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On correlation of the energies of primary and secondary storm microseisms

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ABSTRACT

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The estimations made by Ostrovsky (1979) have revealed that the energy correlation of primary and secondary storm microseisms should substantially increase with increasing period of the oceanic waves generating them. Comparison with experimental data (Korhonen, 1971; Korhonen and Pirhonen, 1976; Bossolasco et al., 1973) showed that these conclusions are confirmed in many cases. This permitted a new interpretation of some of the results. The dependence of the intensity of primary and secondary microseisms on the period of oceanic waves is suggested as an additional criterion for the detection of the generation zones of microseisms.

1. Introduction

A long history of observations and analysis of microseisms has accumulated a great amount of theoretical and experimental data (see review by Monakhov, 1977).

A definite correlation between the strengthening of microseisms and the appearance of intensive cyclones over seas and oceans was revealed. The results of numerous measurements yielded two main mechanisms of microseism generation: the surf mechanism (Wiechert, 1904) generating primary microseisms with a period equal to the storm wave period, and the interference mechanism (Longuet-Higgins, 1950) generating secondary microseisms with a period equal to a half of that of the storm waves. In many papers these mechanisms were opposed to each other because of the contradictions which arose in the interpretation of empirical data. Though at present many scientists use both mechanisms for the analysis of microseism records, discussion of this problem still continues.

The main criterion used to determine whether surf or standing waves were the source of microseisms and whether location of the source of recorded microseisms coincided with the region where oceanic waves were observed was the coincidence in frequency of the spectral maximum of microseisms and the normal or double dominant frequency of oceanic waves.

Determination of main sources of microseisms became the first step in the solution of an important problem in seismology, which is the development of a quantitative model to define and forecast the intensity of microseisms in a given region on the basis of hydrometeorological parameters of the cyclone causing them. This problem was considered in hundreds of papers but it is still far from solution. Therefore, the determination of

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the correlation between the intensity of primary and secondary microseisms and the parameters of sea waves is urgent. This complicated problem was examined by Bath (1949), Hieblot and Rocard (1959), Hasselman (1963), and Darbyshire and Okeke (1969). They obtained theoretical correlations which have made possible an interpretation of much of the experimental data; however, need was felt to search for simpler models. Ostrovsky (1979) suggested such a model which connected the energy ratio of primary and secondary microseisms with the parameters of near-coast sea waves. The present paper contains the first results of a comparison of the theoretical estimates obtained there with the results of experiments on the recording and analysis of microseisms carried out by some European seismological observatories (Korhonen, 1971; Bossolasco et al., 1973; Korhonen and Pirhonen, 1976).

2. Analysis of the model

The energy correlation of primary and secondary microseisms generated by surf and by the interaction of opposing waves in the coastal zone was estimated (Ostrovsky, 1979) by the ratio of energy fluxes transferred by travelling waves towards the coast and radiated by a zone of wave interaction towards the bottom. It was assumed that energy loss in the two fluxes under study was the same during passage through water–coast and water–bottom interfaces, and that microseisms were recorded not far from the surf zone considered so that other sources of microseisms were negligibly small and the differences in attenuation of primary and secondary microseisms were insignificant.

Calculations showed that the ratio of energy flux transferred by surf towards the coast (W_1) to energy flux radiated by a zone of standing waves towards the bottom (W_2) is

$$K = \frac{W_1}{W_2} = \frac{c\lambda^{5/2}}{2^{11/2}\pi^{5/2}Ra^2x_0g^{1/2}}$$

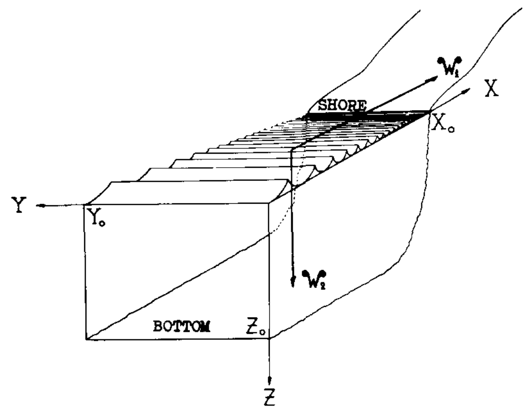

Fig. 1. Scheme for the generation of coastal microseisms. W_1 = energy flux transferred by surf towards the coast, W_2 = energy flux radiated by a zone of standing waves towards the bottom.

where c is the velocity of sound in water, λ is the wavelength, R is the reflection coefficient (which depends on the topography of the beach), a is the wave amplitude, g is the free fall acceleration, and x_0 is the length of coastal standing wave zone (Fig. 1).

One of the consequences of the estimates obtained is that an extension, all other things being equal, in the area of the standing wave zone would result in a relative increase in the intensity of secondary microseisms.

Another consequence is that W_1/W_2 is proportional to T^5/a^2 because, for deep sea areas, the sea wave period, T, is related to λ by the simple relation $T^2 = 2\pi\lambda/g$.

So, with small variations of surf amplitude, the W_1/W_2 ratio should increase noticeably with increasing dominant period of the storm sea waves which caused the analysed microseisms. This conclusion was correlated with experimental data obtained mainly for the Scandinavian-Baltic area.

3. Experimental data

The first correlation we made was with data obtained by a long-period seismograph at the seismic station at Oulu (Finland) in mid-1960s (Korhonen, 1971). The form of microseism spectra was studied by the analysis of hydrometeorologi-

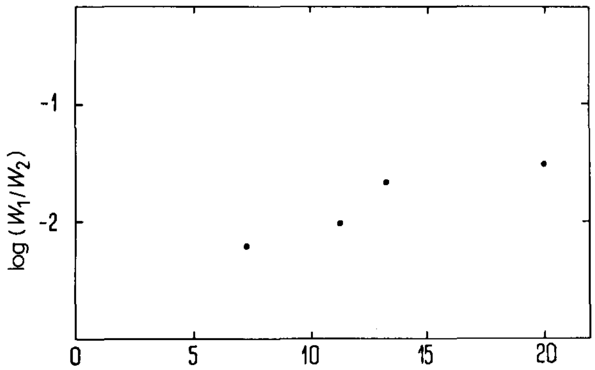

Fig. 2. The ratio W_1/W_2 versus T for the microseisms originating during storms in the Norwegian Sea (Korhonen, 1971). Here, and also in Figs. 3–5, note the increase of W_1/W_2 with increasing T.

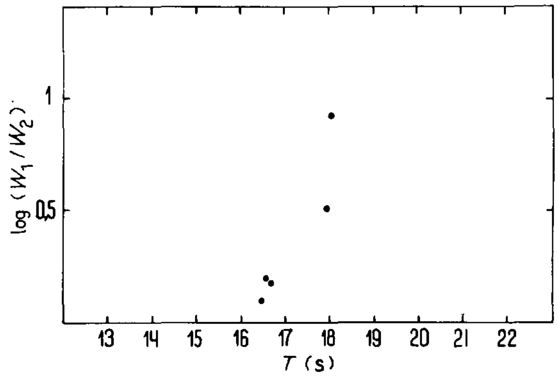

Fig. 3. The changing of the response of the corrected ratio W_1/W_2 versus T for the microseisms, recorded by NORSAR during storm 6 on May 1972 near the Norwegian coast [data and numbering of Korhonen and Pirhonen (1976)].

cal conditions in adjacent regions. All spectra were divided into two unequal groups according to the location of the source. The first small group was related to storms in the North Atlantic; the second, and larger group, included spectra of microseisms generated by surf near the Norwegian coast. All spectra show maxima with periods equal to or half that of the respective sea waves. Thus, the conditions of microseism generation near the Norwegian coast were approximately similar to the model analysed.

For comparison, the spectra from the second ("Norwegian") group, which had noticeably varying periods of primary microseism peaks, were taken. According to Korhonen (1971), these periods equalled the periods of surf-generated microseisms, which agrees with the model. The values of the W_1/W_2 ratio versus T are given in Fig. 2. The figure shows that, on a background of the over-all domination of secondary microseisms, the ratio W_1/W_2 increases significantly with increasing T.

In 1979 data were published on microseism recordings by long-period seismographs of the seismological system NORSAR (Korhonen and Pirhonen, 1976; Bungum et al., 1971). Together with the microseism recordings, the principal meteorological conditions in the North Atlantic, the Norwegian and North Seas were observed. Several intensive storms were chosen for analysis. The variation with time of the values of the spectral density and peak periods of primary and secondary microseisms, the direction and velocity of wind, and the direction and height of sea waves were studied. Wave observations were carried out on board an oceanographic vessel.

For comparison, storms 6 and 7 (number system by Korhonen and Pirhonen, 1976) were chosen, during which considerable period variations took place. As in the first case, the ratio W_1/W_2 was determined by the ratio of the spectral densities of the peaks of microseisms of the two types (in this case after correction for long-period seismograph response); the first peak period was assumed equal to the wave period and the second to half the wave period; thus the microseisms were supposed to be generated according to Wiechert (1904) and Longuet-Higgins (1950). Figures 3 and

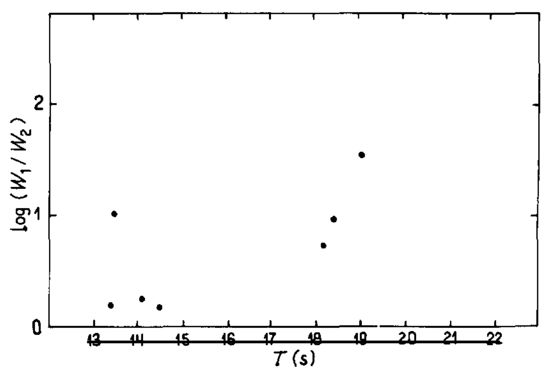

Fig. 4. The same as Fig. 3 for storm 7 on June 1972.

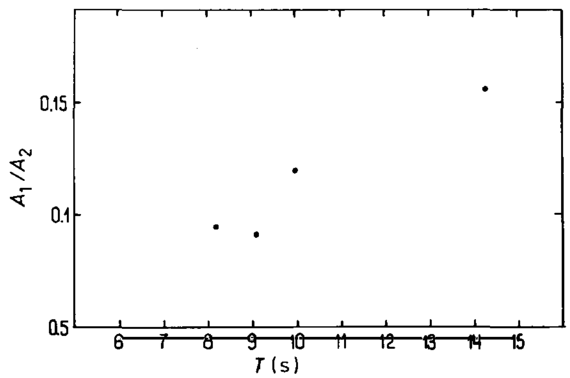

Fig. 5. The variation of A_1/A_2 with T for the spectra of microseisms recorded in Genoa at different times on December 30, 1970, according to the data of Bossolasco et al. (1973).

4 present W_1/W_2 versus T for both the storms mentioned. For storms 1, 2, and 8, the variation of the sea wave period was small; nevertheless they also showed a tendency for W_1/W_2 to increase with increasing T. The data on storms 3 and 5 revealed no change in W_1/W_2 with T, and for storm 4 the opposite dependence was observed.

The fourth and last comparison was made with data of Bossolasco et al. (1973). They were obtained in the vicinity of a coastal line that agreed best with the model. By measuring the ratio of the amplitudes of secondary (A_2) and primary (A_1) microseisms with varying surf periods for various storm conditions in the Mediterranean Sea in the vicinity of Genoa, Bossolasco et al. (1973) obtained data that disagree with ours. However, examination of the variation of A_1/A_2 with T for some storms reveals a situation which meets the model discussed here. For example, for the storm which occurred on December 30, 1970 (Fig. 5), the variation of the amplitude ratio of microseisms with changing surf period agreed with the model; however, on December 28, an opposite pattern was observed (Bossolasco et al., 1973).

4. Discussion

In our opinion, the data presented qualitatively confirm the estimates obtained earlier by Ostrovsky (1979). In spite of substantial assumptions which had simplified the model, its application can be useful for analysis of records of microseism spectra. Thus, we believe that using the model suggested in the analysis of data of Bossolasco et al. (1973) would permit them to be interpreted in more detail and, in some cases, possibly without the assumption of a considerable difference in the attenuation coefficients of primary and secondary microseisms.

Nevertheless, the process of microseism generation is obviously much more complicated and diverse in reality; therefore the model given does not pretend to be a complete quantitative description. It gives only a qualitative presentation of microseism sources, using comparatively simply measured quantities.

A satisfactory agreement of the model and the experiments indicates that in many cases. microseisms are generated in coastal zones according to the concepts of Wiechert and Longuet-Higgins. Nevertheless, there are data which do not agree with the model. As has been mentioned, for some of the storms analysed by Korhonen and Pirhonen (1976), W_1/W_2 was not dependent on T. This was probably due to lack of information on changes in sea wave amplitudes which caused the microseisms analysed (there were only on-board data on the amplitudes obtained far away from the zones of microseism origination) and also to considerable deviations of the real situation from the model (existence of many independent sources, interference of waves radiation by them, etc.).

One of the difficulties which the scientist meets is the necessity to determine the ocean region in which storm sea waves caused the microseisms under study. As already mentioned, the main criterion in this case is usually the coincidence or non-coincidence of the sea wave period with the primary peak period in the microseism spectrum. We suggest that an additional criterion for this analysis would be the presence or absence of a correlation between the variations of sea wave period and the intensities of primary and secondary microseisms. Further experiments should prove the effectiveness of such an approach, and further improvements in the model (e.g. the introduction of a coefficient correcting for coastal slope) would pave the way for a more detailed analysis of the process of microseism generation in coastal zones.

5. Conclusions

(1) Experimental data were compared with theoretical results obtained earlier in the description of the model for the generation of primary and secondary microseisms in the coastal zone.

(2) It is shown that, within the model, the energy ratio of primary and secondary microseisms is proportional to the fifth power of the period and inversely proportional to the square of the amplitude of surf waves which generate microseisms

$$\frac{W_1}{W_2} \approx \frac{T^5}{a^2}$$

(3) The results of observation and spectral analysis of storm microseisms showed that the ratio W_1/W_2 often increases with increasing T.

(4) The results obtained testify in favour of the concept of near-coast generation of storm microseisms, proposed by Wiechert and Longuet-Higgins, not excluding, however, the possibility of the generation of secondary-type microseisms far out in the ocean.

(5) The presence or absence of the correlation between variations of the sea wave period and the ratio of the intensities of primary and secondary microseisms can serve as an indication of the region of microseism generation.

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