A PRELIMINARY INVESTIGATION OF MICROTREMOR SPECTRA IN BRITISH COLUMBIA

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SYNOPSIS

Microtremor readings have been recorded and analysed at a number of sites in the Vancouver and Victoria areas. The sites cover a variety of subsurface conditions. The expected variations in amplitudes between "hard" and "soft" sites have observed, and at some locations a definite site periodicity has been noted. The analysis is based on the Fast Fourier Transform of digitized microtremor signals. It is stressed that the results are intended only as an introductory report on the nature of microtremor spectra at some locations in western British Columbia, and on the feasibility of employing "relative site amplification spectra" as a technique for microseismic zoning in that region.

1. GENERAL

1.1. Introduction: It is clear from observational studies of past earthquakes that damage to man-made structures situated in the epicentral region of a strong shock is greatly influenced by the local soil conditions. Instrumental evidence also exists which shows that site ground motion can be modified by the nature of the soil underlying the recording station. An historical development of our level of understanding of the effect of soil type and profile on earthquake damage, and on ground motions, can be traced by studying the published works of a number of investigators, including those by Freeman (1), Duke (2) and the more recent state of the art papers by Ohsaki(3) and Seed (4).

As a result of empirical findings and modern analytical techniques, many building codes now attempt to account, at least qualitatively, for the influence of soil conditions on structural response when determining design seismic coefficients. However, despite this recognition, the development of a meaningful and reliable procedure for predicting the seismic response characteristics of a potential building site probably represents the major problem still to be solved by earthquake engineers.

Damage studies, field and laboratory investigations and theoretical analysis have all been employed in the search for a method offering this predictive capability. Ideally, the determination of these site characteristics should be obtained by a direct measurement of the in situ dynamic properties of the deposit, should not be strictly dependent on, nor await the prior and relatively rare occurrence of a strong shock or a series of shocks, and should not require detailed subsurface explorations or questionable assumptions to be made regarding the dynamic properties of the underlying soil strata. These specifications can be satisfied simply and directly by a straightforward analysis of microearthquake and microtremor recordings, if it is accepted that such vibrations represent suitable energy sources for evaluating site effects.

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Microtremors are continuous ground motions whose amplitudes range from between 0.1 to 1 microns. They are believed to originate primarily from artificial (man-made) sources. Kanai and Tanaka (5) have used the variation of microtremor spectra over a given urban area as a means of microzoning for damage susceptibility and extensive progress has been made in the exploitation of this technique for site response studies in Japan by these investigators and their colleagues. For this purpose, the basic information required can be expressed in the form of a ground amplification spectrum over the frequency range for which damage to engineering structures is a maximum. Unfortunately, since the generation, propagation and order of magnitude of microtremors are not necessarily similar to the comparable characteristics of a strong motion earthquake, predictions based on this technique are open to criticism. The site properties obtained from microtremor effects may not, in fact, be the site properties which dominate in the transmission of strong motion shocks. Although the usefulness of microtremor data may be limited by this fact, they do provide one experimental bound for checking analytical procedures and are potentially valuable as a microzoning tool, should techniques become available for extrapolating microtremor effects to strong motion conditions.

1.2. Object and Scope of Investigation: The studies described in this paper form part of a general research program initiated by one of the authors with a view to predicting site behaviour during strong earthquake ground motions. An earlier report (6) explored the feasibility of using depth charge blasts for establishing site response characteristics. The present investigation represents a continuation of that work and utilizes microtremors as the energy source for ground excitation. The results are offered only as a preliminary report on the nature of microtremor spectra obtained at a number of sites with differing soil profiles. The ultimate aim of the overall program is to contribute towards an understanding of the influence of soil type on the dynamic characteristics of the ground. The immediate goal is to examine the extent to which microtremor amplitude spectra are representative of typical sites in western British Columbia and to attempt to correlate these distributions with the site soil conditions.

The possibility of correlating microtremor characteristics with those of strong ground motions is also being provided for by including in the recording schedule sites associated with stations of the regional strong motion network. To date, three low intensity earthquake accelerograms have been recorded by the accelerographs of the west coast regional network (7), and two of these are incorporated in this report, both for comparative purposes and for sake of completeness.

The microtremor experiments forming the subject of this paper were performed at six recording sites, some of which were situated at strong motion stations. The soil conditions at these locations are briefly described in the following section. The instrumentation system employed in the survey and the method of processing the data is then discussed. This is followed by sections on site amplification spectra and the analysis of microtremor and strong motion data for Fourier amplitude spectra. Some general comments and discussions are offered, including statements relative to the assumptions inherent in the microtremor technique.

2. MEASUREMENTS AND ANALYSIS

2.1. Site Soil Conditions: Microtremor measurements were taken at the site of the strong motion stations on the University of British Columbia Campus in Vancouver, and at five locations in the Victoria area, including the strong motion station at the University of Victoria. The first two earthquake accelerographs obtained in Canada were recorded at this latter location. Table I summarizes the recording conditions and soil profiles at these sites. A variety of soil conditions is represented in the table. Each series of microtremor recordings is identified and described by a code number, and this identification is used throughout the remainder of the paper.

2.2. Instrumentation System: The overall procedure followed in handling the microtremor data, from signal input through to data processing and spectrum analysis, is shown in block diagram form in Fig.1. The vibration signals were detected with a Willmore MK.II seismometer and passed through a Teledyne EA-300 amplifier, equipped with interchangeable low pass filters and having a maximum voltage gain of 400,000. The amplified voltages were recorded on a Precision Instrument PI 6200 FM magnetic tape recorder and also on a Teledyne Model 2484B Heliocorder pen recorder. The latter component provided a visual record of the microtremors which was used to monitor the vibrations in the field and to help select representative sample functions for analysis.

The analog tape was later fed through a Scientific Data Systems AD20-11 analog-digital converter with 4 channel multiplexer, which digitized the record for subsequent analysis. The input to the digitizer passes through a "sample and hold" amplifier to ensure that, for multichannel recording, all channels are sampled simultaneously. Signals between ± 10 volts can be sampled to within 10 mv. The converter was interfaced to a small Interdata 4 Computer, to give a binary output on magnetic tape that is compatible with the I.B.M. 360-67 Duplex System Computer on which the spectral analysis calculations were performed.

The natural frequency of the Willmore seismometer was set at 1.2 Hz. for tests M1 and M3 and at 1.0 Hz. for the remaining tests; the damping was approximately 0.7 of the critical value. The transducer was calibrated with its amplifier using the method of Kollar and Russel(8). The resulting system velocity sensitivity curve (in volts/unit velocity), which is simply the absolute value of the system transfer function or complex frequency response, is not flat over the frequency range of most interest to earthquake engineers. However, the calibration enables the Fourier amplitude spectrum of the actual ground velocity to be recovered from the Fourier amplitude spectra of the recorded system output over the frequency range 0.5 to 12 Hz. Theoretically, it is possible to apply this approach down to 0 Hz., but, since the instrument response falls off very rapidly below 1 Hz., the signal-to-noise ratio becomes unacceptable at the low end of the frequency scale. There is also a cut-off point on the upper end of the frequency scale due to the low pass filter in the amplifier.

The above correction for instrument response was made in the computer, as a part of the overall Fourier spectral analysis program.

2.3. Recording Procedures and Data Preparation: The seismometers were orientated to measure horizontal components of motion only. A single sensor was employed in all tests except M5, M6 and M7; for these latter series simultaneous measurements were taken with a pair of Willmores and the records placed on two channels of the magnetic tape. From Table I it may be seen that the paired instruments were used for the simultaneous recording of microtremors on soil and bedrock outcrop stations, or for the simultaneous recording of an orthogonally placed set at any one station. At one of the stations records were taken during both the daytime and nighttime. The average recording interval for each test was approximately 5 minutes; all measurements were made under conditions of little or no wind.

The microtremors were recorded at a tape speed of 3.75 in/sec.; the playback speed for digitizing the record was 37.5 in/sec. The analog voltages were converted to digital form at a sampling rate of 1600 readings/sec. for one channel or 800 readings/sec. for two channels. Since only every second digital point was considered in the single channel tests, the overall real-time sampling frequency for all the tests was 80 readings/sec. The low pass filter at the output of the FM tape was set at 100 Hz, which corresponds to a real-time cut off of 10 Hz. The sampling interval was therefore very much less than the Nyquist interval and hence the aliasing problem was minimized. The conversion scheme described above permits a record to be digitized in one tenth of the time required to record the original analog signal.

Only a portion of each digitally converted 5-min. record was used in the spectral analysis. The desired data blocks were selected after visually editing the seismometer recordings on the Heliocorder so as to ensure that the microtremors were representative sample functions of the site and were not contaminated by undesirable short term disturbances, such as might be caused by passing vehicular noise. Generally, each sample function was defined by 4096 data points representing approximately 51.2 secs. of recording time.

2.4. Fourier Spectrum Analysis of Microtremors: Computations for Fourier amplitude spectra were made using the I.B.M. fast Fourier transform routine (FORT), which is based on the Cooley-Tukey algorithm(9); support programs developed in the Department of Civil Engineering at The University of British Columbia were also employed in the analysis.

(FORT) requires that the number of data points be an integral power of 2 and that the sample points be equally spaced time-wise. The microtremor amplitude spectra were derived from data blocks consisting of 1024 digitization points; the Fourier coefficients were averaged over two or four blocks, depending on the record length. The band width used was 0.078 Hz. and the coefficients were hanned. The amplitude spectra for the different tests summarized in Table I are shown in Figs. 4 to 9. These graphs were obtained directly from a digital plotter.

2.5. Analysis of Strong Motion Earthquake Records: To date, two low amplitude acceleration records have been obtained with the Department of Energy, Mines and Resources accelerograph located at the regional strong motion station at the University of Victoria. These accelerograms were due to the Seattle Earthquake of 29 April 1965 (M = 6.5 and epicentral distance = 148 km) and the Bellingham Earthquake of 14 February 1969 (M = 4.2 and epicentral distance = 60 km). The maximum ground acceleration amplitudes recorded at the University of Victoria site during these earthquakes were approximately 0.015g and 0.010g respectively. Although these figures represent relatively low shaking intensities, the corresponding ground vibrations are of a higher order of magnitude than those produced by microtremors. This affords an opportunity for comparing the spectral characteristics of these different energy sources, with a view to possible future correlation and extrapolation of microtremor effects to strong motion conditions.

Fourier amplitude spectra for these two events were prepared from digitized accelerograph data supplied by Milne and Rogers; these authors have presented an independent analysis of the same material (7). A parabolic base line correction (10) was applied to the raw data before proceeding with the analyses. Computer output plots of the amplitude spectra are reproduced in Figs. 8 and 9; only the horizontal components have been included here. The digital sample size obtained from the 1965 and 1969 earthquake accelerograms contained 1534 and 1000 data points respectively. Since the (FORT) program requires 2^n points for its operation (n an integer), the spectra shown are based on a significantly fewer number of data readings than were actually available.

2.6. Site Amplification Spectra: Consider a site cross-section consisting of a soil deposit and an adjacent rock or firm ground outcrop as shown in Fig.3. For this rock-soil system, the input or base rock motions and the output or surface motions can be represented in the time domain by an excitation-time history and in the frequency domain by a Fourier amplitude spectrum. From linear system analysis, the response recorded on the soil surface at any time t, $y_s(t)$, is given by the convolution integral

$$y_s(t) = \int_{-\infty}^{\infty} x_s(\tau)\ h_s(t - \tau)d\tau \qquad (1)$$

where $x_s(t)$ is the excitation history at the base of the soil and $h_s(t - \tau)$ is the impulse response or transfer function of the soil. τ is a dummy time variable which disappears on integration. Similarly, using the r subscript to refer to the firm ground or rock formation, the response recorded on the rock outcrop is

$$y_r(t) = \int_{-\infty}^{\infty} x_r(\tau)\ h_r(t - \tau)d\tau \qquad (2)$$

where $x_r(t)$ is the motion developed in the rock beneath the outcrop at the rock-soil interface elevation.

These equations can be converted from the time to the frequency domain by Fourier transform principles such that

$$Y_s(\omega) = |H_s(\omega)|X_s(\omega) \qquad (3)$$

$$Y_r(\omega) = |H_r(\omega)|X_r(\omega) \qquad (4)$$

in which $Y(\omega)$ and $X(\omega)$ are the Fourier amplitude spectra of $y(t)$ and $x(t)$ respectively and $|H(\omega)|$ is the absolute value of the corresponding complex transfer function. The ratio of Eqs. (3) to (4) yields

$$A(\omega) = \frac{Y_s(\omega)}{Y_r(\omega)} = \frac{|H_s(\omega)|}{|H_r(\omega)|}\ \frac{X_s(\omega)}{X_r(\omega)} \qquad (5)$$

$A(\omega)$ is here defined as the site amplitude amplification spectrum; it is the ratio of the Fourier amplitude spectra of soil-to-rock outcrop motions. In general, $A(\omega)$ provides an indication of the amplification and filtering properties of a local soil deposit.

It seems reasonable to assume that the motion of the rock below the outcrop is not altered significantly during its transmission from the interface elevation to the surface, so that $|H_r(\omega)|$ can be effectively eliminated from Eq.(5), which then takes the form

$$A(\omega) = |H_s(\omega)| \frac{X_s(\omega)}{X_r(\omega)} \tag{6}$$

If, in addition, it is assumed that the motions developed in the rock at the base of the soil are the same as those developed in an adjacent rock outcrop, then $X_r(\omega) = X_s(\omega)$ and Eq.(5) reduces to

$$A(\omega) = \frac{Y_s(\omega)}{Y_r(\omega)} = |H_s(\omega)| \tag{7}$$

which represents the site amplification spectrum or transfer function for the soil strata alone. While the assumption leading to this latter simplification is questionable, the influence of differences between $X_r(\omega)$ and $X_s(\omega)$ on the surface motions is likely to be small.

Amplification spectra were determined at two stations from an analysis of microtremor readings taken simultaneously on "soft" and "hard" sites. The results are shown in Figs.(5) and (6).

3. DISCUSSION OF RESULTS

3.1. Results of Fourier Spectral Analysis: Soil profiles and other information related to the test series described below are provided in Table I. The results of the investigations have been grouped appropriately and are presented in Figs.4 to 9.

(1) M5 Series: Fig.4 shows the spectra obtained for a site having a multilayered soil profile. The plots of Figs.4(a) and 4(b) were derived from two different blocks of data, which were separated in time but were taken from the same microtremor recording and are identified as tests M5EA and M5EB. These two spectra are similar in appearance and consistently exhibit peaks at the same frequencies, including the two largest spikes at 1.9 Hz. and 11.3 Hz. This tends to suggest that the microtremors at this site are reasonably stationary, at least over a short time interval. Similar comments apply to the M5N series, Figs.4(c) and 4(d).

M5E and M5N represent the results for a set of mutually perpendicular and simultaneously recorded microtremor measurements. The differences in their shapes may be due to directional non-homogeneity as regards soil profile and/or excitation.

(2) M6 and M7 Series: These tests illustrate the differences in spectral characteristics for rock and soil founded sites and point out the feasibility of employing site amplification spectra for defining the in situ dynamic properties of a local soil profile. Two independent pairs of sites are included in this series; each pair consists of a soil and an adjacent rock outcrop station.

The curves of Figs.5 and 6 clearly indicate the frequency dependent nature of the site amplification spectra. The spectrum in Fig.6(a), which was derived from data obtained at rock outcrop site M7EH, is reasonably flat over the 1 - 10 Hz. frequency band. This tends to suggest a "white noise" type input on the underlying bedrock. The spectrum for the adjacent soft site, M7ES, Fig.6(b), is characterized by two major peaks, the largest occurring at approximately 3 Hz. The ratio of the spectra for soil to rock founded stations yields the site amplification spectrum, Fig.6(c), which has been normalized here with respect to its peak amplitude ratio. This spectrum is very similar in appearance to the spectrum for the "soft" site, which is expected in view of the "white-noise" type input to the soil base.

The above remarks are also applicable to test series M6E, Fig.5. Except for a pronounced spike at about 5 Hz., the spectral character of the base rock input, M6EH, is again essentially flat; the rise in this spectrum at the low end of the frequency scale is believed to be instrumental in origin. Figs.5(b) and 5(c) illustrate the modifying influence which the soil layers have on the 5 Hz. peak. On these spectra, the amplitude at this frequency is attenuated relative to the amplitudes at adjacent frequencies.

The maximum site amplification factor or transfer function ratio reaches a value of 52.5 in test M6. This value seems abnormally high and is subject to the error which can arise when taking ratios of coefficients that fluctuate rapidly with small changes in frequencies.

(3) M1, M3 and M8 Series: The microtremor amplitude spectra for this series are shown in Fig.7. The measuring stations were located on well consolidated deposits. The frequency content is fairly uniform over the range 1.5 Hz. to 8.8 Hz. and this seems reasonable for sites located on this type of soil profile. The sharp rise at the low frequency end of the M3N and M8E spectra, Figs.7(b) and 7(c) respectively, is attributed to system noise rather than the presence of a low frequency component in the microtremor signal. The amplitudes of the microtremors recorded during the daytime, Fig.7(a), are greater than those measured at midnight, Fig.7(b). This situation is normally expected because of the relatively quiescent state of the artificially induced vibrations during the night hours.

(4) M9 and Strong Motion Series: Figs.8 and 9 show the Fourier spectra corresponding to accelerograms of two low amplitude earthquakes which were recorded on separate occasions at one of the regional strong motion stations. Included in this set are microtremor spectra for the same location; the latter are expressed in acceleration units to conform with the units normally used with accelerograph recordings. The gradual rise in the M9N microtremor spectrum amplitudes beyond 8 Hz., Fig.8(a), and the major spikes in the M9E spectrum, Fig.9(a), may have been due to surface noise sources at the site or to the spectral characteristics of the input motion in the underlying bedrock. The north-south component acceleration spectra of the two earthquakes exhibit certain similarities (note change of scale) in location of peak frequencies and in the frequency band defining major energy content. However, there does not appear to be any correlation between the microtremor and earthquake spectra for this site.

3.2. Summary and Concluding Remarks: General conclusions on the capabilities of the microtremor method are not warranted in view of the limited nature of the tests. The work described in this paper should only be considered as a preliminary study for a potential research project.

Some distinct site spectra have been obtained and the technique seems worthy of further exploration. Measurements should be made at a large number of local sites with a variety of soil conditions. In this connection, the concept of relative site amplification spectra for examining site response may represent a practical approach to the microzoning problem.

The relevance of the results of microtremor surveys in respect to real earthquake excitations depends on a variety of factors regarding the input motions including the accuracy of the assumption that (i) microtremors represent oscillations in depth at a site and are not merely a surface phenomenon; (ii) the basic excitation in bedrock is "white" over the frequency range of interest;(iii) the ground characteristics evaluated from a single sample function at a site are repeatable; (iv) the characteristics established by the microtremor technique are valid under conditions of strong motion excitations or can be extrapolated to fit these conditions. While these assumptions have been examined at some length by Kanai and Tanaka(5) and others, their appropriatness for British Columbia sites must be established.

ACKNOWLEDGEMENTS

The writers are especially grateful to Dr. W. G. Milne, Seismology Division, Earth Physics Branch, Department of Energy, Mines and Resources, and to Dr. R. M. Ellis and Mr. R. D. Meldrum, Department of Geophysics of the University of British Columbia for making available the recording and data processing equipment used in this investigation and for helpful consultations. The research was supported by a grant from The National Research Council of Canada.

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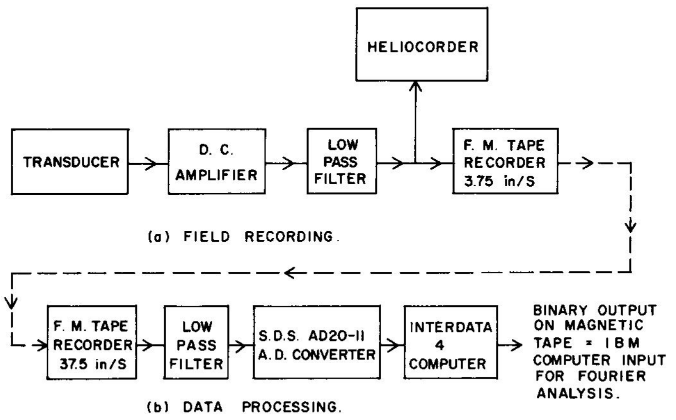
TABLE I: SITE INFORMATION

Test	Location	Time (24 hr.)	Date	Soil Profile	Remarks
M1N*	Basement of Civil Structural Testing Lab., U.B.C.	15-16 to 15-37	28 May 1970	Glacial and interglacial deposits of mainly dense fine silty sand with some thin silt layers and some thin sandy gravel layers. Heavily consolidated by repeated glaciation. Sandstone bedrock lies at approximately 280 ft. below surface.	Location of regional strong-motion station
M3N	Basement of Civil Structural Testing Lab., U.B.C.	23-50 to 00-07	8-9 June 1970		
M5EA M5EB M5NA M5NB	Vancouver Island Coach Lines Depot, Victoria	00-40 to 02-00	20 Aug. 1970	Although bedrock outcrops a few hundred yards away, test borings locate the depth to bedrock at about 100 ft. A typical bore log consists of:- 0-18 ft. miscellaneous clay fill, 18-25 ft. recent organic silt and sea shells, 25-34 ft. firm brown silty clay, 34-100 ft. soft grey silty clay.	E and N components recorded simultaneously. A and B represent two sections selected from the same recording.
M6ES M6EH	South side of Macaulay Pt. School Hall, Victoria Rock outcrop, 750' to south of M6ES	10-55 to 11-15	20 Aug. 1970	Soil overlying bedrock is stiff brown clay to depth of 15 ft. then soft grey clay at depths varying from 23 ft. to 60 ft.	M6ES (soil) M6EH (rock) recorded simultaneously.
M7ES M7EH	Marg. Jenkins School, Victoria. Rock outcrop 500' E in corner of school grounds	15-15 to 15-30	20 Aug. 1970	Soil overlying bedrock is generally 0-2 ft. brown sandy gravel, 2-6 ft. loose brown sandy clay, 6-10 ft. firm brown clay, 10 ft. to bedrock medium soft grey clay. Bedrock at 22 ft. to 41 ft.	M7ES (soil) and M7EH (rock) recorded simultaneously.
M8E	Bank St. School, Victoria	15-30 to 15-35	20 Aug. 1970	3-4 ft. wet sandy clay overlying dense sandy glacial till. Bedrock at 5-6 ft.	
M9E M9N	South side of library building at University of Victoria campus, Victoria	16-15 to 16-30	20 Aug. 1970	Glacial and interglacial deposits of sand and silt. Heavily consolidated bedrock at depth approx. 100 ft.	Location of regional strong-motion station

* Identification code:- Each record has a label with the form M n d [H or S] [A or B] in which
n is an identification number
d is a direction code - N is north-south, E is east-west
H indicates recording on bedrock
S indicates recording on adjacent soil strata
A & B indicate different sections of the same record



(a) FIELD RECORDING.

(b) DATA PROCESSING.

FIG. I BLOCK DIAGRAM SHOWING RECORDING AND DATA PROCESSING SCHEME.

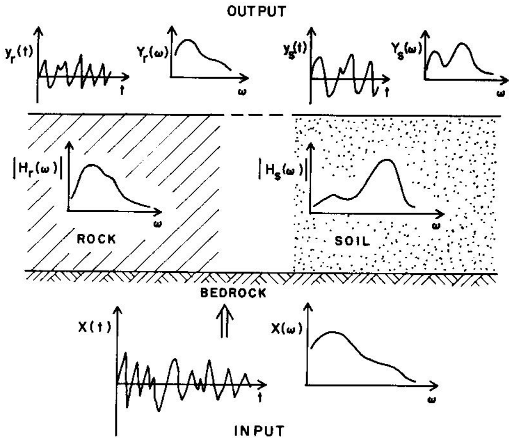
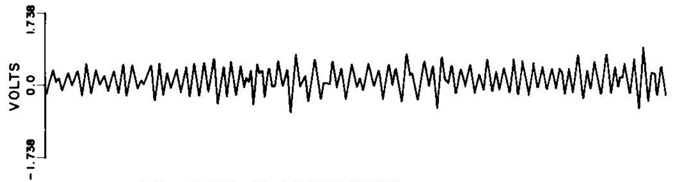
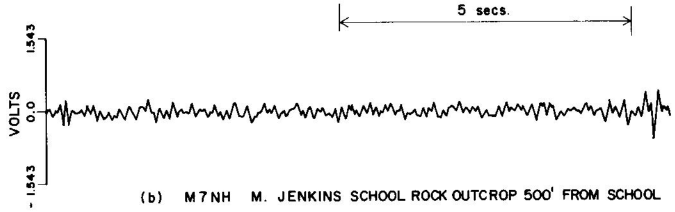


FIG. 3 MODIFICATION OF BASEROCK MOTION.



(a) M7NS M. JENKINS SCHOOL



(b) M7NH M. JENKINS SCHOOL ROCK OUTCROP 500' FROM SCHOOL

FIG. 2 REPRESENTATIVE MICROTREMOR RECORDS.

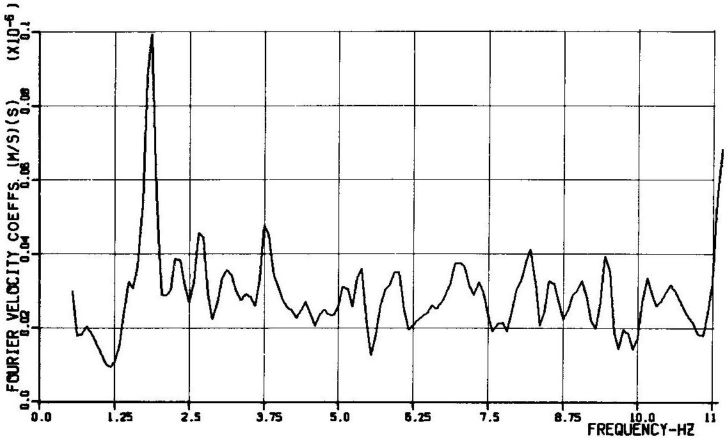


FIG. 4a FOURIER ANALYSIS OF M5EA (NIGHT, BUS STOP, VICTORIA)

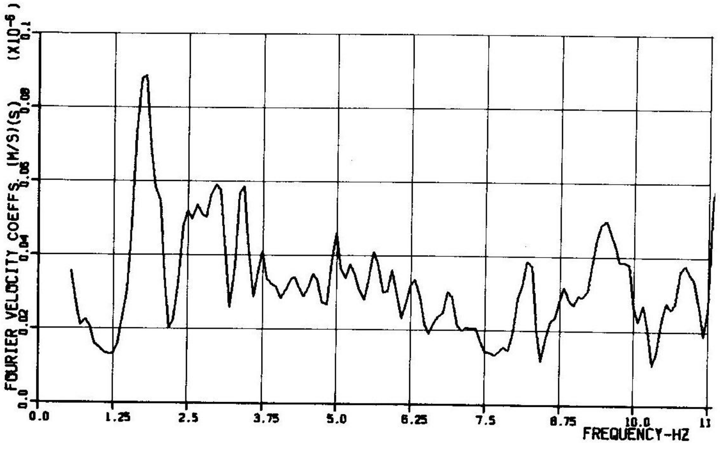


FIG. 4b FOURIER ANALYSIS OF M5EB (NIGHT, BUS STOP, VICTORIA)

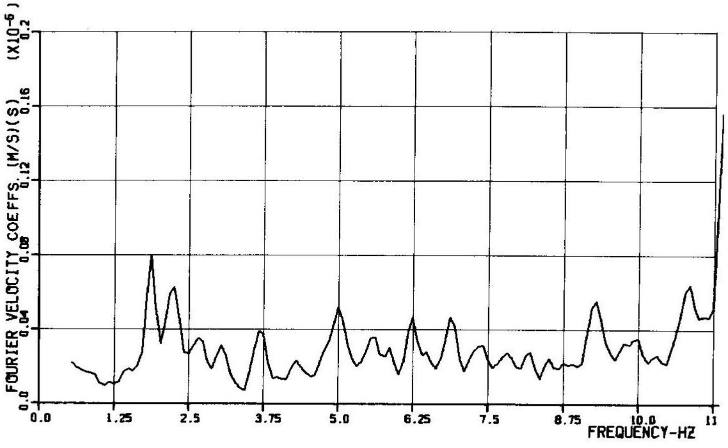


FIG. 4c FOURIER ANALYSIS OF M5NA (NIGHT, BUS STOP, VICTORIA)

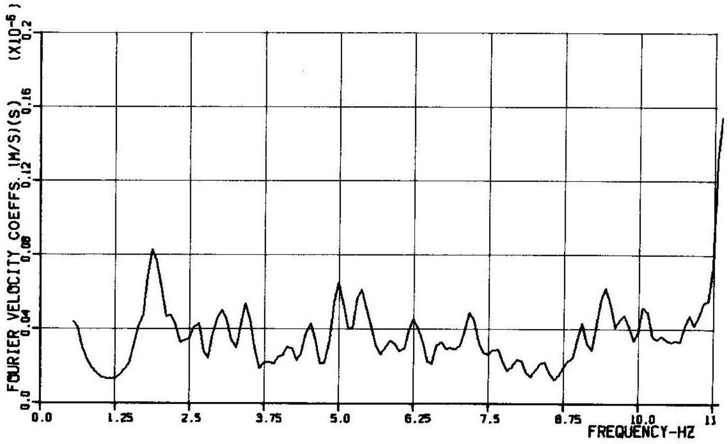


FIG. 4d FOURIER ANALYSIS OF M5NB (NIGHT, BUS STOP, VICTORIA)

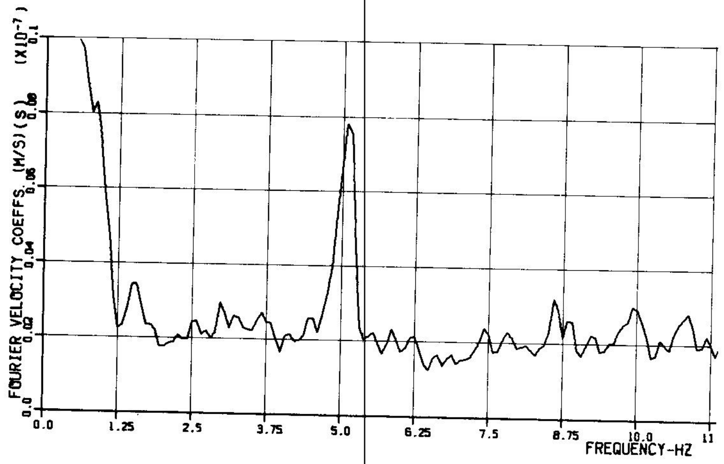


FIG. 5a FOURIER ANALYSIS OF M6EH (ROCK OUTCROP 750 'S. OF MACAULAY SCH.)

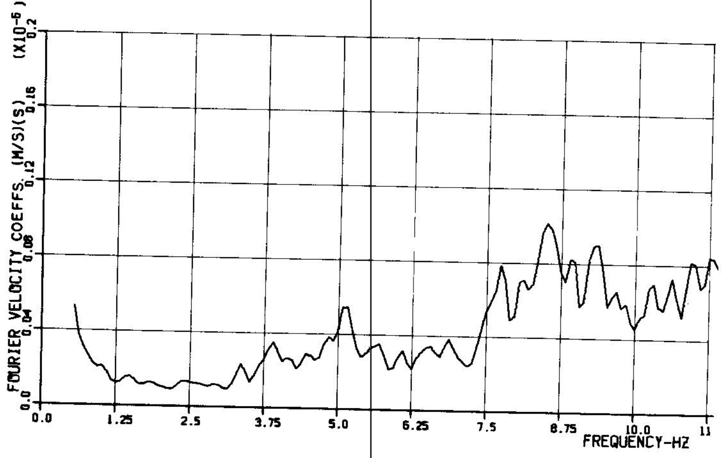


FIG. 5b FOURIER ANALYSIS OF M6ES (STH. SIDE OF MACAULAY SCH.HALL)

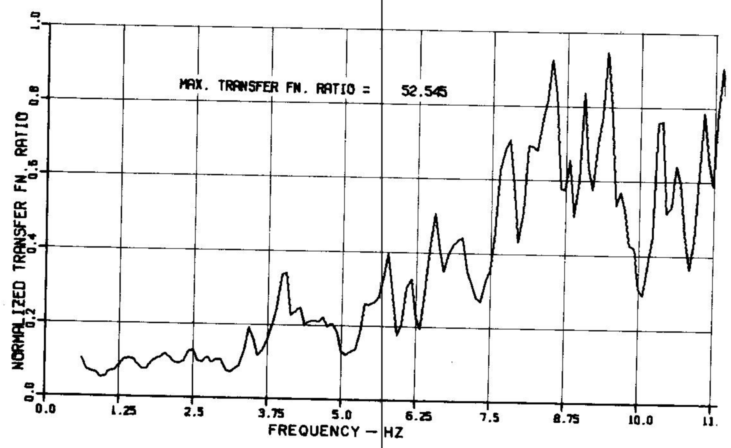


FIG. 5c RATIO OF VEL. SPECTRA(EW) MACAULAY SCH. AND ROCK OUTCROP 750 'S.

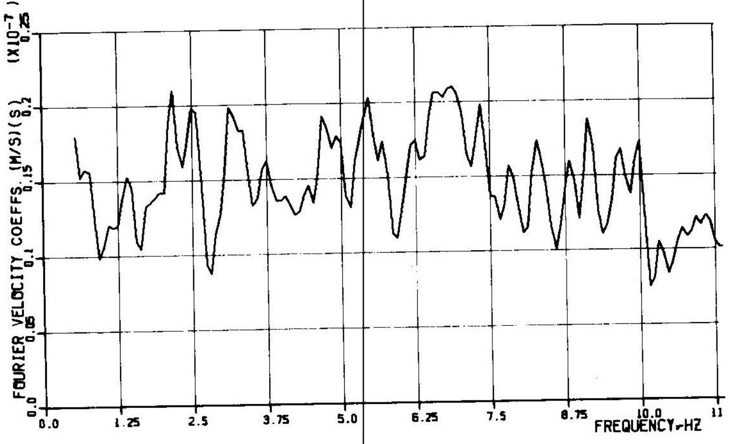


FIG. 6a FOURIER ANALYSIS OF M7EH (ROCK OUTCROP 500 'E. OF M.JENKINS SCH.)

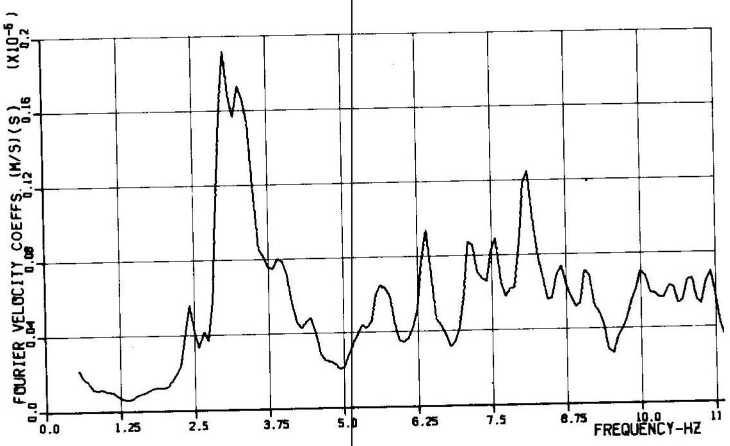


FIG. 6b FOURIER ANALYSIS OF M7ES (M.JENKINS SCH.)

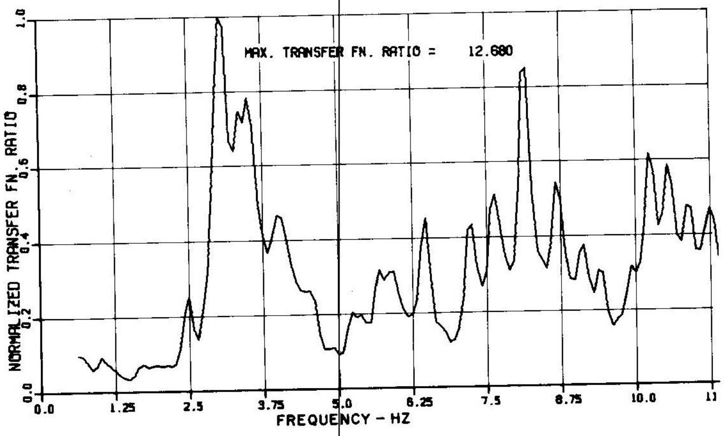


FIG. 6c RATIO OF VEL. SPECTRA(EW) M.JENKINS SCH. AND ROCK OUTCROP 500 'E.

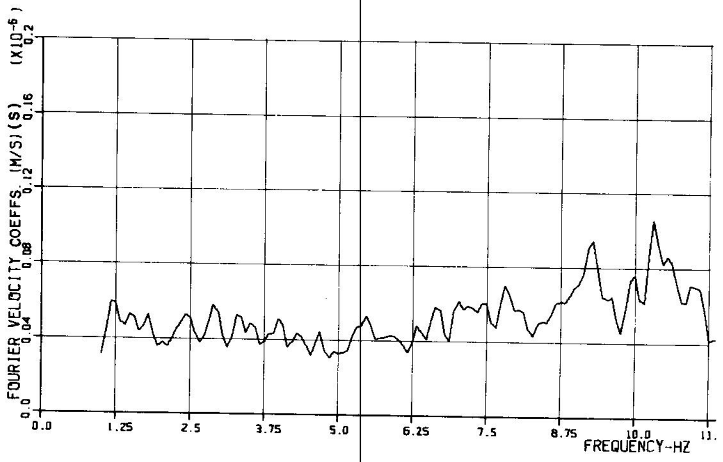


FIG. 7a FOURIER ANALYSIS OF M1N (DAY-NS-INSIDE)

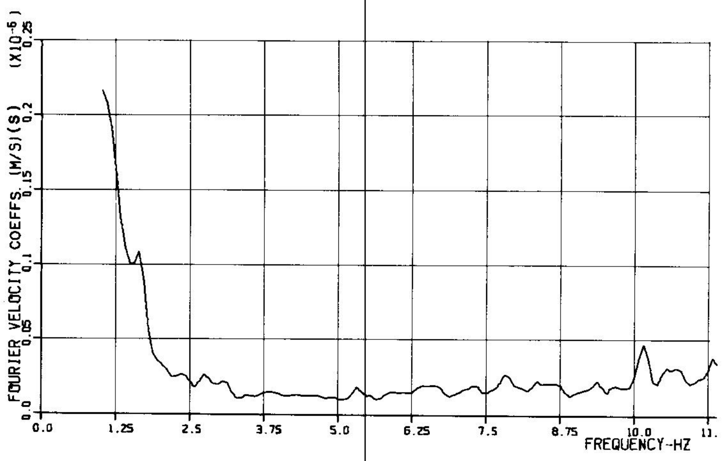


FIG. 7b FOURIER ANALYSIS OF M3N (NIGHT-NS-INSIDE)

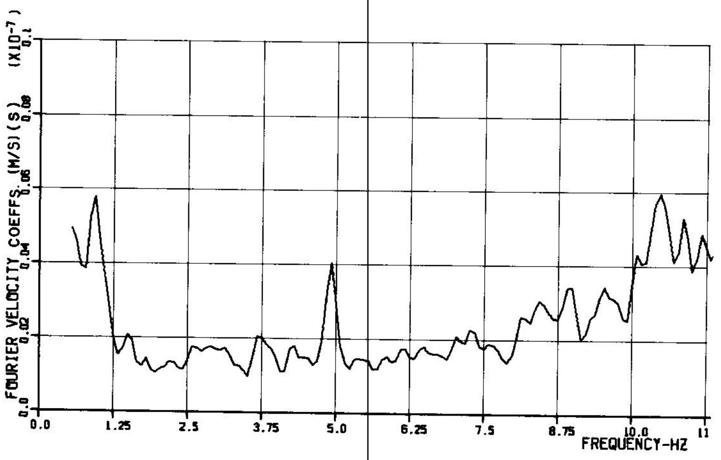


FIG. 7c FOURIER ANALYSIS OF M8E (BANK ST SCHOOL. BEDROCK)

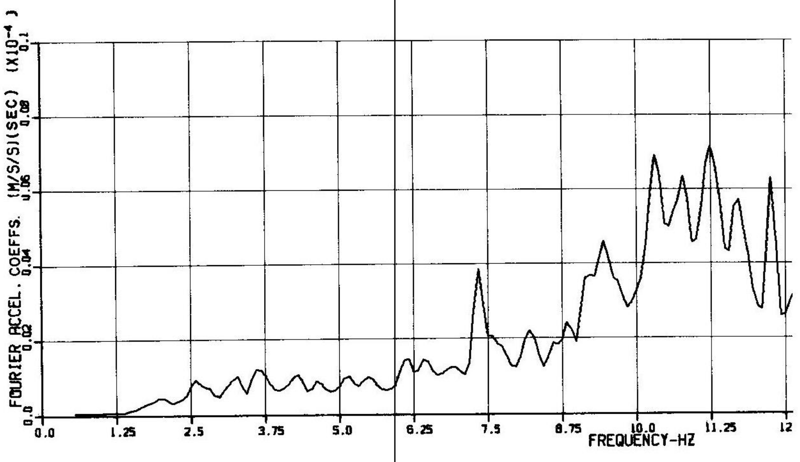


FIG. 8a FOURIER ANALYSIS OF M9N (UVIC OUTSIDE STH WALL OF LIBRARY)

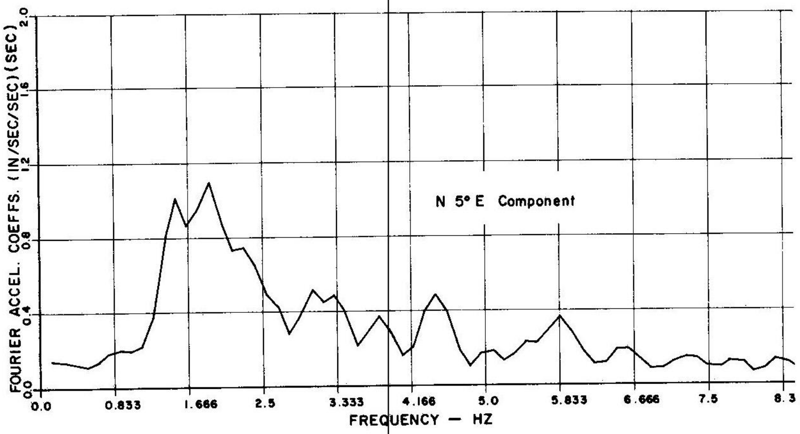


FIG. 8b FOURIER ANALYSIS FOR U. VIC. RECORDING OF SEATTLE EARTHQUAKE 29 APRIL 1965.

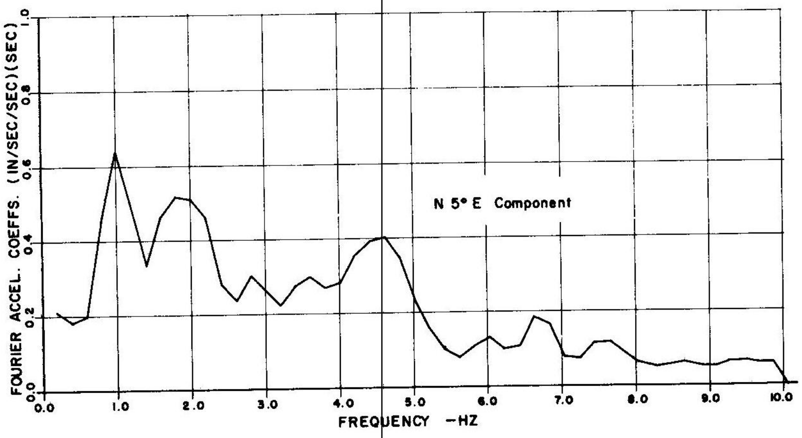


FIG. 8c FOURIER ANALYSIS FOR U. VIC. RECORD OF BELLINGHAM EARTHQUAKE OF 14 FEB. 1969.

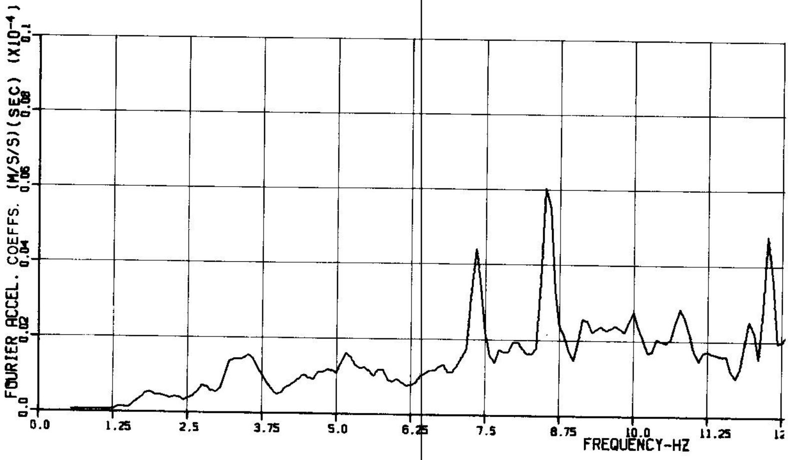


FIG. 9a FOURIER ANALYSIS OF M9E (UVIC OUTSIDE STH WALL OF LIBRARY)

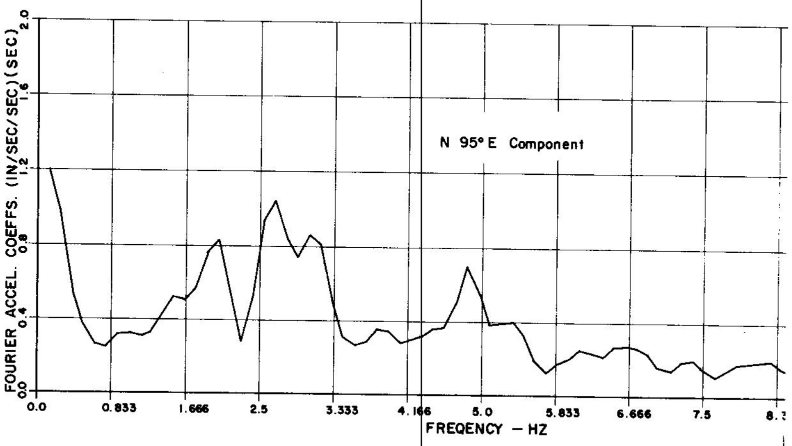


FIG. 9b FOURIER ANALYSIS FOR U. VIC. RECORDING OF SEATTLE EARTHQUAKE 29 APRIL 1965.

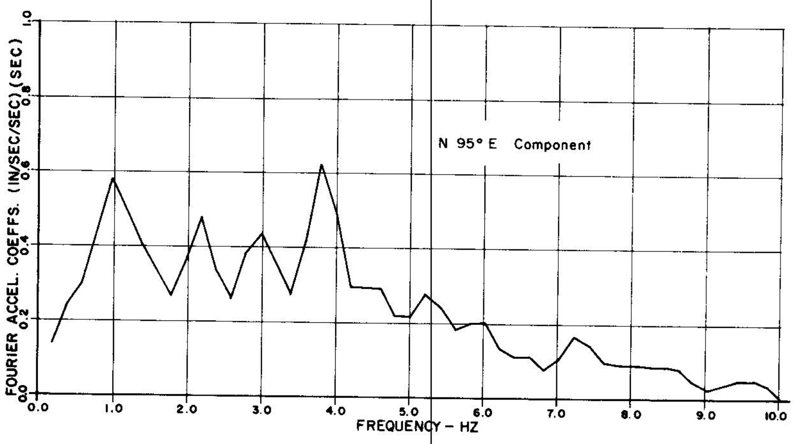


FIG. 9c FOURIER ANALYSIS FOR U. VIC. RECORD OF BELLINGHAM EARTHQUAKE OF 14 FEB. 1969.