Structure of Microseisms from Bay of Bengal

B. P. SAHA

Central Seismological Observatory, Shillong

(*Received 9 September 1965*)

ABSTRACT. The ground motion of microseisms from the Bay of Bengal was studied with the help of records obtained from the three component seismographs of the Press-Ewing type. The results of the study indicate that the microseisms from the Bay of Bengal consist of 70 per cent Rayleigh waves and 30 per cent Love waves.

Carder and Eppley (1959) in their report on microseismic programme of United States Navy have remarked that southern Asia, where microseismic research is underway in India and Pakistan is another area of interest because sources of disturbances are localised. The area is bounded on the north by high mountains which block transmission from that direction and on the south by large ocean. Consequently nearly all microseisms should have southern sources. From April 1963, a three component long period Press-Ewing seismograph ($T_0 = 30^s.0$, $T_g = 100^s.0$) is in operation as a part of the programme of world-wide network of standardised seismograph system of United States Coast and Geodetic Survey. The special advantage of the set up is that the three components are matched units, all having identical magnification and frequency response. The records could be checked every day by recording calibration pulses at the time of putting and taking off the records. The data from the three matched components could be utilized directly without applying any correction for the difference in response characteristics of the individual components. It is proposed, in the present investigation, to study the structure and composition of microseisms on account of a cyclonic storm which originated in the Bay of Bengal during May 1963 immediately after the installation of the World-Wide Standardised Seismograph network.

The study of microseisms with three component seismograph began in 1930. The notable authors are Lee (1932, 1934, 1935a and 1935b), Leet (1934), Wadati and Masuda (1935), Archer (1937). Thereafter, Ramirez (1940), Wilson (1942), Leet (1947, 1948), Kishinouye and Ikegami (1947), d'Henry (1950) and Ikegami and Kishinouye (1951) made study of the total ground motion at different places and somewhat divergent observations have resulted from these investigations. As a result, microseisms are considered as Rayleigh waves or combination of Rayleigh and Love types.

Since no attempt has been made for the complete study of the ground motion of microseisms recorded at Indian stations it is hoped that this work will be useful so far as the structure of microseisms from the Bay of Bengal is concerned. The knowledge of the structure of microseisms is essential before we could use conventional methods for determining the direction of approach. These methods have been discussed in detail by Bath (1962) in his paper on 'Direction of approach of microseisms'. Recently Straback (1964) theoretically investigated the statistical properties of the resultant ground motion outside the generation area. Further use was made of the theory developed to investigate the character of the microseismic waves. The application showed the microseisms to be composed not only of clear fundamental mode Rayleigh waves, but that Love wave motion was also present. In the present investigation, it is proposed to use microseismic data from a tropical cyclone in the Bay of Bengal. The storm track and the position of the recording station is shown in Fig. 1. It would be seen that the centre of the cyclone is almost south of Shillong and the nearest coast is at a distance of about 400 km from Shillong. The advantage of recording microseisms at Shillong at a distance from the coast is that local disturbances due to the proximity of the sea are practically absent in the long period records.

Derbyshire (1954) made a systematic study of the relative amplitudes of east-west, north-south and vertical component microseisms recorded at Kew, England. His results indicate that the three components show more or less equal energy contents. He made a study of the phase differences among three components. His results strongly suggested the existence of quadrature component between the horizontal and vertical movements, and in-phase and out-of-phase movements between orthogonal horizontal movements. His observations fitted a model for microseisms of an approximately equal mixture of Rayleigh and Love waves.

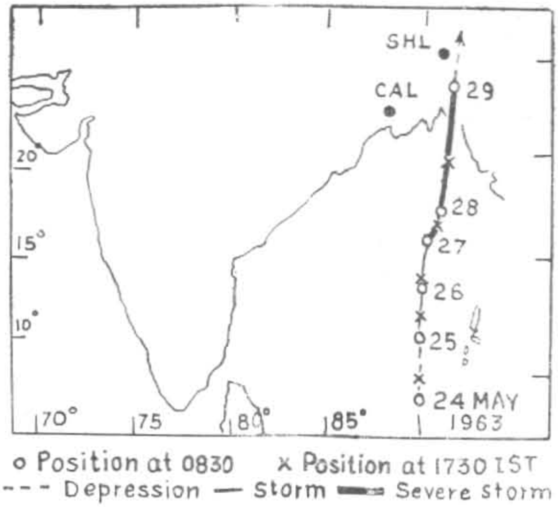

Fig. 1. Track of storm — May 1963

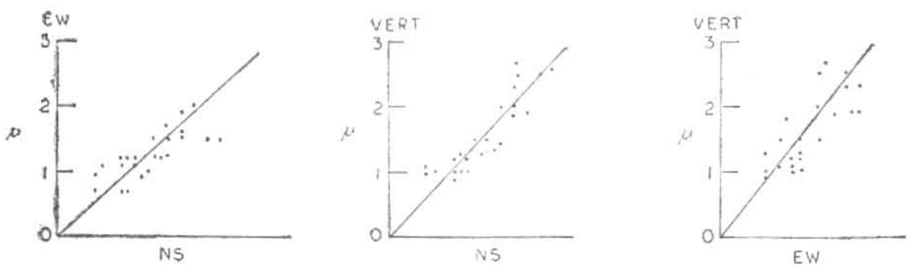

Fig. 2. Amplitude variations of microseism components

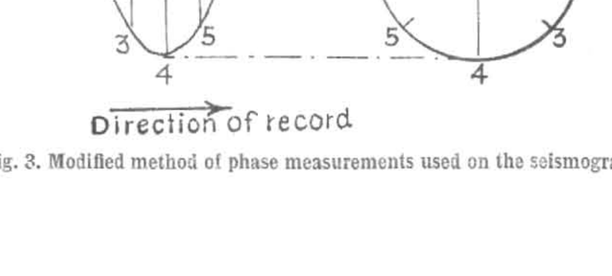

Fig. 3. Modified method of phase measurements used on the seismograms

The author has measured the period and maximum amplitudes at different hours when the microseismic disturbances commenced appearing in Shillong records. The periods of the waves are practically same (mean period is about 5·0 secs) in different components and the periods increase slightly with the increase of amplitudes. The results of the measurement of maximum amplitudes in different components are indicated in Fig. 2. The analysis of the maximum amplitude data would indicate equal energy partition between two horizontal components. This is also apparent from the nature of the records of these components reproduced in Fig. 3.

Before applying Lee's method of determining phase differences among ZN, ZE and NE, let us assume that microseisms are mixture Rayleigh and Love waves and coming from a point source, *viz.*, the centre of the barometric low of the cyclonic storm.

If x,y,z = rectangular co-ordinates directed eastwards, northwards and up respectively with station at the origin,

h = horizontal (used as suffix to denote horizontal components),

α = direction of approach of microseisms, counted from north over east,

R,Q = Rayleigh and Love wave amplitudes respectively,

t = time,

ω = angular frequency (assumed to be same for R and Q)

U = displacement, with components U_x, U_y and U_z ,

γ = phase displacement between R and Q waves.

The x and y components of R and Q can then be written as follows —

$$\left.\begin{aligned} R_x &= R_h \sin\alpha,\ Q_x = Q\cos\alpha \\ R_y &= R_h \cos\alpha,\ Q_y = Q\sin\alpha \end{aligned}\right\} \qquad (1)$$

The displacements at time t along co-ordinate axes are —

$$\left.\begin{aligned} U_x &= R_x \sin\omega t + Q_x \sin(\omega t+\gamma) \\ U_y &= R_y \sin\omega t + Q_y \sin(\omega t+\gamma) \\ U_z &= R_z \sin(\omega t - \pi/2) \end{aligned}\right\} \qquad (2)$$

The above equations will be simplified as follows when Love waves are absent —

$$\left.\begin{aligned} U_x &= R_x \sin\omega t \\ U_y &= R_y \sin\omega t \\ U_z &= R_z \sin(\omega t - \pi/2) \end{aligned}\right\} \qquad (3)$$

TABLE 1

Percentage frequency of phase differences in different components

Components	Phase difference in degrees 0°	45°	90°	135°	180°	225°	270°	315°
ZN	16	10	32	12	16	3	5·5	5·5
ZE	18	20	20	14	10	5	8	5
NE	16	14	9	14	14	9	7	17

The direction of approach can be easily obtained simply from the observed ratio of U_x/U_y .

$$\frac{U_x}{U_y} = \frac{R_x}{R_y} = \frac{R_h \sin\alpha}{R_h \cos\alpha} = \tan\alpha$$

Moreover U_x and U_y represent to S.H.M.s at right angles without any phase difference; the resultant motion should be linear. On the other hand, the resultant motion (particle trajectory) in the case ZN and ZE should be elliptical. Blaik and Donn (1954) made a study of microseism ground motion at Palisades and Weston and found that the dominant type of microseism at the above stations resembles that of theoretical Rayleigh wave. They concluded that microseisms studied for Palisades and Weston are either pure Rayleigh waves or combination of Rayleigh waves approaching from different directions.

For determining the statistical distribution of phase angles between different components, many workers have made use of the methods due to Lee (1935). We shall use slightly simplified procedure. The phases at the beginning of the minute were allotted numbers 0 to 15 by Lee. We shall allot numbers 0 to 7 as indicated in Fig. 3. The entries 0 and 4 indicate that the beginning of the break coincides with the crest and trough respectively. The measurements of the phases are made at the break of every minute near every hourly and half-hourly marks distributed over 48 hours of the microseismic storm. The phase difference between different components were calculated. The percentage frequency of the observed difference of ZN and ZE and NE are given in Table 1. It would be seen from Table 1 that the percentage frequency of phase difference in ZN components is highest for the phase difference of 90°. This is presumably due to the preponderence Rayleigh wave component in the north-south on account of the fact that the source (meteorological storm centre) was almost due south of Shillong. The position of the cyclonic storms at different hours is shown in Fig. 1. The quadrature phase relationship is also maintained

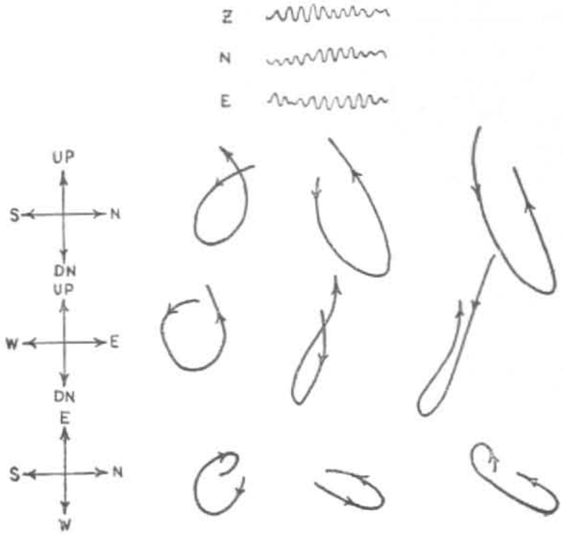

Fig. 4. One minute trace portions from the Shillong three component seismograph and earth particle trajectories for the three principal waxes at 07 to 20 seconds on 28 May 1963 at 1030 GMT

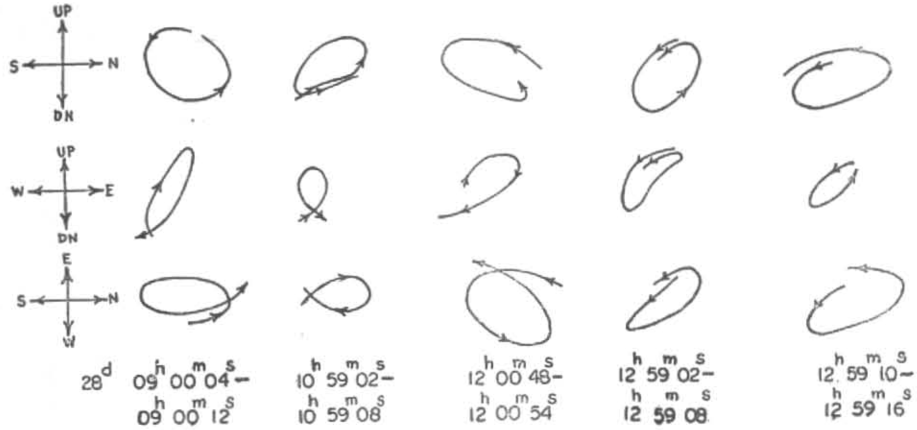

Fig. 4 (a)

to a certain degree indicated by the percentage frequency of 20 for phase difference of 90° in Z-E components. The quadrature relationship is, however, small for the horizontal components N-E. The highest frequency of phase relationship in orthogonal horizontal components is for 0° and 315°. This is in favour of linear trajectory for horizontal particle motion presumably due to the preponderence of Rayleigh wave type.

Let us now make an analysis of individual wave motion by selecting several wave groups for detailed study. Measurement of amplitude was made every one second in each component. Particle trajectories in each of the prime planes were reconstructed by plotting trace amplitudes. No corrections were considered necessary for magnification and phase response. An example of the results for the microseism storm and traces from which they were derived are shown in Fig. 4. Similar diagrams of other data are shown in Fig. 4(a).

It is evident that the motion in the vertical planes (N-S and E-W) are elliptical on frequent occasions but show varying degrees of distortion. It is apparent that the axes of the orbital ellipses projected in the vertical plane are inclined. This confirms similar conclusions arrived at from many investigations for Rayleigh wave from explosion and earthquakes. To consider the trajectories in the horizontal plane, the ground motions shown are not linearly polarised which should be the case for pure Rayleigh wave coming from uniform direction.

We shall now examine the composition of the observed microseism from some other consideration —

Using the equation (2) for horizontal displacements U_x and U_y we have,

$$U_x = R_x \sin \omega t + Q_x \sin (\omega t + \gamma)$$
$$= A_x \sin (\omega t + \phi)$$

where, $A_x^2 = (R_x + Q_x \cos \gamma)^2 + Q_x^2 \sin^2 \gamma$
$$= R_x^2 + Q_x^2 + 2 R_x Q_x \cos \gamma \qquad (4)$$

and $\tan \phi = (Q_x \sin \gamma) / (R_x + Q_x \cos \gamma)$

$$U_y = R_y \sin \omega t + Q_y \sin (\omega t + \gamma)$$
$$= A_y \sin (\omega t + \phi')$$

where, $A_y^2 = (R_y + Q_y \cos \gamma)^2 + Q_y^2 \sin^2 \gamma$
$$= R_y^2 + Q_y^2 + 2 R_y Q_y \cos \gamma \qquad (5)$$

and $\tan \phi' = (Q_y \sin \gamma) / (R_y + Q_y \cos \gamma)$

where A_x and A_y represent peak values of U_x and U_y in the E-W and N-S components respectively. From the recorded maximum amplitude as shown in Fig. 2, they are more or less of the same magnitude in the two horizontal components. Or in other words, we can consider $A_x = A_y$ at least approximately.

On equating $A_x = A_y$ from (4) and (5) we have—

$$R_x^2 + Q_x^2 + 2 R_x Q_x \cos \gamma$$
$$= R_y^2 + Q_y^2 + 2 R_y Q_y \cos \gamma$$

Putting the value of R_x, R_y, Q_x and Q_y from equation (1), we have —

$$R_h^2 (\sin^2 \alpha - \cos^2 \alpha) = Q^2 (\sin^2 \alpha - \cos^2 \alpha)$$

i.e., $(\sin^2 \alpha - \cos^2 \alpha) (R_h^2 - Q^2) = 0$

This gives rise to two conditions.

The first condition is —

$$\sin^2 \alpha - \cos^2 \alpha = 0$$

$$\sin \alpha = \cos \alpha \quad \text{or} \quad \alpha = 45^\circ$$

This is quite obvious because for the direction of approach of 45°, the amplitude of R_h and Q are equally partitioned in two horizontal components. This condition has no application to our case because the source of microseismic disturbance obviously the centre of the meteorological disturbance was almost due south of Shillong.

The second condition is —

$$R_h = Q$$

This means in this case that horizontal component of Rayleigh wave part of microseism is equal to the Love component of the microseisms.

The polarisation factor K is defined as the ratio of horizontal to vertical movement for the Rayleigh wave part of microseisms. Iyer (1959) computed the value of the polarisation factor from abundant data collected at Kew and analysed by correlation technique. The value of the polarisation factor K is almost constant near 0·7. The theoretical value of the Rayleigh wave constant K for an elastic half space is 0·68. If we take $R_h / R_z = 0 \cdot 7$; $R_h^2 / R_z^2 = 0 \cdot 49 = 0 \cdot 5$ (approx).

Total energy $= R_h^2 + R_z^2 + Q^2$

$= 2 R_h^2 + R_z^2 = 4 R_h^2 = 4Q^2$ ($\because R_h = Q$)

These observations, therefore, fitted with a model of microseismic energy of distribution of approximately 75 per cent of Rayleigh waves and 25 per cent of Love waves. Lee (1932) made investigations on the polarisation of microseisms at Kew. His mean value was 0·9. From theoretical considerations he proved that the value fitted for Kew with 1 km of lime-stone over granite. This value may be approximte for Shillong with granite bottom underlying metamorphic rocks. In that case we may conclude from similar calculation that the energy of microseisms from the Bay of Bengal consists of 70 per cent Rayleigh and 30 per cent Love waves when we take $R_h / R_z = 0 \cdot 9$.

The most important drawback of the method is that we have assumed a point source so that microseisms are coming from one uniform direction. There are evidences that microseisms are combination of Rayleigh waves approaching from different directions. The tropical cyclones in the Bay of Bengal are very much localised, and it may be considered as point source for all practical purposes. It is proposed to use other methods in future to verify the present findings of the author, *viz.*, the method used by Straback (1964) when the details of the method are available.

REFERENCES

Archer, J. A. 1937 *Mon. Not. R. astr. Soc. geophys. Suppl.*, **4**, 185-196.

Bath, M. 1962 *Geophys. J.*, **6**, pp. 450-461.

Blaik, M. and Donn, W. L. 1954 *Bull. seismol. Soc. Amer.*, **44**, pp. 597-612.

Carder, D. S. and Eppley, R. A. 1959 The microseism programme of U.S. Navy, U.S. Dep. Commerce.

REFERENCES (contd)

Derbyshire, J.	1954	*Proc. roy. Soc*, Ser. A, **223**, pp. 96-111.
d'Henry, G.	1950	*Ann. Geofis.*, **3**, 87-94.
Ikegami, R. and Kishinouye, F.	1951	*Bull. Earthq. Res. Inst.*, **29**, 305-312.
Iyer, H. M.	1959	Doctoral Thesis, Univ. of London.
Kishinouye, F. and Ikegami, R.	1947	*Bull. Earthq. Res. Inst.*, 25, 43-48.
Lee, A. W.	1932	*Mon. Not. R. astr. Soc. geophys. Suppl.*, **3**, 83-105.
	1934	*Ibid.*, pp. 238-252.
	1935a	*Geophys. Mem.*, **66**, pp. 1-10.
	1935b	*Proc. roy. Soc.*, Ser A., **149**, pp. 183-189.
Leet, L. D.	1934	*Beitr. Geophys.*, **42**, pp. 232-245.
	1947	*Geophysics*, **12**, 639-650.
	1948	*Bull. seismol. Soc. Amer.*, **38**, 173-178.
Ramirez, J. E.	1940	*Ibid.*, **30**, pp. 35-84.
Straback, K.	1964	*Earthq. Notes*, 35, p. 47 (Abstract).
Wadati, K. and Masuda, K.	1935	*Geophys. Mag.*, **79**, 292-340.
Wilson, J. T.	1942	*Trans. Amer. geophys. Un.*, Pt. II, 228-231.