APPLICATION OF MICROTREMOR MEASUREMENTS TO EARTHQUAKE ENGINEERING

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INTRODUCTION

Two previous papers published in this Bulletin (Refs 1, 2) described the methods developed at the University of Auckland, School of Engineering for recording and analysing microtremors. In this paper, the applications of microtremor measurements to earthquake resistant design of structures are critically examined. Specific applications are discussed and compared with results obtained by the authors. Finally, it is shown that, using computer techniques, it is possible to simulate ground motions which have the characteristics of recorded microtremor motions.

THE APPLICATION OF MICROTREMOR MEASUREMENTS

Because of the continuous nature of microtremors there is no difficulty in recording them. A review of microtremor investigations (presented in the first paper in this series) revealed that the characteristics of surface recorded microtremors do indeed reflect subsoil conditions. Microtremors recorded on deep soft deposits generally exhibit longer predominant periods than those recorded on harder deposits or exposed bedrock.

Kanai (3,4) has recorded microtremors and earthquake shaking at a number of sites. Generally his results have been published in terms of a period distribution curve in which the frequency of occurrence was plotted against period. The method of deriving this from the original record was outlined earlier (2).

Published period distribution curves of microtremors and earthquakes recorded by Kanai in the U.S.A. (3) show good agreement in some cases, while in other cases there is poor correlation.

From his studies of ground motions, Kanai (4) published an empirical relationship between the magnitude of recorded earthquakes and the associated predominant ground period. He concluded that, provided the magnitude of an earthquake exceeded a certain value, the predominant period of earthquake motion had a constant value at each place and this approximated to the predominant period as observed in microtremors.

In other publications also, Kanai contends that predominant periods in earthquakes and in microtremors will be the same, at a particular site. This conclusion is at variance with that of the present authors.

Kanai and Tanaka (5) have presented an empirical microzoning technique for earthquake resistant structural design based on recorded microtremors. Two proposals are outlined: the first uses the 'mean' period and the 'largest' period (that is the period of the largest amplitude wave), while the second method uses the largest amplitude of the recorded motion and the predominant period at the site to categorize the subsoil material. Subsoils are classified using the characteristics of the observed microtremors with the aid of the microzoning charts reproduced in Figure 1.

The subsoil materials corresponding to each type of spectrum are as follows :-

Type I	ground consisting of rock, hard sandy gravel etc., classified as tertiary or older strata
Type II	ground consisting of sandy gravel, sandy hard clay, loam etc., classified as gravelly alluvium up to 5 m in depth
Type III	as Type II but exceeding 5 m in depth
Type IV	alluvium consisting of soft delta deposits, topsoil, mud etc., exceeding 30 m in depth. Land obtained by reclamation of marsh where more than 30 years have elapsed since time of reclamation.

Having classified the subsoil in this manner, a design seismic coefficient related to the type of construction is obtained by reference to Table 1.

Such design methods are apparently accepted by Japanese engineers. The design procedure has been detailed by the Architectural Institute of Japan (6).

Okamoto et al. (7) measure accelerations during a number of small earthquakes at the base and crest of the Sannokai Dam in Japan. The dam, behaving as a dynamic soil structure, showed higher crest acceleration than base accelerations. Seed and Idriss (8) have published the base motion amplification curve (ratio of maximum crest to maximum base accelerations) for the range of base rock accelerations listed by Okamoto et al. Extrapolating this curve to expected microtremor and strong motion accelerations produces amplification factors which differ by at least a factor of 10. The exact amplification ratio between microtremors and strong motion shaking has not been determined.

Grant-Taylor et al. (9) made a series of

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microtremor recordings to assist in preparing an earthquake microzoning map. Previous experience (10, 11) had shown that the surface microseismic noise level could be broadly related to the thickness of overburden and soft sediments at a particular site.

In this case, however, the uniformity of the recording levels prevented the isolation of distinct zones where selective amplification of seismic waves might occur. That is, the microtremor evidence in this case did not distinguish between areas with differing geological properties and those with differing depths of soft material.

Yamahara (12) examined the relationship between frequency characteristics of earthquakes, aftershocks and recorded microtremors and the incidence of seismic damage to structures. He classified microtremor power spectra according to their 'frequency selectivity'. Spectra having a single sharp peak would be described by Yamahara as having 'high frequency selectivity' whilst those with several (or no) predominant peaks would be described as having 'low frequency selectivity'.

Generally Yamahara found that where the frequency selectivity of the ground was high, as indicated by microtremor or power spectra, the incidence of building damage was higher than where the buildings were founded upon ground with low frequency selectivity.

Yamahara has presented power spectra of earthquake mainshocks, aftershocks and microtremors recorded at two different sites. At the first site, Hachinohe Technical College, aftershocks (of unstated magnitude) and microtremors are claimed by Yamahara to have the same predominant period. At the second site, Port of Hachinohe, microtremors, aftershocks and earthquakes all exhibit different predominant periods (see Figure 2).

Yamahara concludes that the similarity of microtremor and earthquake shaking is dependent upon the 'frequency selectivity' of the ground at a particular site; ground with low 'frequency selectivity' showing poor correlation. It is the contention of the present authors that all sites, except where bedrock extends to the surface, should exhibit a predominant period. Further, the predominant period will be dependent upon the relative magnitude of ground shaking at a particular site. Such contentions are borne out by the spectra published by Yamahara and included in this paper (Figure 2). Spectra published by Yamahara which were obtained at the Hachinohe Technical College, are not considered by these authors to possess a single predominant period.

A simple laboratory demonstration, in which a layer of soil is vibrated on a shaking table, provides what is possibly the most convincing evidence that predominant period is related to amplitude of vibration. The resonant frequency is found to decrease as the amplitude of base motion is increased (13). This is because soil exhibits non-linear behaviour, that is, the shear modulus decreases markedly as the amplitude of shear deformation is increased.

Discussion

The siesmic microzoning charts (Figure 1) produced by Kanai and Tanaka (3) were compared with data obtained from the microtremor recordings made during this study (14). Kanai's first proposal requires the evaluation of both "mean" and "largest" periods. As only predominant periods and amplitudes were determined in this study, only Kanai's second proposal could be evaluated.

Generally the classification method gave a fair indication of the nature of the subsoil at each site. As the method uses the maximum recorded amplitude of motion, it would appear desirable that there should be some minimum excitation level before recording commences. Alternatively there could be a sliding amplitude scale, chart values being dependent upon the range of amplitudes recorded at each session.

Yamahara (12) has published power spectra of microtremors, earthquakes and aftershocks at different sites. Generally his spectra confirm the belief of these authors that microtremors and earthquakes will exhibit different predominant periods. Although the magnitude of the aftershocks and earthquakes are not published, a progressive increase in predominant period from microtremors to earthquake can be noted in Figure 2.

Seed and Idriss (15) have published data concerning the predominant periods of several large earthquakes. Depending on the subsoil conditions, the value of the peak period in the velocity spectrum lies in the range 0.3 - 3 seconds. Velocity spectra of recorded microtremors, published in the second paper in this series (2), showed predominant periods in the range 0.1 - 0.5 seconds.

The use of microtremor measurements to infer <u>directly</u> the possible predominant ground periods during earthquake shaking is not believed by these authors to be a valid practice. The ratio of strains developed during strong shaking, to those under microtremor excitation, may be of the order of 10^4. Thus whatever the form of microtremor waves, the known non-linearity of soil properties will preclude the direct scaling of microtremor spectra.

SIMULATED MICROTREMOR MOTIONS

In recent years considerable advances have been made in the development of mathematical models which simulate the response of layered soil systems to arbitrarily prescribed base excitation. Such models have been developed and used by Seed and Idriss (6), Idriss and Seed (15) and Tsai (16) to name but a few.

A similar program to that used by Seed et al. was developed at Auckland University and used to simulate the response of layered soil deposits to earthquake like excitation, and later to simulate microtremor motions. Surface motions computed are those which would result from the vertical propagation of shear waves through a soil deposit. The soil deposit is idealized as series of lumped masses interconnected by shear springs.

The input motions for the microtremor simulations were a 'white noise' sequence (a randomly generated sequence of acceleration ordinates) and an actual microtremor record obtained on outcropping Waitemata sandstone at the Meadowbank site. The white noise record was scaled to have the same root mean square acceleration value as the Meadowbank microtremor acceleration record.

Soil parameters required for the computer simulations are strain-dependent values of shear modulus and equivalent viscous damping factor. These parameters may normally be obtained from appropriate dynamic laboratory tests or from the "average" damping and modulus curves published by Seed and Idriss (6).

Microtremors, having amplitudes of approximately 1 micron, result in a very low strains being developed in the soil profile. The curves published by Seed and Idriss for saturated clays have a lower strain amplitude of 0.001%. Conventional dynamic testing machines have an accurate lower limit of 0.002% shear strain. Thus to estimate soil parameters at microtremor strains it was necessary to extrapolate the known data back to a lower strain limit. Research at Auckland University (17) has shown that below a shear strain of 0.01%, the dynamic behaviour of soils tends towards elastic behaviour. At greater strains modulus values drop off appreciably. Thus soil moduli and damping parameters are reduced to constant values for each soil layer under microtremor strains.

Spectra of recorded and computed microtremors are presented in Figures 3 and 4. There is good agreement between the computed and recorded spectra at both sites, regardless of the input motion used. It should be noted that both the white noise input and the bedrock microtremor input recorded at Meadowbank produce flat featureless spectra.

That such agreement has been obtained may be purely fortuitous. However, the exercise has shown that there exists a lower bound to computed site periods.

CONCLUSIONS

The application of microtremor measurements to earthquake resistant design of structures has been critically examined. Several writers have suggested that microtremor predominant periods coincide with those recorded during strong motion shaking. This point is disputed by the present authors and evidence has been produced to substantiate their beliefs.

Seismic response studies have shown that microtremor response spectra may be produced which bear a striking resemblance to recorded microtremor spectra. Because of the non-linearity of soil moduli and damping factors simulated microtremor predominant periods are considerably different from strong motion simulations.

Finally, it has not been found possible to determine an empirical scaling factor which may be applied to recorded microtremor spectra to infer possible predominant periods of soil deposits under strong earthquake shaking. Such a factor must depend upon earthquake magnitude, subsoil conditions, dynamic soil parameters and surface topography.

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TABLE 1

SEISMIC COEFFICIENTS

Subsoil Type	Construction Type			
	A	B	C	D
I	0.6	0.6	0.8	1.0
II	0.8	0.8	0.9	1.0
III	1.0	1.0	1.0	1.0
IV	1.5	1.0	1.0	1.0

A	Wooden Construction
B	Steel Framed Construction
C	Reinforced Concrete, steel frame and reinforced concrete or composite steel and concrete construction
D	Masonry, Brick, concrete block

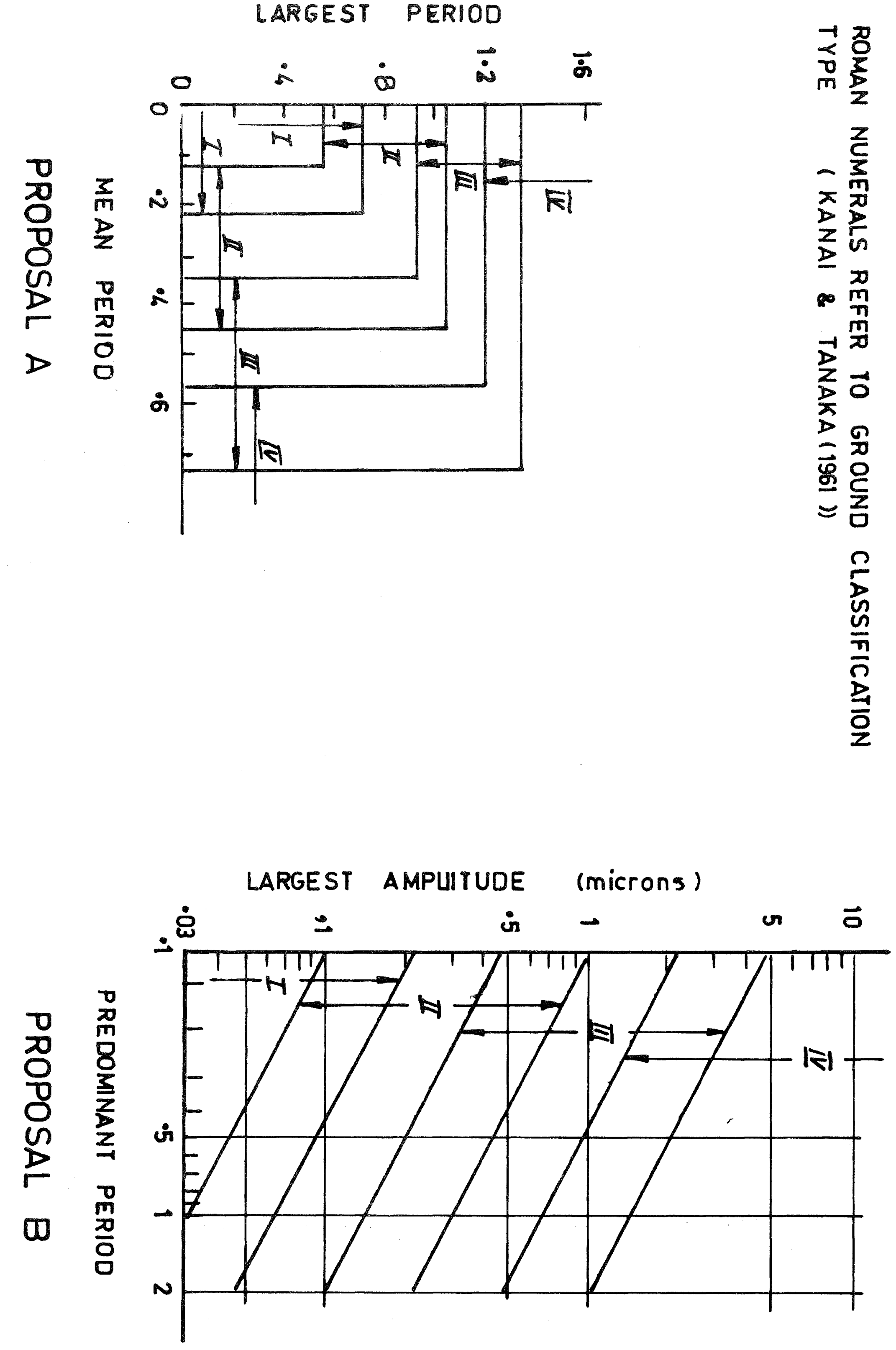

FIGURE 1 : Microtremor Zoning Proposals.

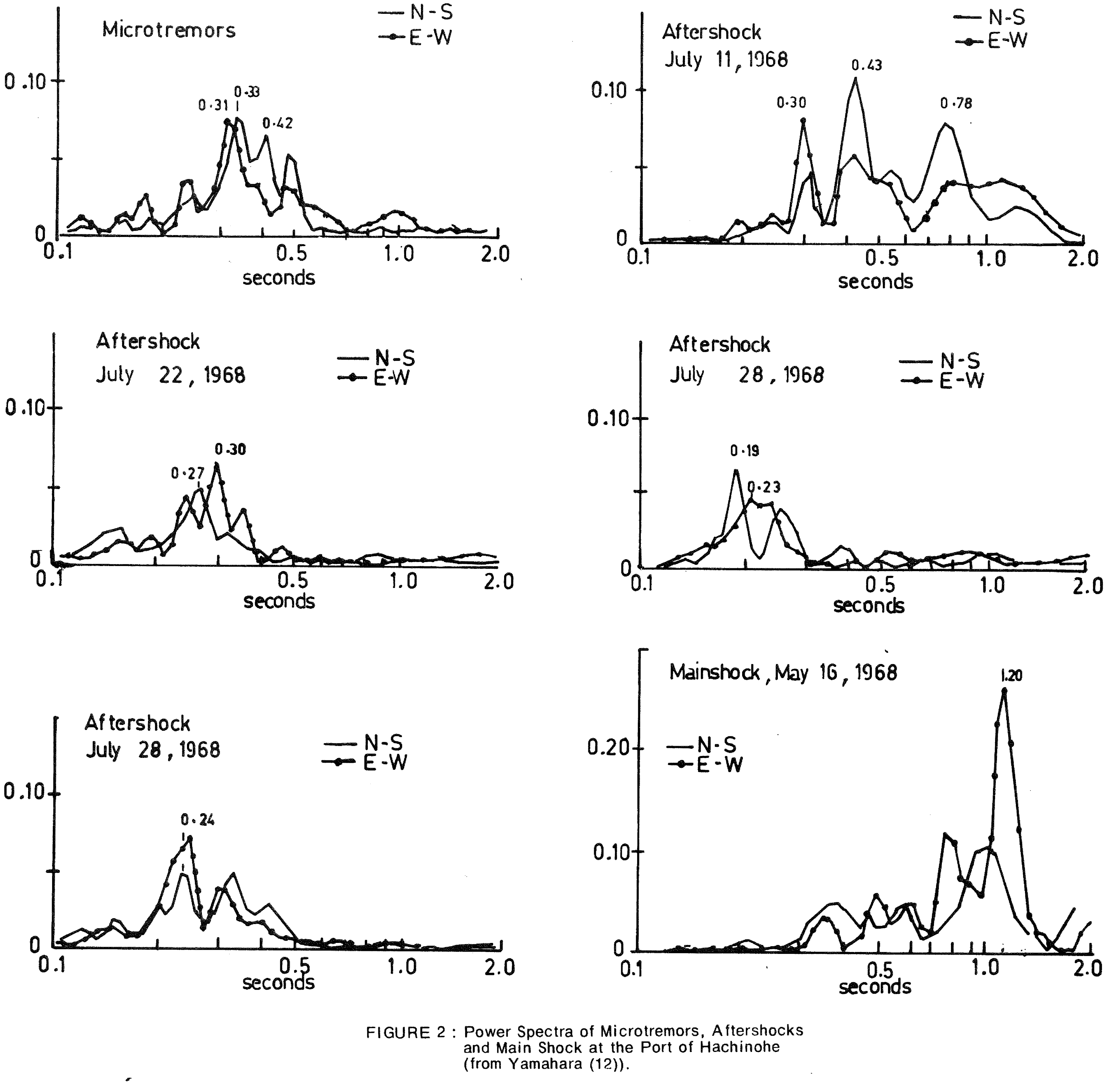

FIGURE 2 : Power Spectra of Microtremors, Aftershocks and Main Shock at the Port of Hachinohe (from Yamahara (12)).

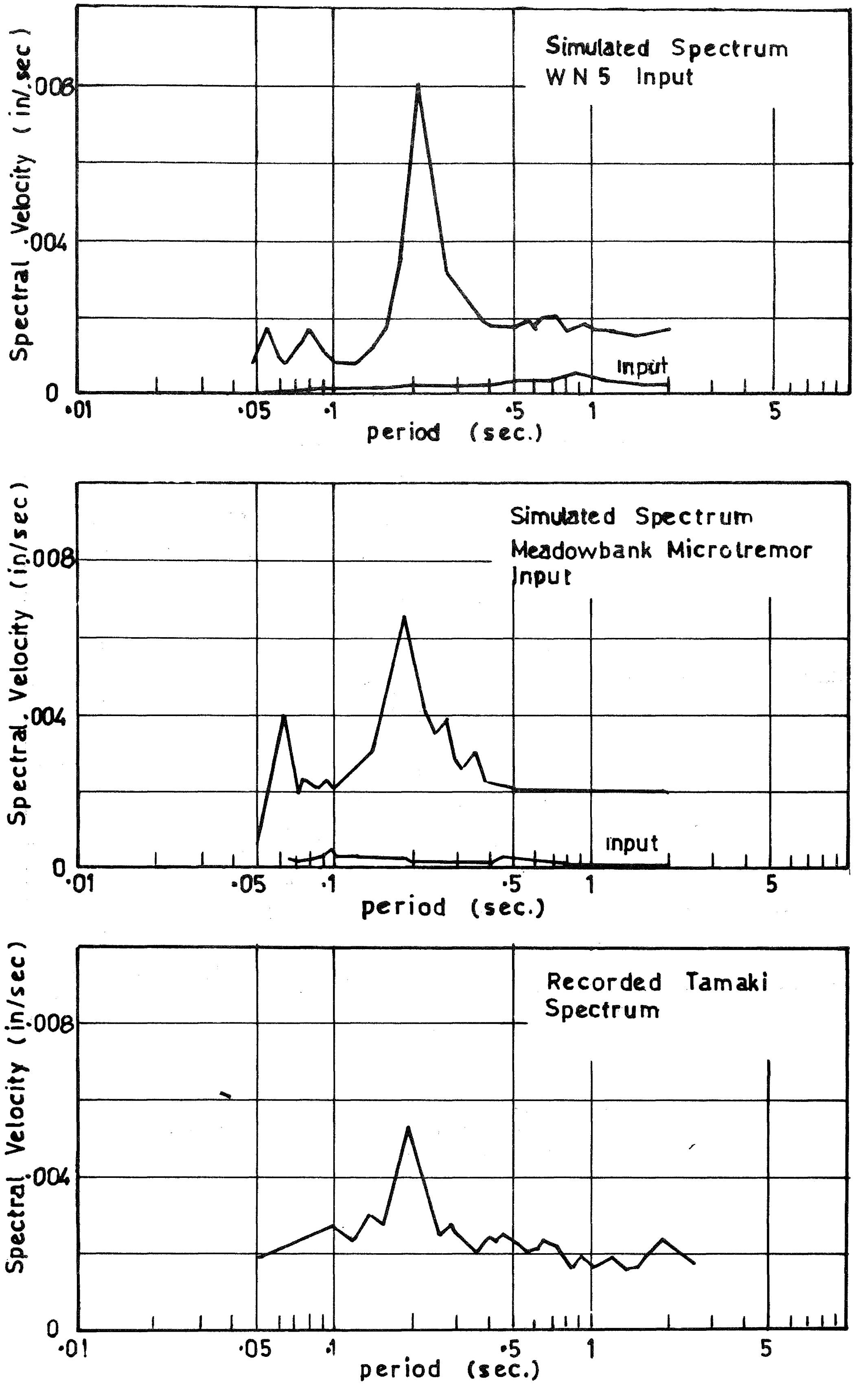

FIGURE 3 : Comparison of Simulated and Recorded Microtremor Response Spectra, Tamaki Site, 5% Spectral damping.

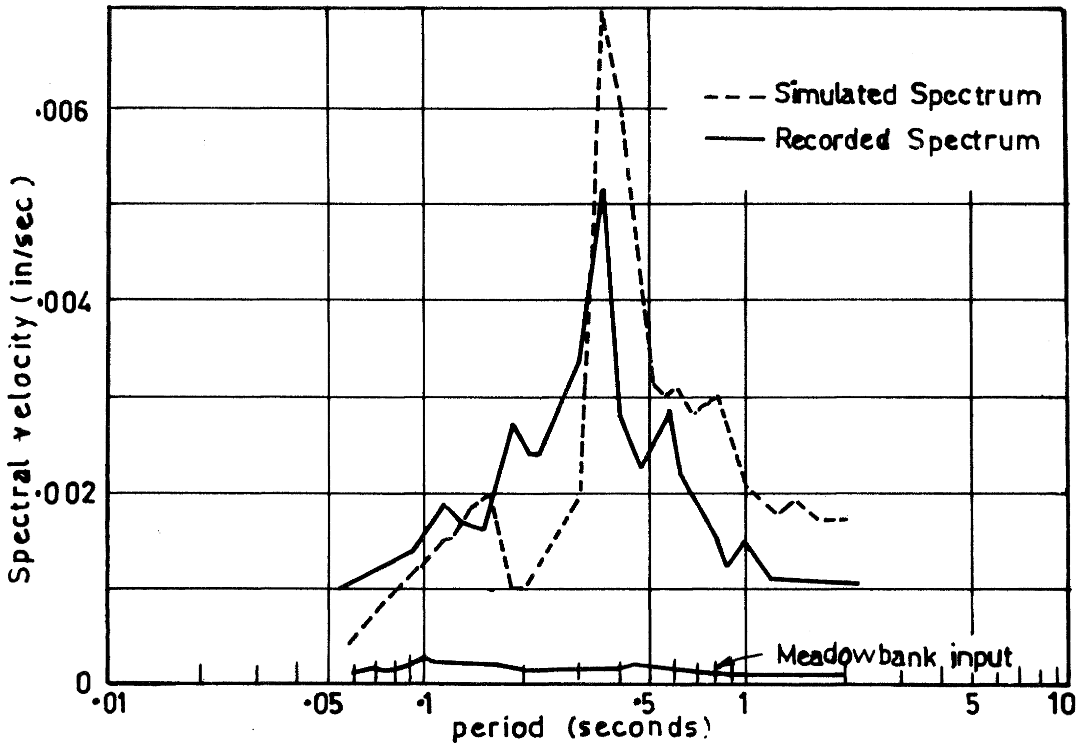

FIGURE 4 : Comparison of Simulated and Recorded Microtremor Response Spectra, Takanini Site, 5% spectral damping.