to one at the present time. Thus, few seismoscopes have been deployed in recent years because of the far greater information potential of the accelerographs.

The first accelerographs installed were built by Fairey Aviation of Canada and were similar to the USCGS design (Rogers et. al. 1970). A total of eleven were constructed. Shortly after this construction program began, the first commercially designed accelerograph, the AR-240, appeared on the market (Halverson 1965). It was more compact and featured numerous engineering and electronic improvements which gave higher reliability and allowed more flexibility in choice of sites. Twelve of these instruments were purchased for installation in Canada before they went out of production in the late 1960's. Two newer instruments, the RFT-250 and the SMA-1 have replaced the AR-240. Both are compact, use seventy millimeter film instead of twelve inch paper as the recording medium, and have numerous engineering advances making them more reliable and more accurate (Halverson 1973). Two thirds of the accelerographs now deployed in Canada are the film recording type. Most of the older Fairey instruments have been replaced by these modern instruments and the remaining ones are scheduled to be phased out.

There are other strong motion instruments on the market such as magnetic tape recording accelerographs, force monitors and response spectrum recorders but thus far, non have been deployed in Canada.

DISCUSSION OF INSTRUMENTATION PROGRAMS

The two Canadian agencies that have been active in installing strong motion instruments are the Seismology Division of the Earth Physics Branch, Department of Energy, Mines and Resources (EMR) in western Canada and the Noise and Vibration Section of the Division of Building Research, National Research Council (NRC) in eastern Canada. Network and instrument servicing headquarters are in Victoria (EMR) and Ottawa (NRC). Both groups have concentrated on obtaining basic ground motion rather than structural response, and thus have deployed most of their instruments in one or two storey buildings or in small huts. Most of the sites are in public buildings but a few instruments are installed on private property. Details of all the accelerograph sites instrumented at the end of 1974 are listed in Tables 2 and 3.

Since the beginning of the instrumentation programs both EMR and NRC have encouraged others to install strong motion instruments but it has only been in the past few years that any other agencies have purchased instruments (see Figure 1). Two factors partially responsible for the increased interest in strong motion instruments are the wide publicity given to the damage and to the strong motion records from the 1971 San Fernando earthquake and the decreasing price of accelerographs in recent years.

Both EMR and NRC have agreed to assist with installation and servicing of instruments of other agencies as far as funds permit and almost all of the instruments installed to date are serviced either by EMR or NRC personnel. Servicing is a very large part of the expense of a strong motion network since each accelerograph should be checked several times a year and seismoscopes at least once a year. The sixteen percent loss rate of accelerograms during the 1971 San Fernando earthquake was almost entirely attributed to inadequate servicing (Maley 1971). To reduce the servicing costs in western Canada a monitoring package developed by EMR is installed on most private accelerographs and on those at sites remote from headquarters. The package enables local non-technical personnel to make simple diagnostic tests thus cutting down the number of servicing trips required by headquarters technical staff.

The locations of the accelerographs in Canada are shown in Figure 2 superimposed on the seismic zoning map (Whitham et. al. 1970). Most of the instruments are located in the Zone 3 sections of eastern and western Canada but some have been located in Zones 1 and 2. One instrument is located in Zone 3 in the Arctic. The concentration of eight instruments shown in the Zone 3 region of eastern Canada are the instruments at the Manicouagan 3 and 5 dams. Likewise, the concentration of three instruments shown in the Zone 1 region of western Canada are those installed at the Mica Creek dam. The heaviest concentration of instruments, which is around the Strait of Georgia in south-western Canada, is shown in larger scale in Figure 3. Seismoscope sites have also been included in the figure to show their distribution.

Most of the strong motion instruments in Canada have been installed with at least one of four earthquake engineering problems in mind: the defining of appropriate design ground motion spectra for Canada; the defining of appropriate seismic wave attenuation curves for Canada; the study of the behavior of particular and typical Canadian soil situations during strong shaking; and the dynamic study of certain structures.

The first problem, the collecting of information to define design ground motion spectra is the principal objective of both the EMR and NRC programs. Most response spectra used today are based on data collected from California earthquakes. Both eastern Canada and the Vancouver Island region in western Canada experience fewer earthquakes than California which may reflect different stress conditions in these areas. This in turn may influence the distribution of energy in the earthquake spectra. At present most instruments are deployed in the more populated areas where the information gained can be most directly applied. This should continue to be the main emphasis but more instruments should be deployed in remote areas for the purpose of increasing the probability of recording large earthquakes. Preferred sites for instruments deployed for this purpose are bedrock locations away from large structures and unusual geological and topographical situations.

Observations of intensity show that the attenuation of strong earthquake motion as a function of epicentral distance is markedly different in eastern and western Canada (Milne and Davenport 1969). Strong motion data acquired in Canada would greatly assist the more accurate definition of these relationships. Ideally, instruments located on bedrock or firm soil with spacings of a few tens of kilometers over a wide area are needed to provide an adequate density of recordings. The instrument network in the southern Strait of Georgia region is beginning to approach this, but the instruments in the rest of the country are still too widely spaced.

The soil response problem is a complex one which is being studied in several countries using many different methods, and there is a wide and contraversial literature on the subject. Actual recordings of strong earthquake motion on sites with well known properties will do a great deal to clear up some of the difficulties. In western Canada more than half of the EMR accelerographs and most of the seismoscopes are deployed on soil sites (Milne and Rogers 1972). For example, the network of instruments radiating out from Vancouver in Figure 3 traverses glacial, glacial marine and alluvial deposits ranging in depth from a few meters up to several hundred meters. Sites have been suitably chosen to parallel population and development trends and a skeleton network of reference instruments is located on bedrock to aid in interpretation. Most instruments are sited in light buildings to minimize building and ground interaction.

Programs to study structural response account for the smallest number of instruments. This type of study is limited to instrumenting two large dams: Mica Creek in the west and Manicouagan 5 in the east.

Three accelerograph records and twelve seismoscope records have now been obtained in Canada from three different earthquakes. All records are from western Canada and are at a very low level of acceleration. A preliminary analysis of the data was presented at the First Canadian Conference on Earthquake Engineering (Milne and Rogers 1971) and a more complete analysis has since been done at Victoria Geophysical Observatory where digitizing and processing facilities for strong motion records are maintained. This is a small data return, but the past decade has been one of the quietest in Canadian seismic history.

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REFERENCES

CLOUD, W.K. AND HUDSON, D.E. 1961. A simplified instrument for recording strong motion earthquakes. Bull. Seism. Soc. Amer., 51, pp 159-174.

HALVERSON, H.T. 1965. The strong motion seismograph. Proc. Third World Conference on Earthquake Engineering, Wellington, Vol. 1, pp 75-92.

HALVERSON, H.T. 1973. A technical review of recent strong motion accelerographs, Proc. Fifth World Conference on Earthquake Engineering, Rome, Vol. 1, pp 1046-1055.

MALEY, R.P. 1971. A statistical summary of accelerograph performance during the earthquake of February 9, 1971, in Strong-Motion Instrumental Data on the San Fernando Earthquake of Feb. 9, 1971. D.E. Hudson, Editor, pp 54-71.

MILNE, W.G. AND DAVENPORT, A.G. 1969. Distribution of earthquake risk in Canada. Bull. Seism. Soc. Amer., 59, pp 729-854.

MILNE, W.G. AND ROGERS, G.C. 1971. Earthquake engineering research at Victoria Geophysical Observatory. Proc. First Canadian Conference on Earthquake Engineering, U.B.C., Vancouver, pp 27-37.

MILNE, W.G. AND ROGERS, G.C. 1972. Evaluation of earthquake risk in Canada. Proc. of International Conference on Microzonation, Seattle, Vol. 1, pp 217-230.

ROGERS, G.C., MILNE, W.G. AND BONE, M.N. 1970. The strong motion seismograph network in western Canada, 1970. Pub. Earth Physics Branch, Vol. 41, pp 15-29.

WHITHAM, K., MILNE, W.G. AND SMITH, W.E.T. 1970. The new seismic zoning map for Canada - 1970 edition. The Can. Underwriter, June, 1970. 8 p.

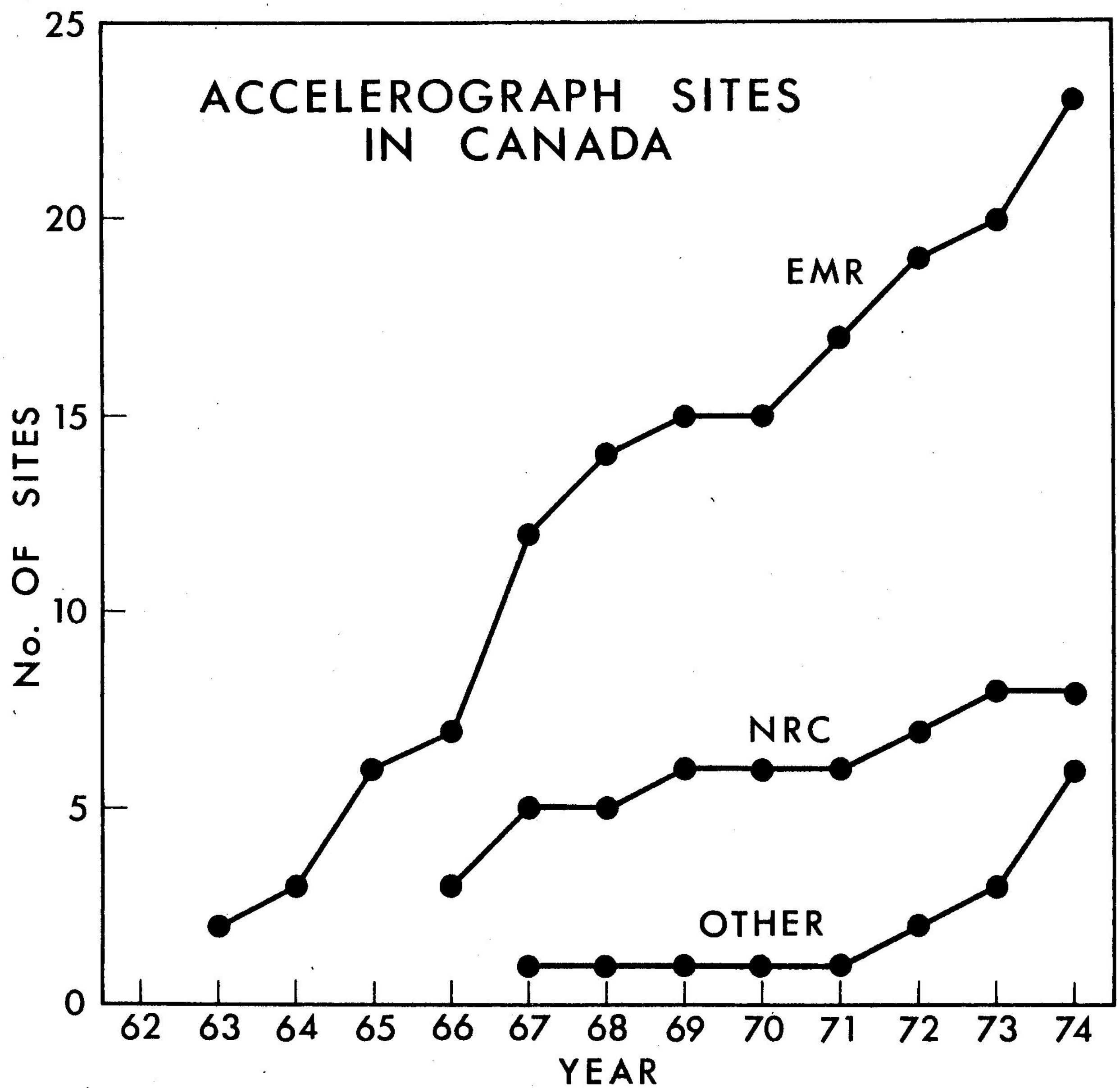

FIG 1 THE NUMBER OF ACCELEROGRAPH SITES IN CANADA EACH YEAR. SOME SITES HAVE MORE THAN ONE ACCELEROGRAPH. INSTRUMENTS ARE OWNED BY THE DEPARTMENT OF ENERGY, MINES AND RESOURCES (EMR), THE NATIONAL RESEARCH COUNCIL (NRC) AND OTHERS LISTED IN TABLE 4.

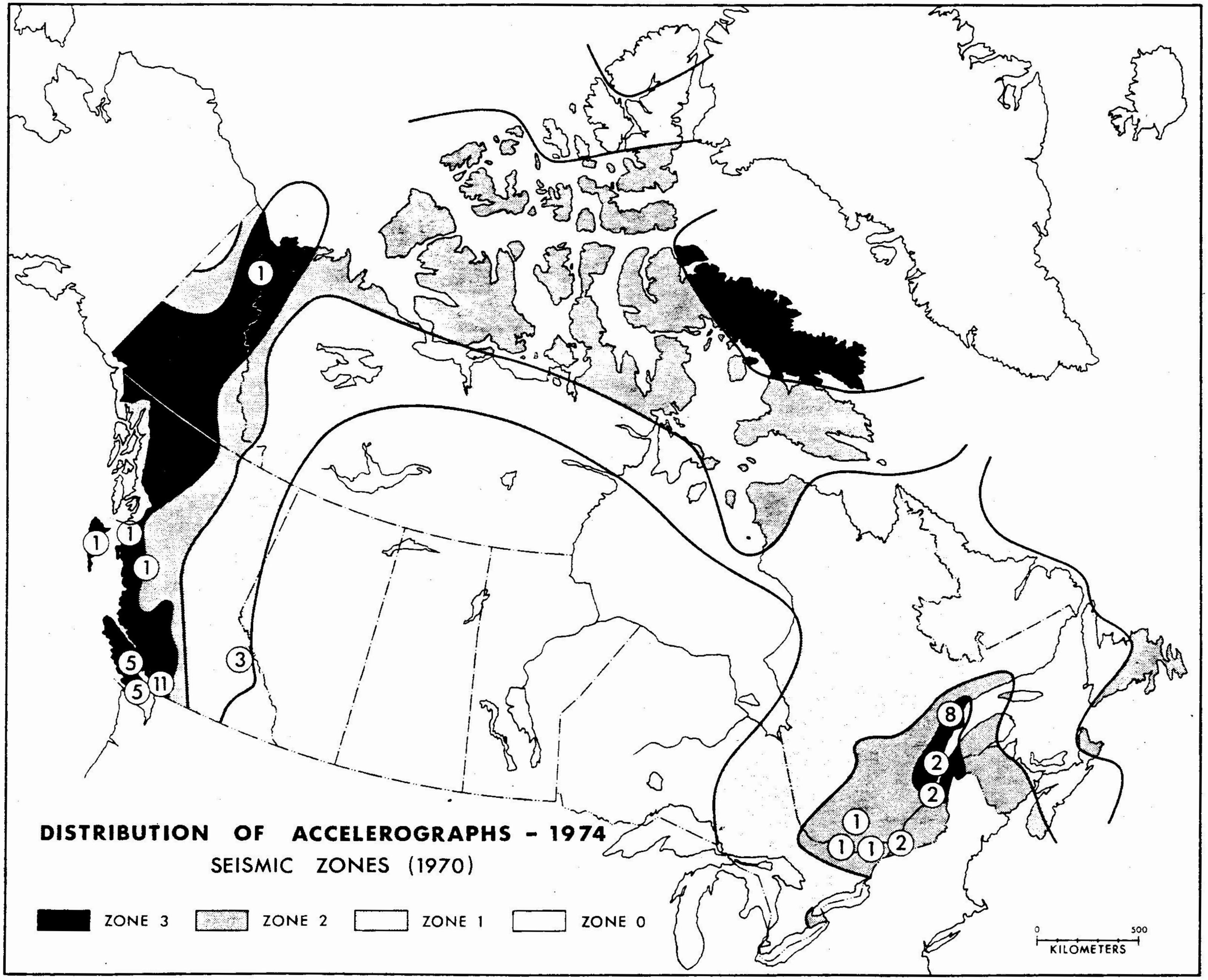

FIG. 2 NUMBERS IN CIRCLES ARE THE NUMBER OF ACCELEROGRAPHS IN THAT AREA AT THE END OF 1974. THEY ARE SHOWN SUPERIMPOSED ON CANADA'S SEISMIC ZONING MAP (1970 EDITION).

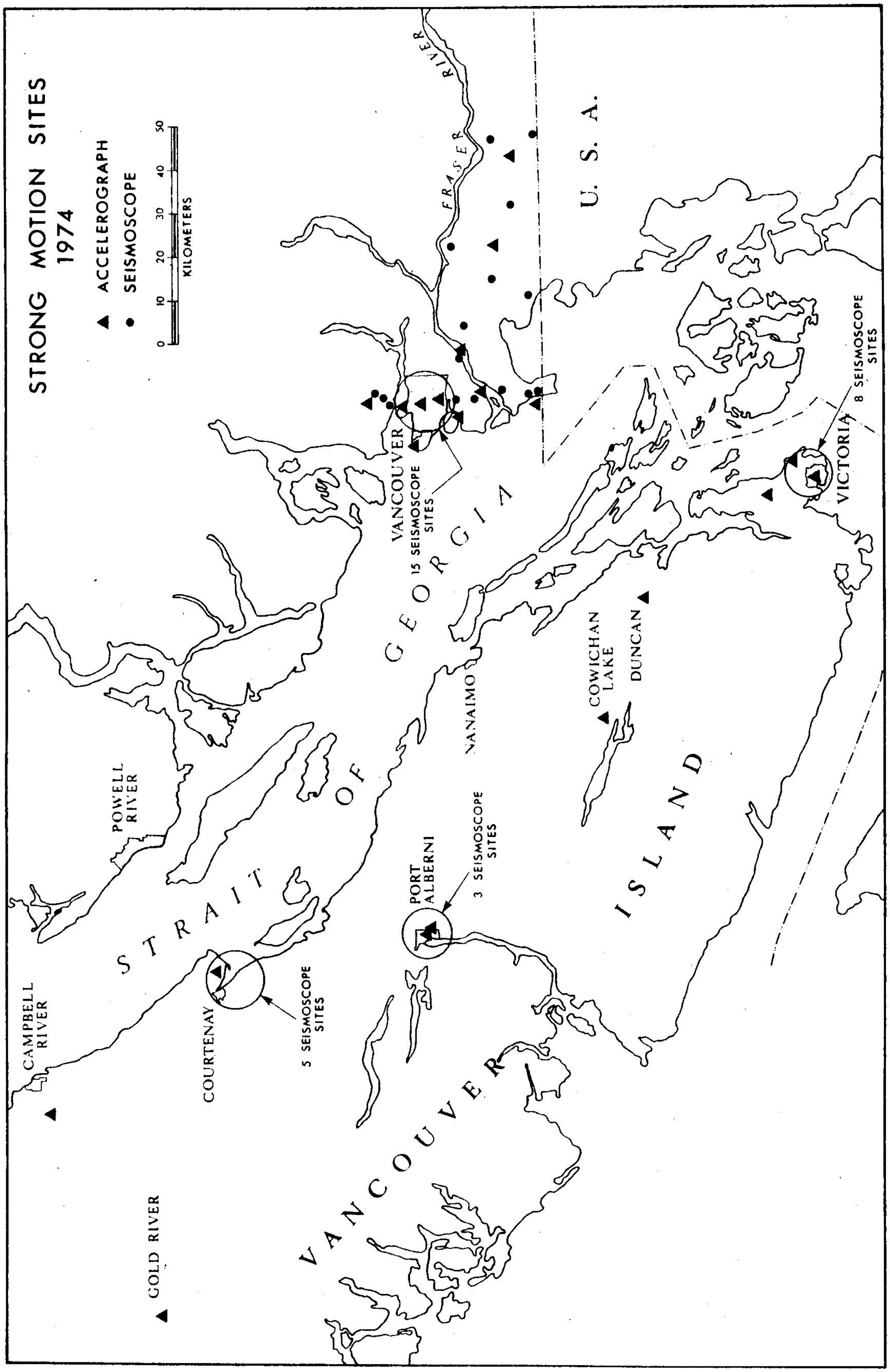

FIG. 3 ACCELEROGRAPHS AND SEISMOSCOPES DEPLOYED AROUND THE STRAIT OF GEORGIA IN WESTERN CANADA AT THE END OF 1974. MOST ACCELEROGRAPH SITES WITHIN SEISMOSCOPE NETWORKS ALSO ARE INSTRUMENTED WITH SEISMOSCOPES.

TABLE 1 STRONG MOTION INSTRUMENTS DEPLOYED IN CANADA - 1974

INSTRUMENT	DESCRIPTION	NUMBER
FAIREY	A self triggering three component accelerograph similar to the USCGS design. Records on 12 inch wide photographic paper. Manufactured by Fairey Aviation of Canada Ltd. No longer in production.	4
AR-240	A self triggering three component accelerograph. Records on 12 inch wide photographic paper. Manufactured by Teledyne-Geotech. No longer in production.	11
RFT-250	A self triggering three component accelerograph. Records on 70 mm film. Manufactured by Teledyne-Geotech. Priced about $1500.	5
SMA-1	A self triggering three component accelerograph. Records on 70 mm film. Manufactured by Kinemetrics. Priced about $1500.	25
SEISMOSCOPE	A non powered conical pendulum having a period near 0.75 seconds and damping near 0.1 critical. A scriber marks on smoked glass. There have been several manufacturers but currently marketed by Kinemetrics. Priced about $250.	75
PEAK RECORDING ACCELEROGRAPH	A non powered three component peak recording accelerograph. Records on chips of magnetic tape. Manufactured by Teledyne-Geotech. Priced about $250.	7

TABLE 2 ACCELEROGRAPH SITES IN WESTERN CANADA

LOCATION	DATE	COORDINATES	INSTRUMENT	OWNER	BUILDING	FOUNDATION
Victoria Law Courts Building	1/63	48.42 123.36	Fairey	EMR	Five storey reinforced concrete. Instrument on concrete basement floor slab.	bedrock
Vancouver B.C. Hydro Building	7/63	49.28 123.12	Fairey	EMR	Twenty-two storey reinforced concrete. Instrument on concrete floor in lower basement.	bedrock
Victoria University of Victoria	9/64	48.46 123.31	Fairey	EMR	Three storey reinforced concrete. Part of foundation is reinforced concrete footings and part is 'Franki' piles. Instrument on concrete pier on basement floor slab.	clay
Port Alberni Pulp & Paper Mill	7/65	49.24 124.81	SMA-1	EMR	Two storey reinforced concrete. Instrument on concrete floor over a stiff cellular substructure built on wood piles.	sand and grave
;ampbell River .adore Dam	7/65	50.01 125.39	Fairey	EMR	Concrete gravity dam 140 feet high. Instrument on concrete floor near base of dam.	bedrock
/ancouver Jniversity of B.C.	8/65	49.26 123.25	AR-240	EMR	Two storey building. Instrument on concrete floor slab.	sand and grave
;omox ;t. Joseph's Hospital	8/67	49.67 124.94	SMA-1	EMR	Four storey reinforced concrete. Instrument on concrete pier at ground level.	glacial till
ichmond lassey Tunnel	9/67	49.12 123.08	AR-240	EMR	Reinforced concrete tunnel in partial trench dredged in river bottom. Instrument on concrete floor about 50 feet below ground surface.	sand and silt
;andspit .irport Terminal Bldg.	9/67	53.25 131.81	SMA-1	EMR	One storey wood frame. Instrument on concrete slab at ground level.	sandy gravel
)uncan ;owichan Hospital	10/67	48.79 123.72	SMA-1	EMR	Varying from one to six storeys, reinforced concrete. Instrument on pier on concrete footing at basement level.	sand
orth Vancouver leveland Dam	1/68	49.36 123.11	AR-240	EMR	Concrete gravity dam 300 feet high. Instrument at end of gallery on concrete floor directly above bedrock.	bedrock
elta oberts Bank Seaport	11/69	49.02 123.16	RFT-250	EMR	In small hut. Instrument on concrete slab.	silt fill

TABLE 2 ACCELEROGRAPH SITES IN WESTERN CANADA (continued)

LOCATION	DATE	COORDINATES	INSTRUMENT	OWNER	BUILDING	FOUNDATION
Langley Municipal Hall	3/71	49.10 122.62	RFT-250	EMR	One storey wood frame. Instrument on reinforced concrete basement floor slab.	clay
Matsqui Municipal Hall	3/71	49.05 122.32	RFT-250	EMR	Two storey reinforced concrete. Instrument on concrete floor slab.	sand and grave
Fort McPherson R.C.M.P. Residence	6/71	67.5 134.9	SMA-1	EMR	One storey wood frame. Instrument on concrete basement floor slab.	permafrost
Mica Creek Mica Creek Dam	5/72	52.0 118.5	SMA-1 (3 units)	BCHPA	Three locations in 800 foot high earth fill dam.	bedrock
Vancouver Manitoba Works Yard	12/72	49.21 123.11	RFT-250	EMR	Two storey steel frame, masonry walls. Instrument on concrete floor slab over pile foundation.	alluvium
Delta Annacis Island	12/72	49.18 122.93	RFT-250	EMR	One storey. Instrument on concrete floor slab.	alluvium
Lake Cowichan Satellite Station	3/73	48.8 124.2	SMA-1	COTC	One storey structure next to earth station antenna. Instrument on concrete floor slab.	bedrock
Gold River Public Safety Building	8/73	49.78 126.04	SMA-1	EMR	One storey reinforced concrete block. Instrument on concrete floor slab.	bedrock
Victoria Geophysical Observatory	5/74	48.52 123.42	SMA-1	EMR	Three storey, part wood frame and part masonry. Instrument in seismic vault on main floor level.	bedrock
Vancouver Bloedel Conservatory	5/74	49.24 123.11	AR-240	EMR	Triodetic dome structure 50 feet high and 140 feet in diameter. Instrument on concrete foundation.	bedrock
Richmond Brighouse Library	5/74	49.16 123.14	AR-240	EMR	One storey reinforced masonry. Instrument on concrete basement floor slab.	alluvium
Prince Rupert Airport Terminal Bldg.	5/74	54.29 130.44	SMA-1	EMR	One storey heavy wood portal frames and purlins with masonry walls. Instrument on concrete floor slab.	bedrock
Port Alberni Maquinna Elementary	11/74	49.23 124.79	SMA-1	EMR	One storey wood frame. Instrument on concrete basement floor slab.	bedrock
Kemano Switching Station	1/75	53.56 127.93	SMA-1	ALCAN	One storey masonry construction. Instrument on concrete floor slab.	gravel

TABLE 3 ACCELEROGRAPH SITES IN EASTERN CANADA

LOCATION	DATE	COORDINATES*	INSTRUMENT	OWNER	BUILDING	FOUNDATION
St. Fereol Seismograph Station	1/66	47.12N 70.85W	AR-240	NRC	In underground seismic vault. Instrument on concrete pier.	bedrock
Ottawa N.R.C. Building	3/66	45.45 75.61	SMA-1	NRC	One-storey steel frame, masonry walls. Instrument on concrete basement floor slab.	bedrock
Montreal CIL Building	8/66	45.50 73.58	AR-240	NRC	32 storey steel frame, curtain wall, four basement storeys. Instrument on bottom basement floor slab.	bedrock
Chalk River Reactor Building	4/67	46.05 77.38	AR-240	AECL	Steel frame poured concrete reactor building. Instrument on concrete basement floor slab.	bedrock
Quebec Laval University	6/67	46.78 71.28	AR-240	NRC	Three storey reinforced concrete. Instrument on concrete pier on basement floor slab.	bedrock
La Malbaie Post Office	9/67	47.68 70.15	AR-240	NRC	One storey steel frame masonry walls. Instrument on concrete pier on basement floor slab.	bedrock
St. Pascal Post Office	10/69	47.52 69.80	AR-240	NRC	One storey reinforced concrete and, masonry. Instrument on concrete basement floor slab.	bedrock
Mont Laurier Mercier Dam	8/72	46.67 75.98	SMA-1	NRC	Small shack. Instrument on concrete slab.	bedrock
Montreal Brebeuf College	12/73	45.53 73.61	SMA-1	NRC	Four-storey steel frame curtain wall, poured concrete. Instrument in seismic vault in basement.	bedrock
Baie Comeau Manicouagan 5 Dam	6/74	50.67 68.73	SMA-1 (6 units)	QHEC	Several locations in reinforced concrete dam of multiarch construction. Instruments vary from bedrock to 600 ft level in dam.	bedrock
Baie Comeau Manicouagan 3 Dam	9/74	49.77 68.62	SMA-1 (2 units)	QHEC	One in small hut on concrete slab. One in instrument room in rock tunnel. Instrument on concrete pier.	bedrock

* Coordinates supplied in degrees and minutes have been converted to the nearest 0.01 of a degree.

TABLE 4 STRONG MOTION INSTRUMENT OWNERSHIP - 1974

ABBREVIATION	OWNER	ACCELEROGRAPHS	SEISMOSCOPES	PEAK RECORDERS
EMR	Department of Energy Mines and Resources	23	63	-
NRC	National Research Council	8	2	-
QHEC	Quebec Hydro-Electric Commission	8	4	-
BCHPA	British Columbia Hydro and Power Authority	3	2	7
AECL	Atomic Energy of Canada Limited	1	4	-
COTC	Canadian Overseas Telecommunications Corporation	1	-	-
ALCAN	Aluminum Company of Canada	1	-	-