EARTHQUAKE ENGINEERING RESEARCH AT VICTORIA GEOPHYSICAL OBSERVATORY

by

W.G. Milne[I] and G.C. Rogers[I]

ABSTRACT

Earthquake engineering activities of the Earth Physics Branch at Victoria Geophysical Observatory have been concentrated in two fields to date, seismic risk and strong motion seismology. The earthquake risk studies have resulted in the production of a new seismic zoning map for Canada. The strong motion program has been mainly concerned with the establishment of a network of strong motion seismographs in populated regions along the seismically active west coast of Canada. The network presently consists of 17 accelerographs and 59 seismoscopes. Three earthquakes have been recorded on strong motion instruments since the first accelerograph was installed in 1963. Fourier spectra and velocity response spectra have been calculated for each of these earthquakes.

INTRODUCTION

The role of the seismologist in earthquake engineering research is to provide the engineer with information about earthquakes in a suitable form so that it can be used in building design and research into aseismic structures. At Victoria Geophysical Observatory seismologists of the Earth Physics Branch have been carrying on research along two avenues for this purpose. The first has been a thorough study of past earthquakes to estimate the probability of a damaging level of acceleration at any location in Canada (1, 2). The second has been the establishment of a network of strong motion seismographs in western Canada to make on the spot measurements of potentially damaging earthquake waves (3).

The study of past earthquakes has dealt not only with the locations, sizes and numbers of earthquakes, but with an examination of their effects as well. The cumulation of this research has been the production of a new seismic zoning map for Canada (4) adopted in the National Building Code (1970) (fig. 1). This map classifies every part of Canada into one of four risk zones according to the maximum acceleration expected in a 100 year period. The method used to calculate the map does not preclude damaging earthquake accelerations anywhere in Canada, but shows the areas where they are most probable based on an analysis of earthquake observations since the turn of the century. In terms of geologic time, such a period of observation is extremely short and there is therefore some uncertainty as to whether this observed seismicity represents the total expression of the tectonic forces at work. However, in light of the observations available, the map does represent the best current estimate of seismic risk in Canada.

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The map provides the design engineer with a number which, through regulations in the National Building Code, may be used in the static design of earthquake resistant structures. In addition, seismic risk calculations can be made for any site in Canada to provide more detailed information than such a contour map allows. However, simply knowing the peak acceleration to be expected in a region is not sufficient if one is designing an earthquake resistant structure. Two more vital pieces of information are necessary. One is the effect of local variations in the soil response to earthquake waves. The peak acceleration figures provided by the computations are applicable to the average soil of a region, and they will increase appreciably on poorer soil, and decrease on stiffer soils, having the lowest value on rock. The other piece of information missing is the dynamic nature of the accelerations involved: the frequencies at which the accelerations take place, and the duration of the strong shaking. These are extremely complex problems depending on the size of the earthquake, the source mechanism, the volume of the focal region, the distance from the epicentre, the regional structure of the earth's crust, and local soil conditions. It is very difficult to reliably extrapolate such information from other earthquake zones. Thus, the need for microzoning at the local level and the desire for a dynamic picture of potentially damaging earthquake waves have been the main reasons for initiating strong motion research at Victoria Geophysical Observatory. A more accurate relation between actual ground acceleration and intensity values derived from observations of damage is also an aim of this program.

THE DISTRIBUTION OF STRONG MOTION INSTRUMENTS

The network of strong motion instruments in operation May, 1971 consists of 17 accelerographs and 59 seismoscopes. The accelerographs record three components of ground acceleration whenever a sufficiently large horizontal motion occurs to trigger the recording mechanism. The seismoscopes are pendulum devices designed to have a natural period and damping similar to an 8-10 story building (5) (period, 3/4 second; damping, 10% critical). They record by a metal scriber marking on a smoked glass. Their information potential is more limited than the accelerographs but they can be more widely distributed because of their much lower cost. Detailed descriptions of the instruments and their locations have been reported in a description of the network published by the Earth Physics Branch (3).

The distribution of the accelerographs (fig. 2) is a compromise between nearness to past epicentres of major earthquakes (fig. 3), and nearness to present population centres where the information gained can be more directly applied. In four regions of British Columbia (lower Fraser Valley, Victoria, Alberni, and Courtney) seismoscopes and accelerographs are combined in networks to study soil response. Every attempt is made to locate instruments where the most detailed soil testing has been done. The seismoscopes are located on differing soil types and one is placed next to each accelerograph. In this way, the record obtained by the accelerograph can be extrapolated to each seismoscope location by comparing relative amplitudes on the smoked glass records. In doing this it must be assumed that the input acceleration has the same characteristics at each site over the period range of interest. This is not necessarily a valid assumption but the instruments have been placed close together to minimize distance variation, and investigations are currently being contemplated to study the variation of amplitude with frequency at the strong motion sites.

The actual factors taken into consideration in distributing the instruments are illustrated for the case of the lower Fraser Valley array (fig. 4) in figures 5 through 7. The probability of obtaining a record at all is first considered by interpreting the past seismicity in terms of likely accelerations to be obtained in a 100 year period (fig. 5). The distribution of soil types is then considered (fig. 6) so as to obtain records from as many different soil conditions as possible. Finally, the proximity of major structures and proposed development is considered (fig. 7), for it is desired to have the instruments located near enough to some major construction so that damage or non damage can be assessed in terms of a measured input of ground acceleration. The Fraser Valley is unique in that it has such a wide variety of soil types and soil depths and is sufficiently populated that major structures exist on almost every type

RECORDS OBTAINED TO DATE

Since the installation of the first accelerograph in 1963 three earthquakes have been recorded by instruments of the network (fig. 20). The Z, T and L components (II) on the paper chart records from the accelerographs were digitized at equal intervals on a digitizer similar to that described by Wickens and Kollar (6). Fourier spectra were calculated by the fast fourier transform method, and the velocity response spectra (7)(Sv) were calculated with a computer program developed at the California Institute of Technology (8). All of the instruments were triggered by a maximum acceleration in the S wave group, and thus the spectra shown here lack a P wave contribution. It is suspected that the small increase at longer periods in the spectra does not represent earthquake energy, but is due to slight misalignment of the accelerogram in the digitizer. The parabolic base line correction to correct this, described by Nigam and Jennings (8), was not used in calculating these response spectra.

Seattle Earthquake - April 29, 1965 (Magnitude 6.5)

This earthquake was centred in the Puget Sound region, just south of Seattle, and caused twelve and one half million dollars damage in the State of Washington. It was felt throughout the Victoria region with maximum intensity of VI reported. One accelerograph located on the University of Victoria campus was triggered, but another located on bedrock in the Law Courts building in downtown Victoria was not. In Vancouver where the intensity was IV, neither of the two accelerographs in place in 1965 was triggered. There were no seismoscopes in either city at that time.

The first thirteen seconds of each component of acceleration was digitized at the rate of 130 readings per second. The accelerograms along with the calculated fourier spectra and velocity response spectra are shown in figures 8, 9 and 10. There is proportionally much more energy in the higher frequencies than is seen in the majority of published strong motion spectra

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II The T and L labels by which the accelerograms are identified refer to the transverse and longitudinal accelerometers with respect to the front of the recording instrument. Geographic orientations of these accelerometers and the azimuths to the earthquake epicentres are given with the figures.

(Note the spectra of the Bellingham earthquake recorded on the same site, figures 11 and 12.). A high peak of energy below 3/4 of a second is not uncommon, but such a lack of energy at longer periods is an unusual feature. Part of this shift of energy to the higher frequencies could be due to the deeper focal depth of the Seattle earthquake (60 km) inhibiting the production of surface waves, but a very rich high frequency content is a consistant property of Victoria seismograms of the small deeper focus earthquakes in the Puget Sound region.

Bellingham Earthquake - February 14, 1969 (Magnitude 4.2)

This earthquake was centred in the San Juan Islands between Victoria British Columbia and Bellingham, Washington. The felt intensity reached V in some points of Victoria, but was generally IV or less in Canada. In Victoria, the accelerograph at the university that produced a record during the 1965 earthquake was again triggered, but the one on bedrock was not. In addition, four of the seismoscopes in the area had measurable records. In Vancouver, none of the five accelerographs in place was triggered, but eight seismoscopes had small records. The distribution of the instruments that produced records is shown in figures 13 and 14.

It must be emphasized that the intensities produced by this earthquake are at the lower limit of sensitivity of the strong motion seismographs deployed, particularly the seismoscopes, which are designed to produce useful records at intensity V and above. The errors involved in interpreting small seismoscope records in terms of velocity response are large, but a simple comparison of the maximum amplitudes listed in figure 15 clearly shows a variation in soil response.

The seismoscope record at the bus depot in Victoria had a maximum amplitude of 2.5 mm which was considered large enough to calculate an accurate Sv value. The value, adjusted to 10% critical damping, shows an amplification factor of 1 1/2 times at 3/4 second period over each of the horizontal Sv spectra at the university, 6 km distant. The Sv spectra of the L component of the university accelerograph is shown in figure 16 for comparison. The sites are close enough together that the input signal at the base of the soil can be assumed to have the same character, but only a narrow band near 3/4 of a second period can be reliably compared until the frequency response of each site is understood. Acceleration amplitudes at both of these soil sites are considerably greater than amplitudes at nearby sites on glacial till and rock which produced no measurable record.

The first 10 seconds of the horizontal components recorded on the university accelerograph were digitized at 103 samples per second and the velocity response spectra, fourier spectra, and the original accelerograms are shown in figures 11 and 12. The vertical component was not recorded due to an instrument problem. There is a considerable amount of energy in the period range greater than one second that was not present in the 1965 Seattle earthquake recorded on the same site.

Cape St. James Earthquake - June 24, 1970 (Magnitude 6.5)

This earthquake was located south of Cape St. James which is at the southern tip of the Queen Charlotte Islands. It triggered the accelerograph at Sandspit, 165 km from the epicentre, and was felt throughout the Queen Charlotte Islands, on the mainland, and on the northern tip of Vancouver Island. Due to the sparse development in the area no damage was done, but the intensity probably reached VII in the area near Cape St. James.

Fourteen seconds of each component of the accelerogram from Sandspit were digitized at 64 samples per second. The accelerograms and the fourier spectra and velocity response spectra that have been calculated from them are shown in figures 17, 18 and 19. In comparing these spectra with those from the Seattle earthquake, which had the same magnitude, and was recorded at about the same distance from the epicentre two main differences are apparent (see figure 20 for earthquake details). The first is the deficiency of energy at periods greater than 3/4 of a second in the Seattle earthquake that has already been pointed out. The second is the higher amplitude of the whole Cape St. James spectra. It is generally greater by a factor of two. This is most likely amplification due to the soil properties at Sandspit, as the sensitive seismograph located at the same site also shows extremely large short period microseisms. As the name implies, Sandspit is a deep deposit of beach sands and gravels, while the University of Victoria site is a deep pocket of predominately clay soil.

Discussion

The strong motion program of western Canada is organized mainly to permit the study of the variation in soil response to seismic waves. The data obtained to date from three earthquakes at the threshold of the sensitivity of the instruments deployed indicates that some soils alter the effects of an earthquake by a considerable degree. The type of information on the amplification properties of soils that will be obtained from this program during a larger earthquake is indicated by an example recorded in Victoria during the 1969 Bellingham earthquake (figure 16). It is hoped the information gained will form a basis for future recommendations for microzoning in the regions instrumented, and provide qualitative data on the response of major soil types that can be applied to other areas.

The strong motion network is intended to be a growing system but the aim of it will continue to be the collection of response spectra without the influence of structure and thus the instruments are located in low mass buildings wherever possible. However, the distribution of instruments has been planned so that it will form a basis for instrumentation of buildings and special structures. Records obtained in large buildings would meaningfully show the effect of the structure during an earthquake through comparison of nearby instruments showing input ground motion. The owners or designers of major structures are encouraged to expand upon the basic array of strong motion seismographs that has been set out by instrumenting their buildings. A very real contribution can be made to the knowledge and understanding of the effects of earthquakes by each new instrument which is put into operation. Members of the Seismology Division are prepared to offer advice on instruments and installation, and as far as funds permit include any private instruments in the regular servicing schedule provided the owner agrees to open distribution of any information gained.

All records obtained from the strong motion network will be made available in both paper chart and digitized form to interested parties. The records themselves, their spectra and response spectra, along with seismoscope records will be published by the Earth Physics Branch in a manner similar to the way the preliminary analysis and interpretations of the data collected to date are presented here.

ACKNOWLEDGEMENTS

The authors appreciate the support earthquake engineering research has received from the Department of Energy, Mines and Resources, and the encouragement given by Dr. K. Whitham, Chief, Division of Seismology. Mr. B. Fleet and Mr. M.N. Bone have assisted with the installation of the instruments and the fourier analysis program used was provided by Dr. B. Caner of the Earth Physics Branch. The authors also appreciate the reception they have been accorded by the owners of buildings (private and government) to requests for space for instruments. This is an indication that there is an awareness in the western area of Canada of the danger of damage from nearby earthquakes.

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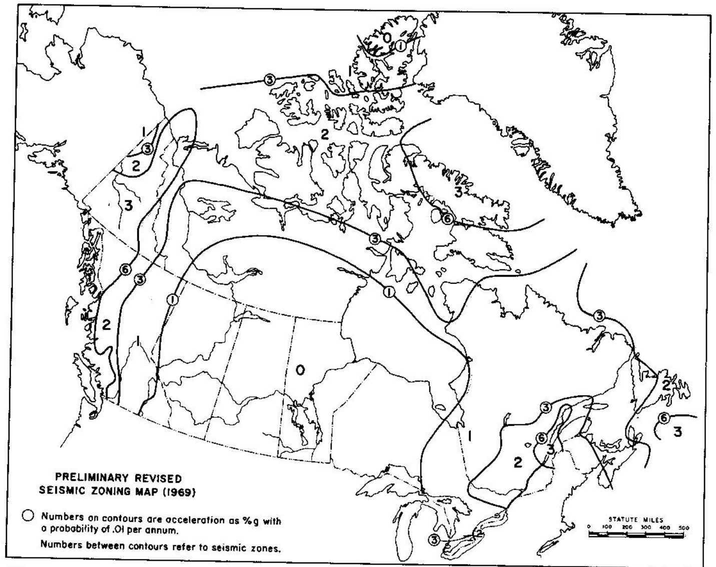

FIG. 1 SEISMIC ZONING MAP FOR CANADA

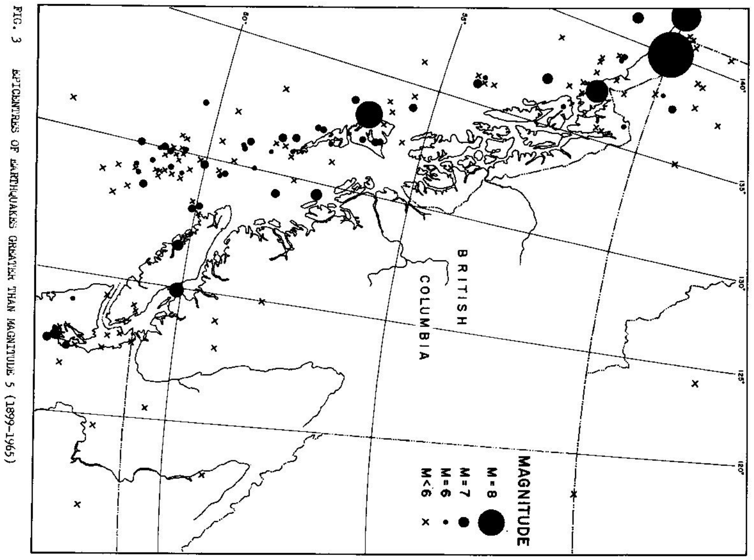

FIG. 3 EPICENTRES OF EARTHQUAKES GREATER THAN MAGNITUDE 5 (1899-1965)

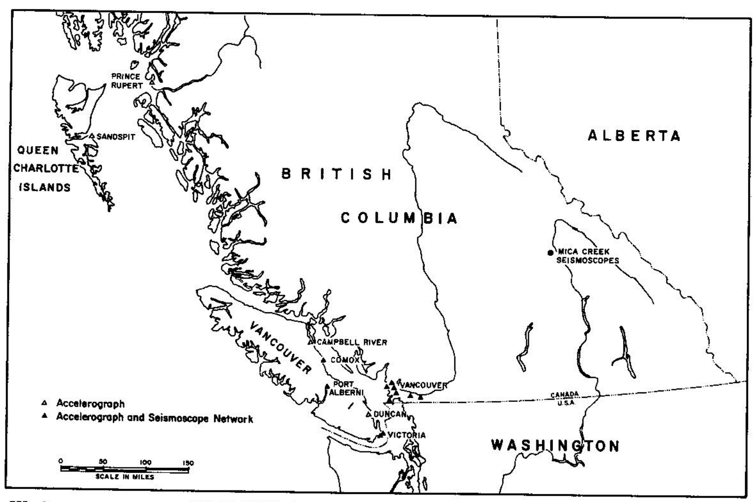

FIG. 2 PRESENT LOCATIONS OF ACCELEROGRAPHS IN BRITISH COLUMBIA

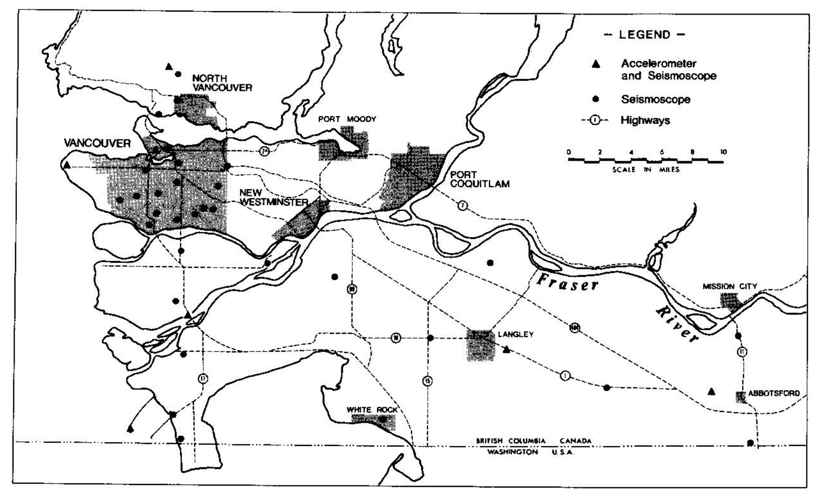

FIG. 4 PRESENT LOCATIONS OF STRONG MOTION INSTRUMENTS IN THE LOWER FRASER VALLEY

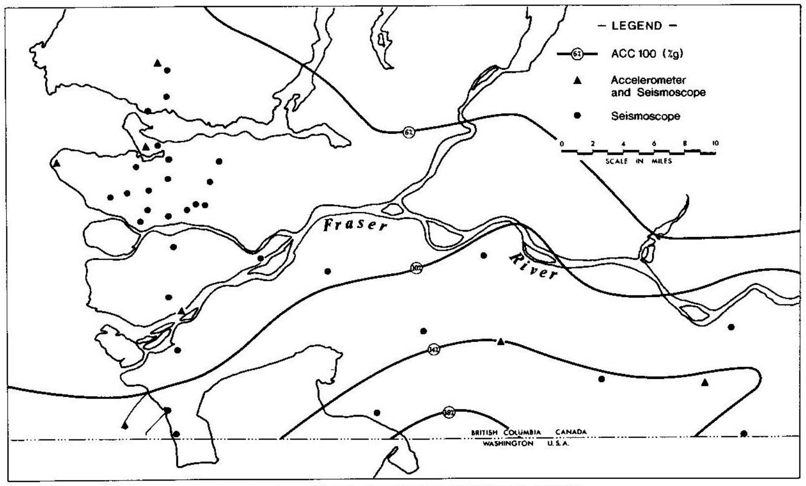

FIG. 5 CONTOURS OF EQUAL VALUES OF MAXIMUM ACCELERATION EXPECTED IN A 100 YEAR PERIOD EXPRESSED AS A PERCENTAGE OF GRAVITY

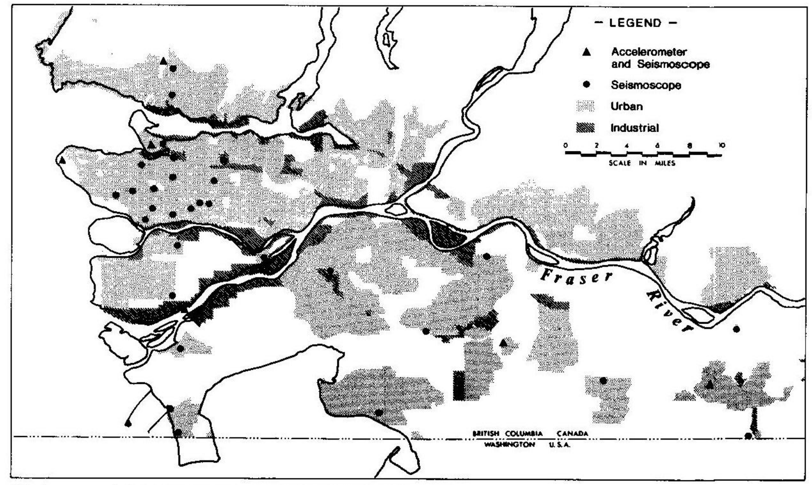

FIG. 7 REGIONAL DEVELOPMENT PLAN FOR THE LOWER FRASER VALLEY. (ADAPTED FROM THE OFFICIAL REGIONAL PLAN OF THE LOWER MAINLAND REGIONAL PLANNING BOARD.)

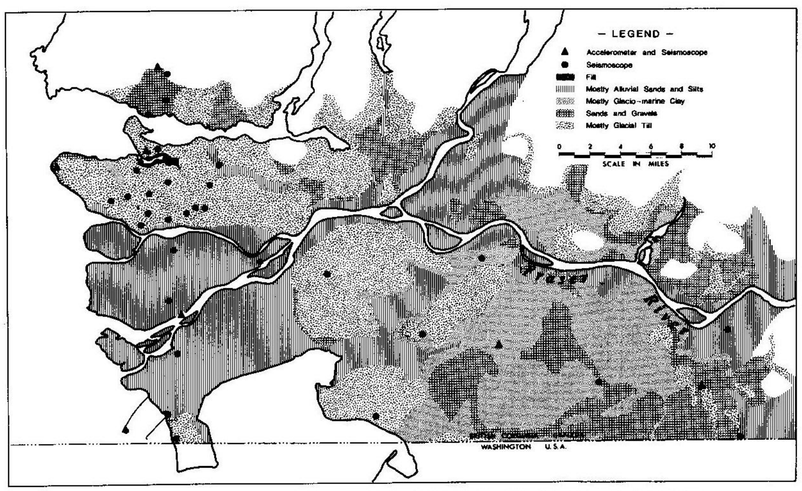

FIG. 6 SOIL TYPES IN THE LOWER FRASER VALLEY. (NOTE THAT THE BOUNDARIES HAVE BEEN SMOOTHED TO SHOW ONLY THE MAIN TYPE OF SOIL IN AN AREA. MORE DETAILED INFORMATION CAN BE FOUND ON THE ORIGINAL GEOLOGICAL SURVEY MAPS 9, 10, 11.)

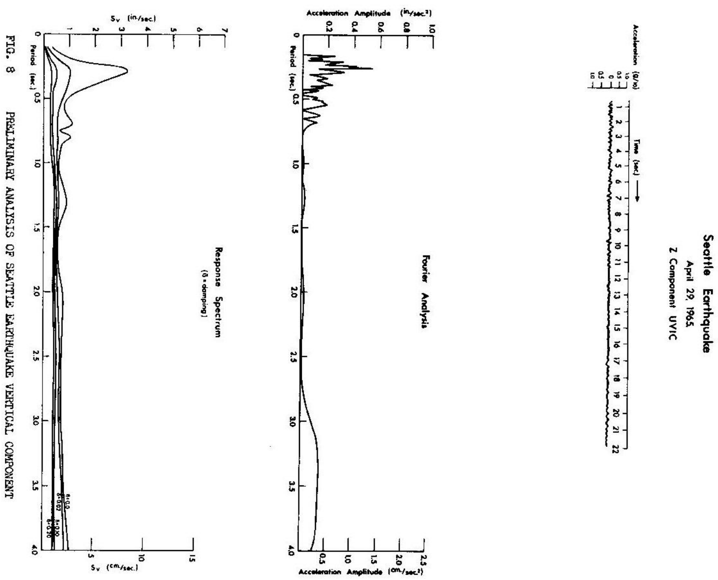

FIG. 8 PRELIMINARY ANALYSIS OF SEATTLE EARTHQUAKE VERTICAL COMPONENT

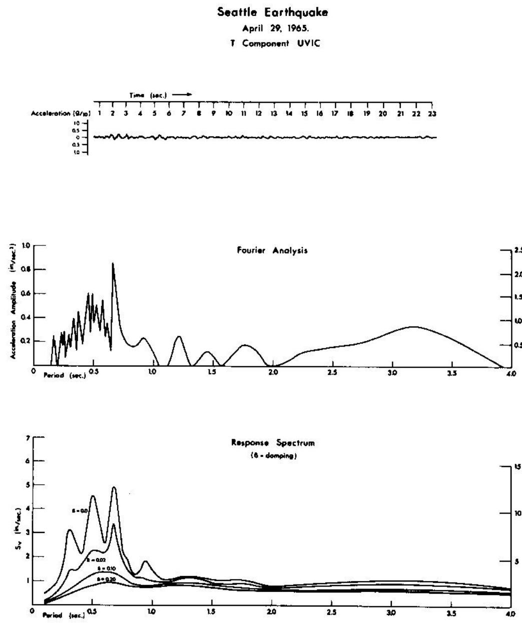

FIG. 9 PRELIMINARY ANALYSIS OF SEATTLE EARTHQUAKE T COMPONENT (N5E) EARTHQUAKE HAS AN AZIMUTH N146°E FROM SITE.

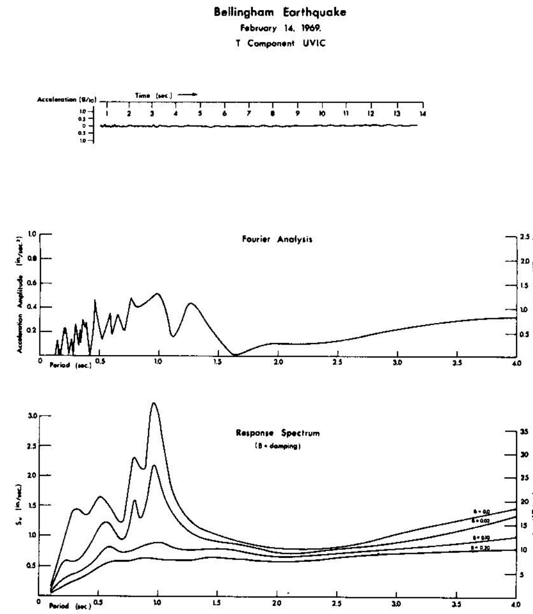

FIG. 11 PRELIMINARY ANALYSIS OF BELLINGHAM EARTHQUAKE T COMPONENT (N5E) EARTHQUAKE HAS AN AZIMUTH N57°E FROM SITE.

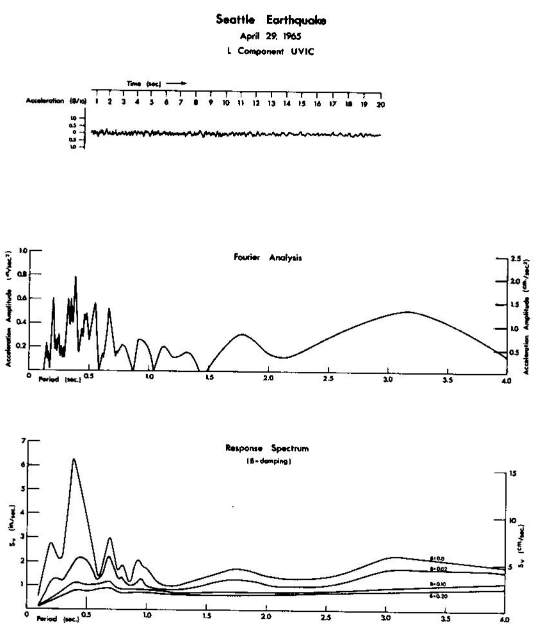

FIG. 10 PRELIMINARY ANALYSIS OF SEATTLE EARTHQUAKE L COMPONENT (N95E) EARTHQUAKE HAS AN AZIMUTH N146°E FROM SITE.

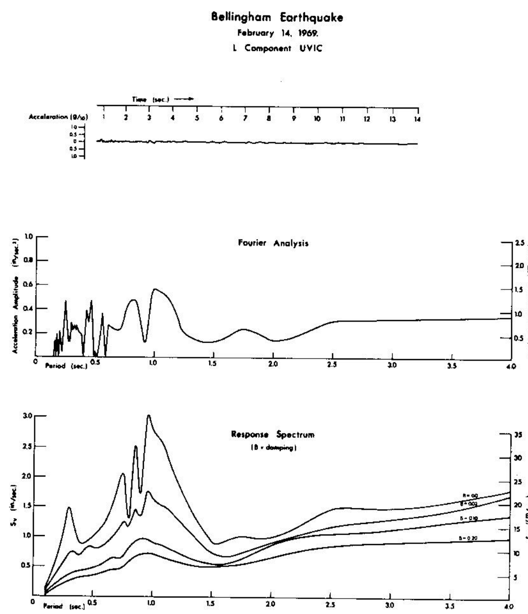

FIG. 12 PRELIMINARY ANALYSIS OF BELLINGHAM EARTHQUAKE L COMPONENT (N95E) EARTHQUAKE HAS AN AZIMUTH N57°E FROM SITE.

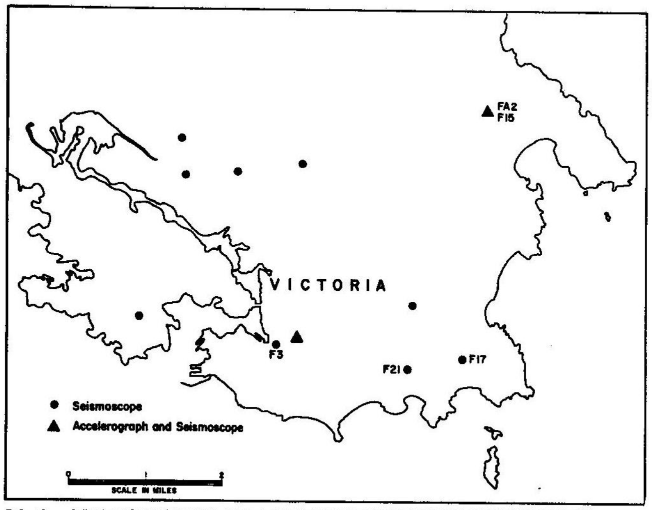

FIG. 13 STRONG MOTION INSTRUMENTS LOCATED IN THE VICTORIA REGION DURING THE BELLINGHAM EARTHQUAKE OF FEBRUARY 14, 1969. THE SEISMOSCOPES THAT HAVE BEEN LABELLED PRODUCED MEASURABLE RECORDS. REFER TO FIGURE 15 FOR DETAILS.

Seismoscope records from the Bellingham earthquake, February 14, 1969

Victoria Area

Instrument	Amplitude	Soil Type
F - 15 *	1 mm	clay
F - 3	2.5 mm	clay and silt fill
F - 17	less than 1 mm	stiff brown clay
F - 21	1 mm	stiff brown clay

* at accelerograph site

Vancouver Area

Instrument	Amplitude	Soil Type
U - 5	2 mm	boggy peat and sand
U - 7	less than 1 mm	glacial till
U - 8	less than 1 mm	glacial till
U - 11	less than 1 mm	muskeg
U - 14	2 mm	soft wet sand
U - 16	1 mm	clay
U - 17	less than 1 mm	clay
U - 20	1 mm	sand, gravel and clay

Figure 15 Intensities produced by the Bellingham earthquake are at the lower limit of seismoscope sensitivity, but a variation of response with the type of soil is apparent.

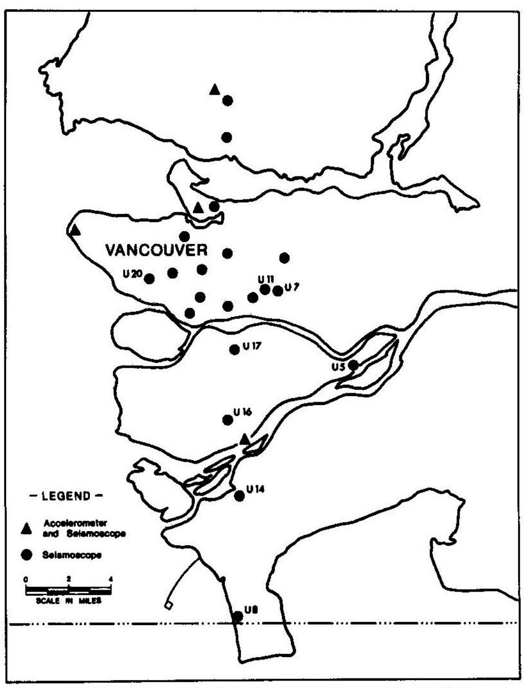

FIG. 14 STRONG MOTION INSTRUMENTS LOCATED IN THE VANCOUVER REGION DURING THE BELLINGHAM EARTHQUAKE OF FEBRUARY 14, 1969. THE SEISMOSCOPES THAT HAVE BEEN LABELLED PRODUCED MEASURABLE RECORDS. REFER TO FIGURE 15 FOR DETAILS.

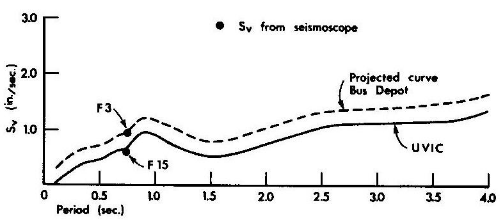

FIG. 16 VELOCITY RESPONSE OF 2 VICTORIA SEISMOSCOPES NORMALIZED TO 10% CRITICAL DAMPING. THE INSTRUMENT LOCATED AT THE BUS DEPOT SHOWS ONE AND ONE-HALF TIMES GREATER VELOCITY RESPONSE THAN THE UNIVERSITY. BOTH OF THESE SOIL SITES ARE AMPLIFIED OVER SITES ON TILL AND ROCK WHICH PRODUCED NO MEASURABLE RECORD. THE DOTTED CURVE IS THE VELOCITY RESPONSE SPECTRUM (10% CRITICAL DAMPING) FROM THE UNIVERSITY SITE AMPLIFIED TO THE LEVEL INDICATED BY THE BUS DEPOT SEISMOSCOPE.

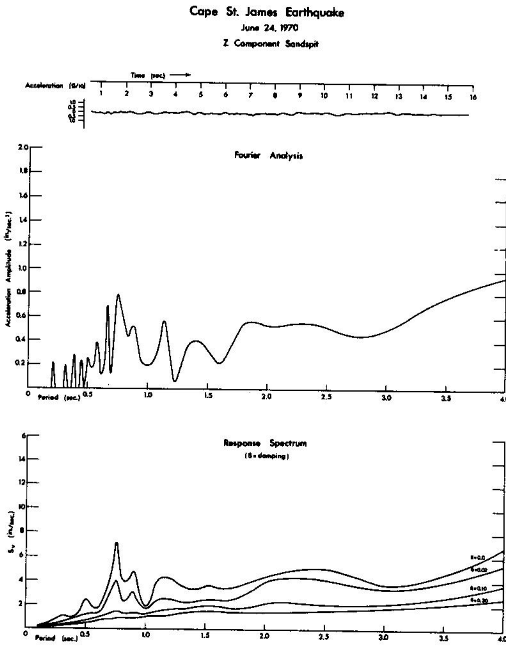

FIG. 17 PRELIMINARY ANALYSIS OF CAPE ST. JAMES VERTICAL COMPONENT

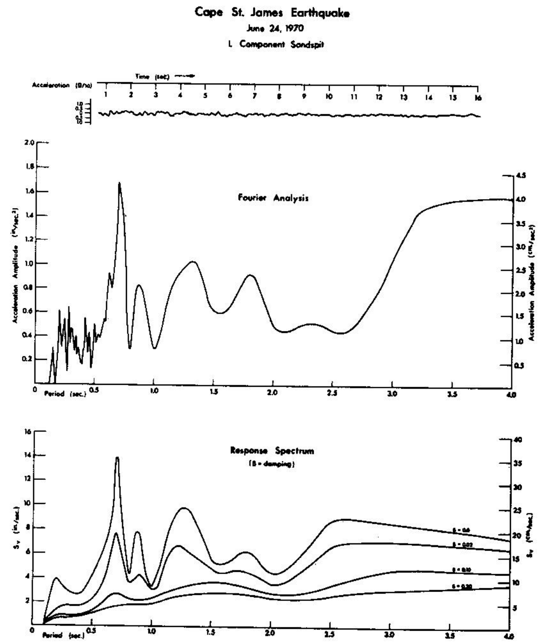

FIG. 19 PRELIMINARY ANALYSIS OF CAPE ST. JAMES EARTHQUAKE L COMPONENT (N115°E). EARTHQUAKE HAS AN AZIMUTH N160°E FROM SITE.

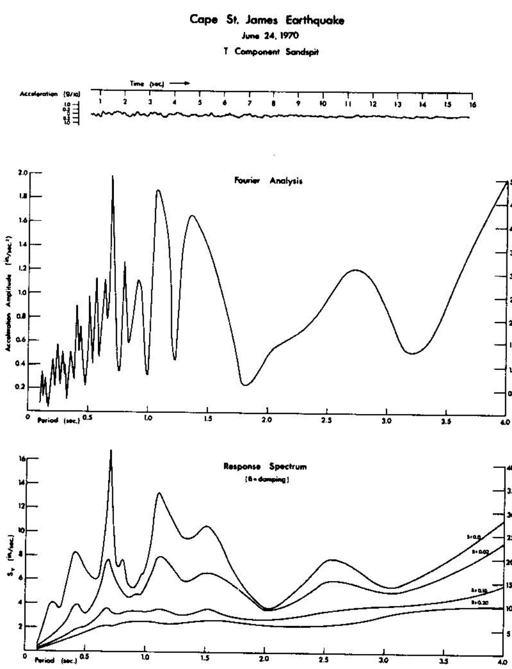

FIG. 18 PRELIMINARY ANALYSIS OF CAPE ST. JAMES EARTHQUAKE T COMPONENT (N25°E). EARTHQUAKE HAS AN AZIMUTH N160°E FROM SITE.

Earthquake Details

	Seattle	Bellingham	Cape St. James
Date	April 29, 1965	February 14, 1969	June 24, 1970
Time (GMT)	15 28 44	08 33 36	13 09 07
Latitude (N)	47° 25'	48° 54'	51° 45'
Longitude (W)	122° 14'	123° 06'	130° 58'
Depth	60 km	shallow	shallow
Magnitude (M_L)	6.5	4.2	6.5
Recording Instruments	1 accelerograph	1 accelerograph 12 seismoscopes	1 accelerograph
Distance of accelerograph from epicentre	148 km	60 km	165 km

Figure 20 Details of earthquakes recorded by instruments of the strong motion network.

DISCUSSION OF PAPER NO. 2

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by

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Question by: Y.P. Gupta

The seismoscope directly provides one point on a strong motion response spectrum. The use at one site of several seismoscopes of differing periods and damping values would provide a number of points on the spectrum curve. Has any thought been given to the use of numerous seismoscopes for evaluating the spectrum at a site?

Reply by: G.C. Rogers

The main reason for the choice of instruments is cost. The 3/4 second period, variable damping seismoscope is commercially available with the present cost being about $200. As far as I am aware seismoscopes of other periods are not being manufactured, and to design and manufacture them ourselves would make the cost prohibitive. The present cost of 3-component self triggering accelerographs is down to about $1600 U.S., so that deploying several seismoscopes in one place with differing periods would soon approach the cost of one accelerograph; the latter instrument is clearly more desirable.

Question by: R.A. Spencer

Do you have any interest at your Station in attempting to model the soil layers for amplification studies relating the bedrock motions to the motions recorded at the surface?

Reply by: G.C. Rogers

We have not undertaken such studies to date. We have, however, been gathering data on soil depths and log borings so that this type of analysis can be made in the event that strong motion records are obtained.

Question by: S. Cherry

Please outline the methods you are using for providing practising engineers with seismic data when they write to the observatory in search of such information.

Reply by: G.C. Rogers

We can supply several different forms of information. For example, a copy of the earthquake risk map which delineates areas according to the acceleration expected in a 100-year period. We can also provide for any location in Canada a detailed site calculation including other return periods. We are also able to provide accelerograph records from our strong motion program in both the original and digitized form.

Question by: J.H. Rainer

Has there been any attempt made to correlate the records you have obtained and their spectra with those obtained from California earthquakes, and if so, how do they compare?

Reply by: G.C. Rogers

No detailed analyses or comparisons have yet been made. However, as has been pointed out in the paper, the Seattle record appears to have almost all the energy concentrated at the high frequency end of the record.