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Amplitude spectra of microseisms generated by cyclonic storms

MATHURA SINGH and S. N. BHATTACHARYA

Meteorological Office, New Delhi

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सार — सूक्ष्म भूकंपों के मानावलीय विश्लेषण द्वारा सूक्ष्म भूकंपों की प्रबल अवधियों का अध्ययन किया गया है । चक्रवातीं तूफानों द्वारा पैदा किए गए ये सूक्ष्म भूकंप कोडईकनाल तथा पूना में रिकार्ड किए गए थे । जब तूफान बंगाल की खाड़ी तथा अरब सागर में विभिन्न गहराइयों पर होते हैं तब आयामी मानावली प्राप्त की जाती है । सूक्ष्म भूकंप दो प्रकार के पाए गए, एक 9.10 से 9.71 सैकण्ड की अवधि परास में और दूसरा 4.14 से 4.55 सैकण्ड की अवधि परास में । ध्यान देने योग्य दिलचस्प बात यह है कि पहले प्रकार का सूक्ष्म भूकंप प्राथमिक सूक्ष्म भूकंप से संबंधित है तथा उसकी अवधि महासागरीय तरंगों की अवधि जितनी ही है, जबकि दूसरा सूक्ष्म भूकंप प्रकार द्वितीयक सूक्ष्म भूकंप स संबंधित है तथा इसकी अवधि सागरीय तरंगों की अवधि से आधी है । ऐसा भी पाया गया है कि प्राथमिक सूक्ष्म भूकंप गहन समुद्र के ऊपर पैदा हुए तूफानों से पैदा हुए जान पड़े जबकि द्वितीयक सूक्ष्म भूकंप उथले और गहरे जल में उठे तूफान से पैदा होते पाए गए ।

ABSTRACT. The predominate periods of microseisms have been studied by spectral analysis of microseisms recorded at Kodaikanal and Poona generated by cyclonic storms. Amplitude spectra have been obtained when storms are at various depths over Bay of Bengal and Arabian Sea. Two types of microseisms are noticed; one in the period range from 9.10 to 9.71 sec and the other from 4.14 to 4.55 sec. It is interesting to note that the former belongs to primary microseisms having the same period as the ocean waves while the latter belongs to secondary microseisms with half the period of sea waves. It has also been found that the primary microseisms appear to be generated from storms over deep sea while the secondary microseisms are observed from storms both over shallow and deep water.

1. Introduction

Microseisms constitute a random process, like atmospheric turbulance and ocean surface waves. The main problem in microseisms research is to establish their origin. Among the recent developed techniques the spectral analysis offers a powerful means of distinguishing microseisms of different origins. In the last two decades, different workers have studied the origin of microseisms by this method (*e.g.*, Darbyshire and Okeke 1969, Bossolasco *et al.* 1973, Bath 1974). The amplitude spectrum of microseisms shows two distinct maxima at about 0.07 Hz and other at about 0.14 Hz. The former agrees with the frequency of ocean waves and this type of microseisms is called primary microseisms. The theory of primary microseisms follows from the works of Banerji (1930) and is generated by interactions of gravity waves with sea bottom. The microseisms around the frequency 0.14 Hz are called secondary microseisms and has half the period of ocean waves. These are generated due to standing waves produced by two travelling ocean waves with same frequency and in opposite direction. Longuet-Higgins (1950) showed that the pressure field associated with standing waves has a component which does not decay with depth and could interact with the ocean bottom to generate microseisms.

Banerji (1930) noted that microseisms generated from Bay of Bengal and Arabian Sea have the period between 4 and 6 seconds. Same period range was observed by Tandon (1957), Singh and Bhattacharya (1983) from cyclones over Bay of Bengal. Tandon (1957) noted that microseisms were of period 4 to 5 sec from cyclones over Arabian Sea. However, Anjaneyulu (1961) observes 3 to 5 sec period of microseisms generated by cyclones over the Bay of Bengal. Since spectral analysis gives us a clear insight about the dominant frequency of microseisms, the above discrepancies, in the results of different workers could be resolved. The object of this paper is, therefore, to study the spectral behaviour of microseisms in the frequency range from 0.03 to 0.5 Hz generated from cyclones over Bay of Bengal and Arabian Sea.

2. Data

In this study we have considered microseisms recorded at Kodaikanal (KOD) and Poona (POO) which lie in the Indian Peninsula. The location of these stations is shown in Fig. 1. Both these stations belong to World Wide Standardised Seismograph network. Fig. 1 and Table 1 show the track and position of the cyclonic storms used in the present study. In this figure depth contours are also shown.

We know that microseisms mainly consist of Rayleigh waves; however, there is also a love-wave component in microseisms. To avoid the contribution of love-wave

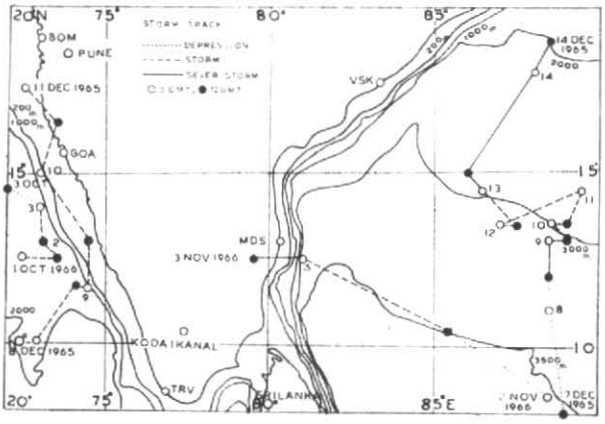

Fig. 1. Position of the recording stations and tracks of storms

TABLE 1

Station	Date	Time hr	Time min	Storm position Lat. (°N)	Storm position Long. (°E)	Intensity of storm	Primary microseisms Freq. (f_p) (Hz)	Primary microseisms Period (T_p) (sec)	Primary microseisms Peak amp. spectrum (mm sec)	Secondary microseisms Freq. (f_s) (Hz)	Secondary microseisms Period (T_s) (sec)	Secondary microseisms Peak amp. spectrum (mm sec)	Mean ground amplitude recorded by L-P vertical seismograph (mm)
KOD	09 Dec 65	03	03	13.0	88.5	SCS	0.134	7.447	0.625×10^{-3}	0.227	4.404	0.519×10^{-2}	4.13
	09 Dec 65	12	02	13.0	88.0	SCS				0.212	4.697	0.446×10^{-1}	3.58
	10 Dec 65	03	08	13.5	88.5	CS				0.217	4.602	0.300×100^{-1}	3.57
	10 Dec 65	12	05	13.5	89.0	CS				0.219	4.551	0.195×10^{-2}	1.91
	01 Nov 66	12	02	9.5	92.3	DD	0.109	9.102	0.233×10^{-1}				1.73
	02 Nov 66	12	06	10.5	85.5	CS	0.115	8.714	0.309×10^{-1}	0.241	4.179	0.979×10^{-2}	2.23
	03 Nov 66	03	11	12.5	81.0	SCS	0.115	8.714	0.163×10^{-1}	0.203	4.934	0.307×10^{-1}	2.74
POO	10 Dec 65	03	05	15.0	73.0	CS				0.227	4.404	0.382×10^{-1}	3.04
	10 Dec 65	12	01	16.5	73.4	CS				0.241	4.137	0.319×10^{-1}	2.21
	11 Dec 65	12	01	17.5	72.5	CS				0.237	4.222	0.115×10^{-1}	2.80
	12 Dec 65	12	03	17.5	72.5	DD				0.222	4.501	0.232×10^{-1}	2.27
	01 Oct 66	02	53	12.5	72.5	CS				0.217	4.602	0.153×10^{-1}	1.48
	01 Oct 66	12	01	12.5	73.5	CS	0.119	8.359	0.336×10^{-2}	0.243	4.984	0.115×10^{-1}	1.99
										0.241	4.137	0.116×10^{-1}	

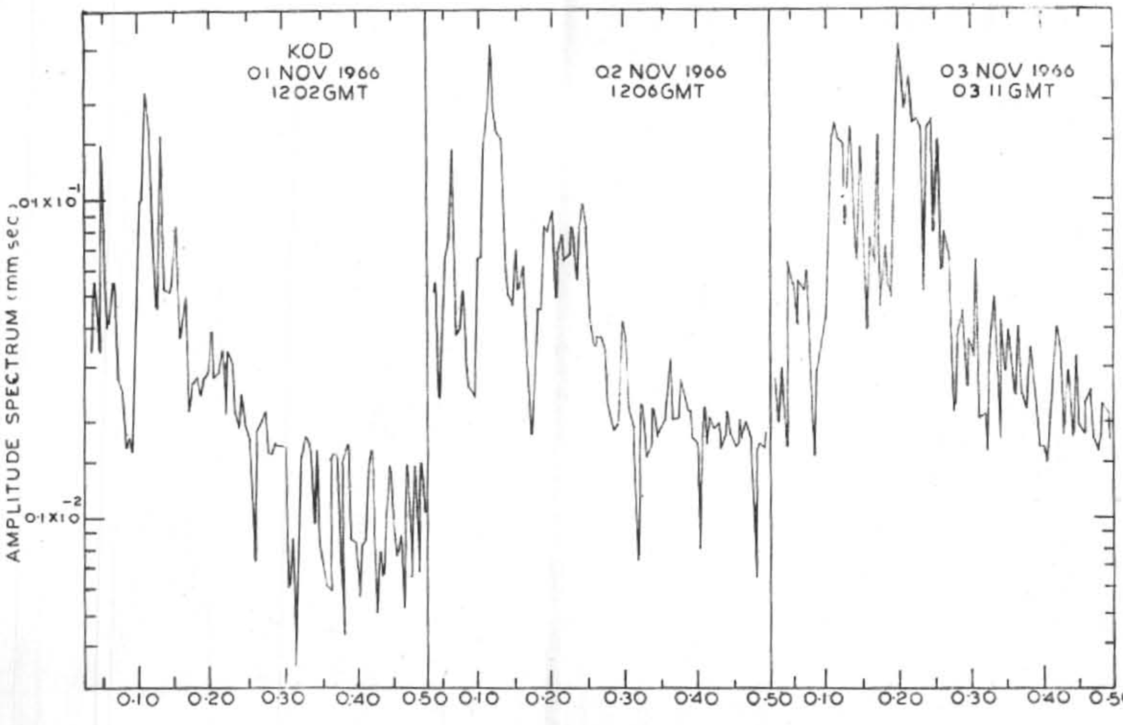

Fig. 2. Amplitude spectra of microseisms by the storm of 1 November 1966 over Bay of Bengal

we have used the data from the vertical component of long period seismograph ($Ts=15.0$ sec and $Tg=100.0$ sec). The recorded microseisms are magnified for digitization. The recording speed of the drum was 30 mm/min during the period 1965 and 1966 which was changed to 15 mm/min later. It is found from experience that the microseismic record of 1965 and 1966 could only be magnified suitably to cover the frequency range of interest.

Microseisms recorded at KOD from all the cyclones over the Bay of Bengal during 1965 and 1966 and microseisms recorded at POO from all the cyclones over Arabian Sea during the same years are considered. Whenever appreciable amplitude of microseisms is noted on seismograms at about 03 GMT and 12 GMT, the recorded amplitude is digitized at an interval of 0.4 sec; 1024 samples are taken from the beginning of time of observations. Digitization at 03 GMT and 12 GMT sometimes could not be performed either due to arrival of an earthquake or due to changing of seismograms during this time.

3. Method

For finding out the amplitude spectra of microseisms, we suppose that microseisms can be regarded as stochastic signals, *i.e.*, the microseisms show a Gaussian distribution repeating in time. This assumption is valid because the microseisms can be considered as a more or less wide band Gaussian noise, mixed with other persistent or quasi-persistent signals or as a summation of these components. However, in case of mutually independent sources, the microseismic energy may be considered as a sum of partial energy from the given number of sources.

For any given time domain function

$$f(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}F(\omega)\,e^{i\omega t}\,d\omega$$

The Fourier spectrum is given by

$$F(\omega)=\int_{-\infty}^{\infty}f(t)\,e^{-i\omega t}\,dt$$

To evaluate $F(\omega)$ we have applied the Fast Fourier Transformation (FFT) with number of points as 1024 ($=2^{10}$). The main advantage of FFT is the increased speed, because of a much lower number of operations compared to other methods, while accuracy is the same.

The Fourier transform $F(\omega)$ is divided by instrumental response $I(\omega)$ to get the ground vibration $G(\omega)$. The instrumental response $I(\omega)$ has been obtained using the formula given by Hagiwara (1958). $G(\omega)$ is a complex quantity and the amplitude spectrum is obtained as

$$A=|G(\omega)|=\sqrt{[\{R_e\,G(\omega)\}^2+\{I_m\,G(\omega)\}^2]}$$

4. Amplitude spectrum

The Fig. 2 shows the amplitude spectrum of microseisms recorded at KOD on 1st (12 hr 02 min), 2nd

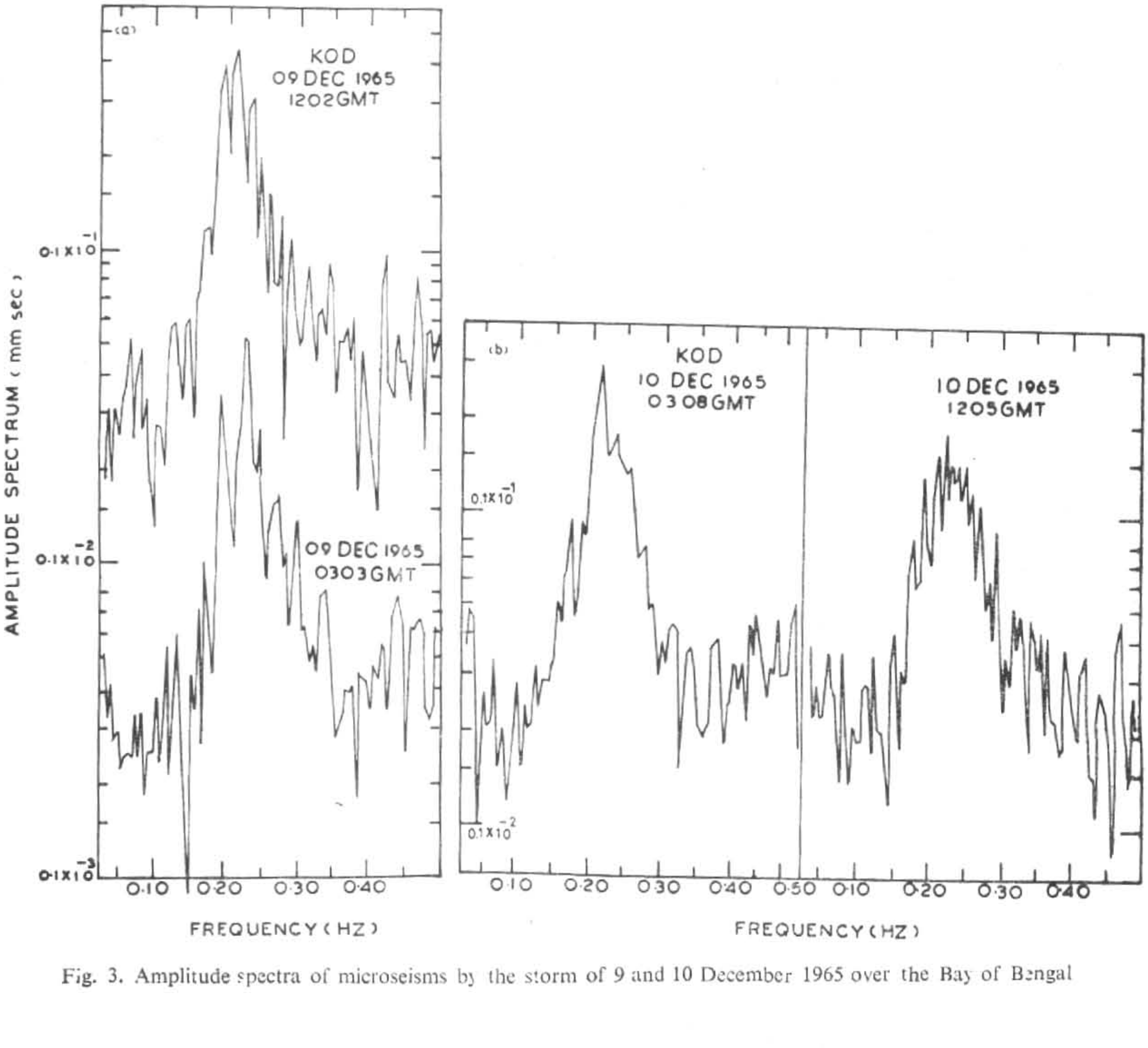

Fig. 3. Amplitude spectra of microseisms by the storm of 9 and 10 December 1965 over the Bay of Bengal

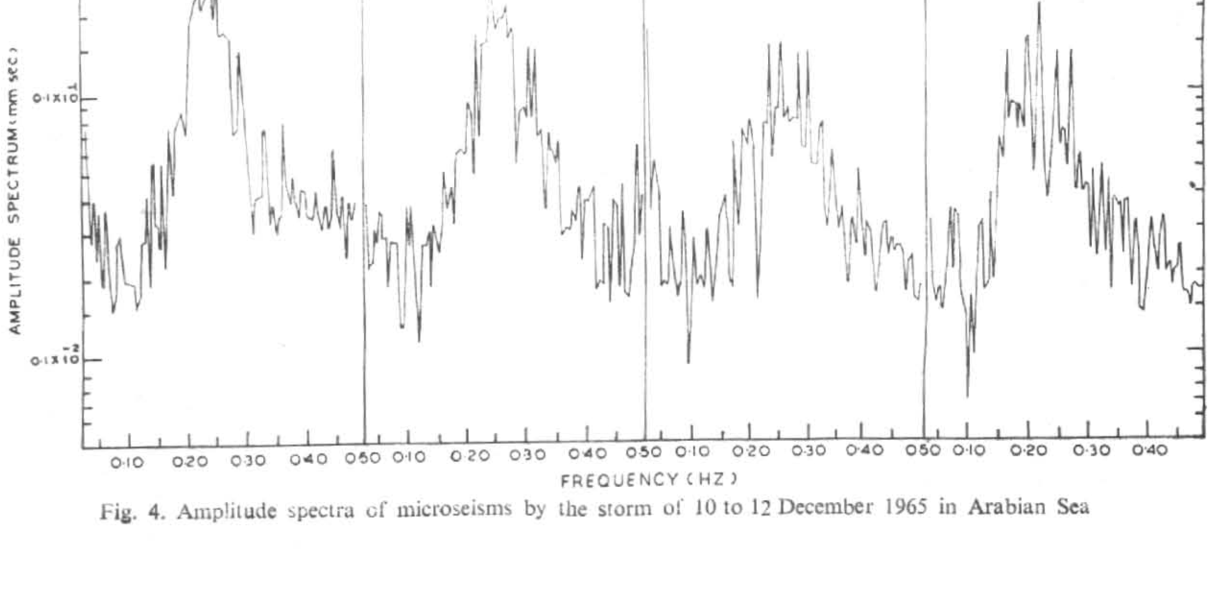

Fig. 4. Amplitude spectra of microseisms by the storm of 10 to 12 December 1965 in Arabian Sea

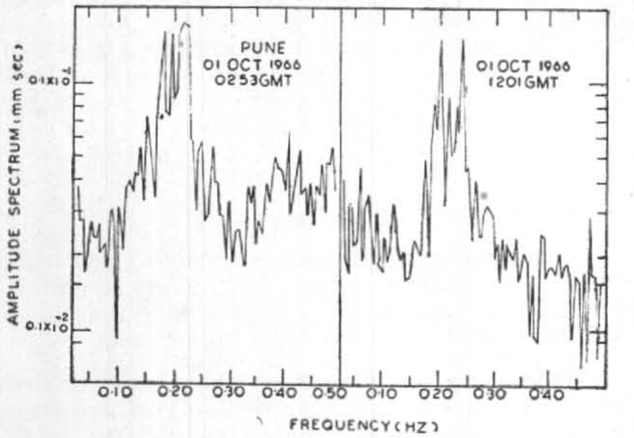

Fig. 5. Amplitude spectra of microseisms by the storm of 1 October 1966 in Arabian Sea

(12 hr 06 min) and 3rd (03 hr 11 min) November 1966 for a cyclone over Bay of Bengal. This cyclone intensified to a severe cyclone (Fig. 1) where the depth of the ocean was approximately 1000 m on 1st evening and afterwards its movement remained in deep ocean approximately (3500 m) till 3rd morning when it came close to the coast. The amplitude spectrum of 1 November 1966 has peak at 0.109 Hz with an amplitude 0.233×10^{-1} mm sec; in this figure a weak maximum may be seen in the frequency range 0.197 to 0.229 Hz. The amplitude spectrum of next day shows peak at 0.115 Hz with an amplitude 0.309×10^{-1} mm sec. However, another peak can be seen at 0.241 Hz on 3 November when the amplitude spectrum shows the peak again at 0.115 Hz; however amplitude at this frequency now decreases to 0.163×10^{-1} mm sec, although the storm comes close to the station. Further, the main peak on 3 Nov is at 0.203 Hz. It may be seen that one peak is appearing in the frequency range 0.109 to 0.115 Hz and the other in the range 0.203 to 0.241 Hz (ignoring the weak max on 1st). Although we do not have frequency of the ocean waves for comparison, we note that the frequency at which the first peak is appearing is nearly half of the frequency at which the second peak is appearing. On the basis of the two theories of origin of microseisms mentioned, we may infer that the former frequency range 0 109 to 0.115 Hz corresponds to the frequency of ocean waves and microseisms of this frequency range are primary microseisms. On the other hand, the microseims of frequency 0.203 to 0.241 are secondary microseisms.

Another storm over Bay of Bengal intensified to severe cyclonic storm from the evening of 8 December 1965 and weakened to cyclonic storm on 10th morning. It again intensified to severe cyclonic storm from the morning of 13th and weakened to cyclonic storm on the evening of 14th. During this period there was another cyclonic storm over Arabian Sea; this also intensified to cyclonic storm near Cannanore islands and remained in this stage till the morning of 11th from the 8th evening, *the track of the storm* remained in shallow water (depth $<$200 m). On the other hand the depth of ocean along the track of the storm in Bay of Bengal from 8th to 10th morning was between 3000 m & 3500 m.

The amplitude spectrum of KOD of 9th and 10th is shown in Fig. 3. It may be noted that during this period although the Bay storm was at a larger distance than the Arabian storm but the effect of both the cyclones is equally significant as the former storm is one stage higher in intensity than the latter. Thus amplitude spectra shown in Fig. 3 are due to both storms, one at deep sea and another at shallow water. The amplitude spectra of 9th at 03 hr 03 min has maximum at 0.227 Hz with amplitude 0.519×10^{-2} mm sec. On 9th at 12 hr 02 min the peak of amplitude is 0.446×10^{-1} mm sec at 0.212 Hz. On 10th, a t03 hr 08 min the peak of amplitude exists at 0. 217 Hz with amplitude 0.300×10^{-1} mm sec and the same at 12 hr 05 min of 10 December is at 0.219 Hz with amplitude 0.195×10^{-1} mm sec. Thus the frequency at which amplitude spectrum is maximum ranges between 0.212 Hz and 0.219 Hz. Presuming the ocean wave has same frequency as in the cyclone of 1-3 November 1966, this amplitude peak corresponds to secondary microseisms. A weak peak exists at frequency 0.134 Hz at 03 hr 03 min on 9th and this corresponds to primary microseisms. Thus, even though one storm was at deep water and other at shallow water, the storms could not generate primary microseisms, in general, in this case.

The amplitude spectrum has been obtained for microseisms recorded at POO during 10 to 12 December 1965 (Fig. 4). Due to the proximity of the Arabian Sea storm the microseisms recorded at POO are mainly due to the generation by this storm. The amplitude of 10 December 1965 at 03 hr 05 min has maximum at 0.227 Hz with amplitude 0.382×10^{-1} mm sec. The peak of the amplitude at 12 hr 01 min of 10 December is at 0.241 Hz with amplitude 0.319×10^{-1} mm sec and the same at 12 hr 01 min on 11 December is at 0.237 Hz with amplitude 0.115×10^{-1} mm sec. On 12 December 1965 at 12 hr 03 min it exists at 0.222 Hz with amplitude 0.232×10^{-1} mm sec. Thus, the peak amplitude is existing in the frequency range 0.222 to 0.241 Hz. In view of the result described above, these also correspond to secondary microseisms.

On 1 October 1966 a cyclonic storm was located over the Arabian Sea where the ocean depth was approximately 2000 m and approximately 200 km from the coast. Spectral analysis of microseisms recorded at POO at 02 hr 53 min. Fig. 5(a) shows peak at 0.217 Hz with amplitude spectrum 0.153×10^{-1} mm sec. The peak of the amplitude spectrum at 12 hr 01 min of 1 October 1966 exists at 0.243 Hz and 0.241 Hz with amplitude 0.115×10^{-1} mm sec and 0.116×10^{-1} mm sec respectively. These correspond to secondary microseisms. However, at 12 hr 01 min a weak peak also appears at 0.119 Hz with amplitude 0.338×10^{-2} mm sec and this corresponds to primary microseisms.

5. Discussions

Table 1 shows the peak amplitude spectrum of primary and secondary microseisms as they are observed. The mean ground amplitude in time domain as magnified by U.S.G.S. long period seismograph has also been given in the table. For the exact ground movement the amplitude should be divided by the magnification of the seismograph. However, as the wave consisted of multiple periods and magnifications are different at different periods. The exact ground movement could not be obtained. The exact ground amplitude at different frequencies has been obtained by spectrum analysis.

The microseisms recorded at KOD from storm location over Bay of Bengal on 1, 2 and 3 November 1966, showed that primary microseisms began generating when the storm is at deep sea. As the storm moved towards the coast, the secondary microseisms started appearing and became prominent when the storm was close to coast. However, primary microseisms dominated till the storm remained over the deep sea away from the coast. On the other hand, the microseisms of KOD from storm location of 9 December 1965 showed only secondary microseisms even though the storm location is at deep sea away from coast. The possible explanation for such a difference is that the situations for creation of standing wave were available in the storm of December 1965 and this was apparently lacking during the storm of November 1966; further, it appears during the storm of November 1966 that the sea waves were high enough for the generation of primary microseisms. It may be mentioned that usually secondary microseisms are noted when the storm is over deep ocean (Darbyshire and Okeke 1969). The microseisms record of POO were obtained only when storm positions were over shallow water (less than 1000 m) and only secondary microseisms were seen.

Thus it is seen that secondary microseisms are generated both in deep as well as in shallow water subject to the condition of formation of standing waves. However, it is noted that effective generation of secondary microseisms occurs when the storm is near the coast as standing waves are formed in association with the reflection of the travelling waves from the coast. We have also noted primary microseisms when the storm is over deep sea away from the coast.

Banerji (1930) showed that primary microseisms may be generated in deep sea also by interactions of sea gravity waves on ocean bottom. Primary microseisms have been seen to be generated from Irish Sea (Darbyshire and Okeke 1969). It seems that when the storm is over deep sea high sea waves are formed which are favourable for generation of primary microseisms. However, the generation of primary microseisms is also possible when the storm is near the coast if amplitude of sea waves is sufficient. However, such situations did not occur in the cases considered here. It may also be mentioned that the attenuation factor γ_r of Rayleigh wave is nearly half at primary frequency relative to the attenuation factor at secondary frequency. As such, primary microseisms are less attenuated with distance compared to secondary microseisms.

It may, thus, be summarised that the frequency of primary microseisms lies in the range of 0.109 to 0.115 Hz while that for the secondary microseisms from 0.219 to 0.241 Hz. However, this frequency range is higher than the microseisms observed from extra-tropical cyclones which could, perhaps, be attributed to the differences in sea wave frequency.

6. Conclusions

(1) The primary microseisms from storms over Indian seas have the frequency range 0.109 to 0.115 Hz (period : 9.10-9.71 sec) and the range of secondary microseisms is 0.219 to 0.241 Hz (period : 4.14-4.55 sec).

(2) Secondary microseisms have been observed to be generated by storms over both shallow and deep water. Secondary microseisms are more likely when the storm is near the coast since condition of standing wave formation is favourable. The standing waves at the centre of the cyclone and in the coastal zone do not differ significantly.

(3) We have noted primary microseisms only when storm is over deep sea; but in conjunction with earlier works (Darbyshire and Okeke 1969) we may conclude that the primary microsiesms are also generated by storms over both shallow and deep water.

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