NATIONAL INSTITUTE OF OCEANOGRAPHY

WORMLEY, GODALMING, SURREY

A Study of Microseisms generated by a storm in February 1949

by

H. M. IYER

N. I. O. Internal Report No. A7

NOVEMBER 1956

A STUDY OF MICROSEISMS

GENERATED BY A STORM IN FEBRUARY 1949

1. INTRODUCTION

The nature of microseismic waves is of theoretical and practical interest in the study of sea waves and wave prediction. Very little consistent work has been done on this subject, but it is known that microseisms can be generated in areas of meteorological disturbance over the sea. They may be due to atmospheric pressure disturbances on the sea surface (Press and Ewing 1948) or, more probably, to pressure fluctuations in wind-generated sea waves (Longuet-Higgins 1950). Lord Rayleigh (1885) has shown that in a homogeneous medium surface waves can be propagated in which the displacement of the particles is partly vertical and partly horizontal in the direction of propagation. The phase difference of the displacements is 90°. Lee (1932) has shown that waves of similar type can exist when the elastic medium is overlain by a second elastic medium; the ratio k of the vertical and horizontal displacements at the free surface depends on the elastic constants of the two media. Scholte (1943) and others have studied the case when the overlying layer is a fluid.

Since microseisms are almost certainly caused by pressure fluctuations transmitted in some way through the ocean, it is reasonable to expect that, in the first place, they consist of waves of Rayleigh type. However, the propagation of the microseismic waves through inhomogeneous media and their reflection and refraction at geological faults may cause part of the Rayleigh waves to be converted into Love waves, in which the displacement of the particle is entirely horizontal and perpendicular to the direction of propagation.

Lee (1935), working with records from Kew Observatory, concluded that microseisms consist entirely of Rayleigh waves. If this is true always, the direction can be found very easily by estimating the ratio of the intensities of the East-West and North-South components which gives the tangent of the bearing to the North. This method, however, has not worked successfully and it is not possible to estimate the bearing of a storm with any accuracy on this assumption. Other workers (Leet 1934, Darbyshire 1954) have started with the more general assumption that microseisms are a mixture of Rayleigh and Love waves, and they have achieved more accurate results. A consistent and thorough study of this subject is bound to present many points of interest and may ultimately lead to a reliable and quick method of estimating the bearing of storms that generate microseisms.

2. OBJECT OF THE PRESENT INVESTIGATION

The main aim of this investigation is to study the variation of the Love-wave/Rayleigh-wave ratio as a function of the position of the generating storms. A storm of February 1949 in the Atlantic was chosen for this study as it had a fairly long track from the south-west to north-west quadrant. The direction of arrival was also estimated by measurements of correlation coefficients and intensity ratios between the various components. An effort was made to study the distribution of Rayleigh wave components along the horizontal and vertical directions.

3. THEORY

Darbyshire (1954) pointed out the possibility of estimating the direction of arrival of microseisms by measurement of the maximum correlation coefficients between the various components.

If the horizontal displacement due to Rayleigh waves is given by
t) and that due to Love waves by L(t), and θ is the bearing to the
rth, then

East-West displacement $\propto$ $x = R(t)\sin\theta + L(t)\cos\theta$

North-South displacement $\propto$ $y = R(t)\cos\theta + L(t)\sin\theta$

Vertical displacement $\propto$ $z = k\,R(t-t_0)$ where t_0 is a phase factor

ow the r.m.s. value of x $\quad \bar{x} = \sqrt{\overline{R(t)}^2 \sin^2\theta + \overline{L(t)}^2 \cos^2\theta}$ (1)

r.m.s. value of y, $\quad \bar{y} = \sqrt{\overline{R(t)}^2 \cos^2\theta + \overline{L(t)}^2 \sin^2\theta}$ (2)

r.m.s. value of z, $\quad \bar{z} = k\,\overline{R(t)}$ (3)

The Correlation Coefficients are given by

$$r_{xz} = \frac{\overline{R(t)}\,\sin\theta}{\bar{x}} \tag{4}$$

$$r_{yz} = \frac{\overline{R(t)}\,\cos\theta}{\bar{y}} \tag{5}$$

$$r_{xy} = \frac{\left[\overline{R(t)}^2 + \overline{L(t)}^2\right]}{\bar{x}\cdot\bar{y}}\,\sin\theta\cdot\cos\theta \tag{6}$$

and $\dfrac{\overline{L(t)}^2}{\overline{R(t)}^2}$ is given by

$$\frac{\overline{L(t)}^2}{\overline{R(t)}^2} = \left(\frac{r_{xy}}{r_{xz}\cdot r_{yz}} - 1\right) \tag{7}$$

Hence an equation obtained by combining (4) and (5):

$$\operatorname{Tan}\theta = \frac{\gamma_{xz}}{\gamma_{yz}} \cdot \frac{\bar{x}}{\bar{y}} \tag{8}$$

is used in the present investigation.

According to this

$$\left[1+\left(\frac{\overline{L(t)}}{\overline{R(t)}}\right)^2\right] = \frac{\bar{x}^2+\bar{y}^2}{\gamma_{xz}^2 \cdot \bar{x}^2 + \gamma_{yz}^2 \cdot \bar{y}^2} \tag{9}$$

(It can be seen that $\left(\overline{L(t)}/\overline{R(t)}\right)^2$ can never be negative in this case.)

A further refinement can be incorporated if the values of γ_{yz} and $\bar{y}$ are also considered unreliable.

By using (1), (3) and (4) we get

$$\gamma_{xz} \cdot \frac{\bar{x}}{\bar{z}} = \frac{1}{k} \operatorname{Sin}\theta \tag{10}$$

It may be pointed out here that if the value of k can be evaluated for a particular seismograph station the bearing can be found by measurement of γ_{xz}, $\bar{x}$ and $\bar{y}$.

4. PROCEDURE ADOPTED

The records from Kew Observatory were made suitable for use in the analyser and correlation meter by magnifying and reproducing them in black and white profile form. The correlation coefficients were measured using the correlation meter described by Tucker (1952). The A.R.L. analyser was used to calculate the r.m.s. values of the displacement by squaring and adding the peaks in the frequency spectra. In using equations (8) and (9) a correction had to be applied for the different sensitivities of E-W and N-S component seismographs. This was found by measuring the average value of $\bar{x}$ and $\bar{y}$ for the whole span of the storm and finding out the ratio $\bar{x}/\bar{y}$ (It follows from (1) and (2) that for a wide range of θ, $\bar{x}_{Av} = \bar{y}_{Av}$). The value of $\bar{x}$ was divided by this ratio to give the actual value. (The value of $(\bar{x}/\bar{y})_{AV}$ was 1.61.) The records were analysed for every three hours from 1200 on 6.2.49 to 0600 on 8.2.49.

5. DISCUSSION OF RESULTS

(a) Variation of L(t)/R(t) with direction.

The most striking result of the investigation was a variation in $\overline{L(t)}/\overline{R(t)}$ with direction (Fig.1). It was about 1.5 when the storm was in the SW and NW directions but reached a maximum of 3.5 when it was westerly. This can give two conclusions -

(i) Rayleigh waves are absorbed most in a westerly direction. (This fits in with the results of a present investigation by Darbyshire on the refraction of microseisms approaching the British Isles.)

(ii) Love waves are produced more in a westerly direction suggesting the presence of a geologic fault or a so-called "microseismic barrier". The investigation seems worth pursuing.

(b) Evaluation of Tan Θ (Fig.1).

The bearing given by this method shows the general trend of the movement of the storm. There is some uncertainty when the storm crosses over from the SW to the NW quadrant. In general the bearings are a few degrees south of the actual positions, and this is to be expected from the wave-interference theory. The uncertainty when the storm approaches due West is to be expected in all techniques involving the N-S component, which is bound to be very small as the Rayleigh wave component will be small in that component for the direction. It is also interesting to note that the bearings become erratic after 1500 hrs. on 7.2.49. This fits in well with the time of arrival of swell from the storm on the coast. The amplitude of the sea waves from records at Perranporth are plotted against time in the same figure for reference. It may be noted that the wave activity on the Irish and west British coasts due to a storm in the West starts about six hours earlier than at Perranporth (Darbyshire, 1950).

(c) Equation (10) looks promising as it holds a solution of Θ with few parameters. Hence the estimation of i/k is very important. In Fig.2 i/k Sin Θ is plotted against time. The graph obeys the general trend of variation of Θ till the swell starts arriving. The second peak after the swell starts coming is interesting as it points to a source mainly caused by swell. With data from more storms giving better records of the N-S component also, it will be possible to evaluate the constant k for Kew Observatory.

6. CONCLUSIONS

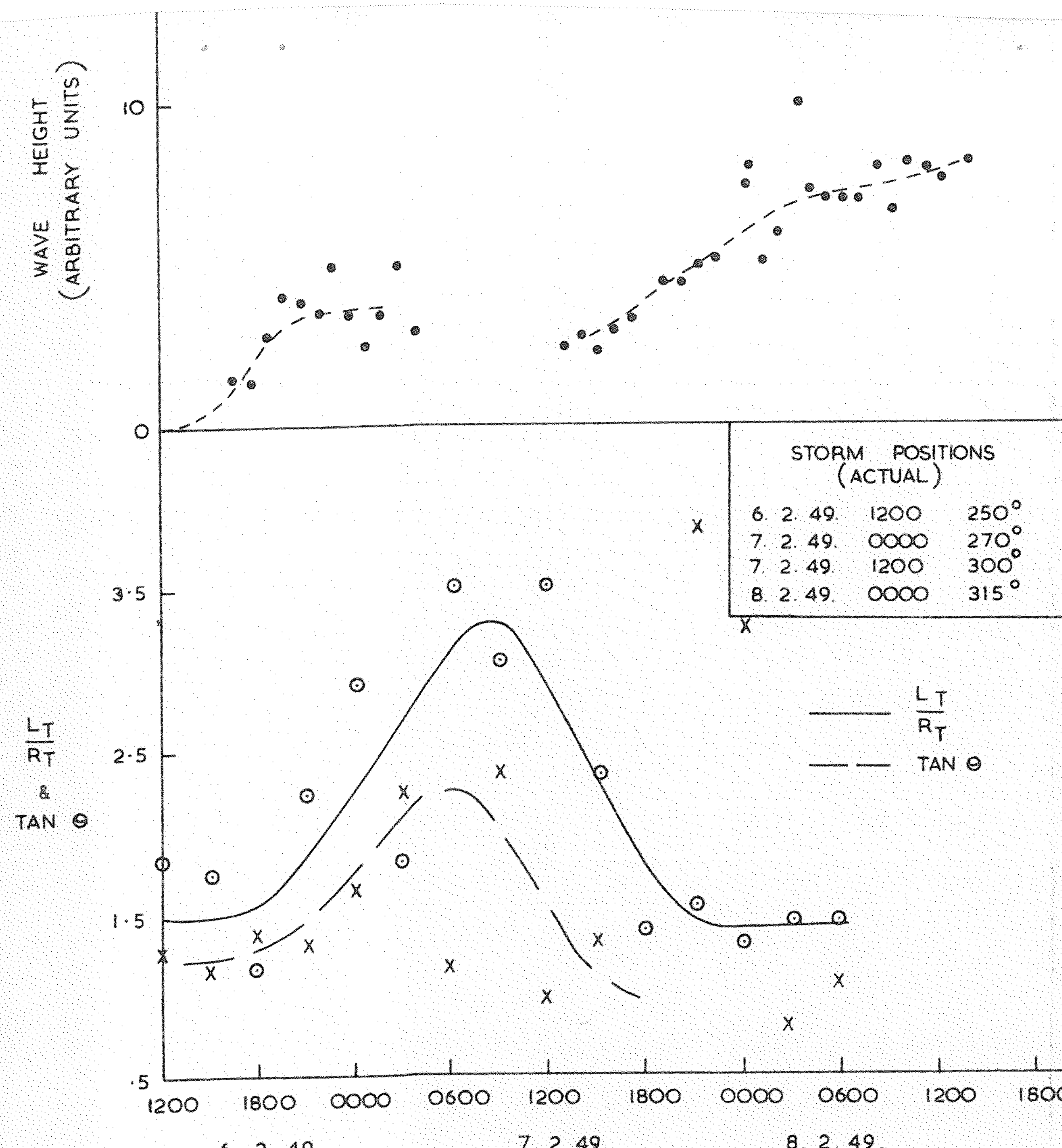
(a) Study of variation of L(t)/R(t) with direction can throw more light onto the generation and propagation of microseisms.

(b) Direction of arrival of microseisms can be studied by fewer measurements of correlation coefficients, using the more accurately measurable quantities Σ and ς.

(c) Direction-finding techniques can be simplified by estimating the Rayleigh wave constant k.

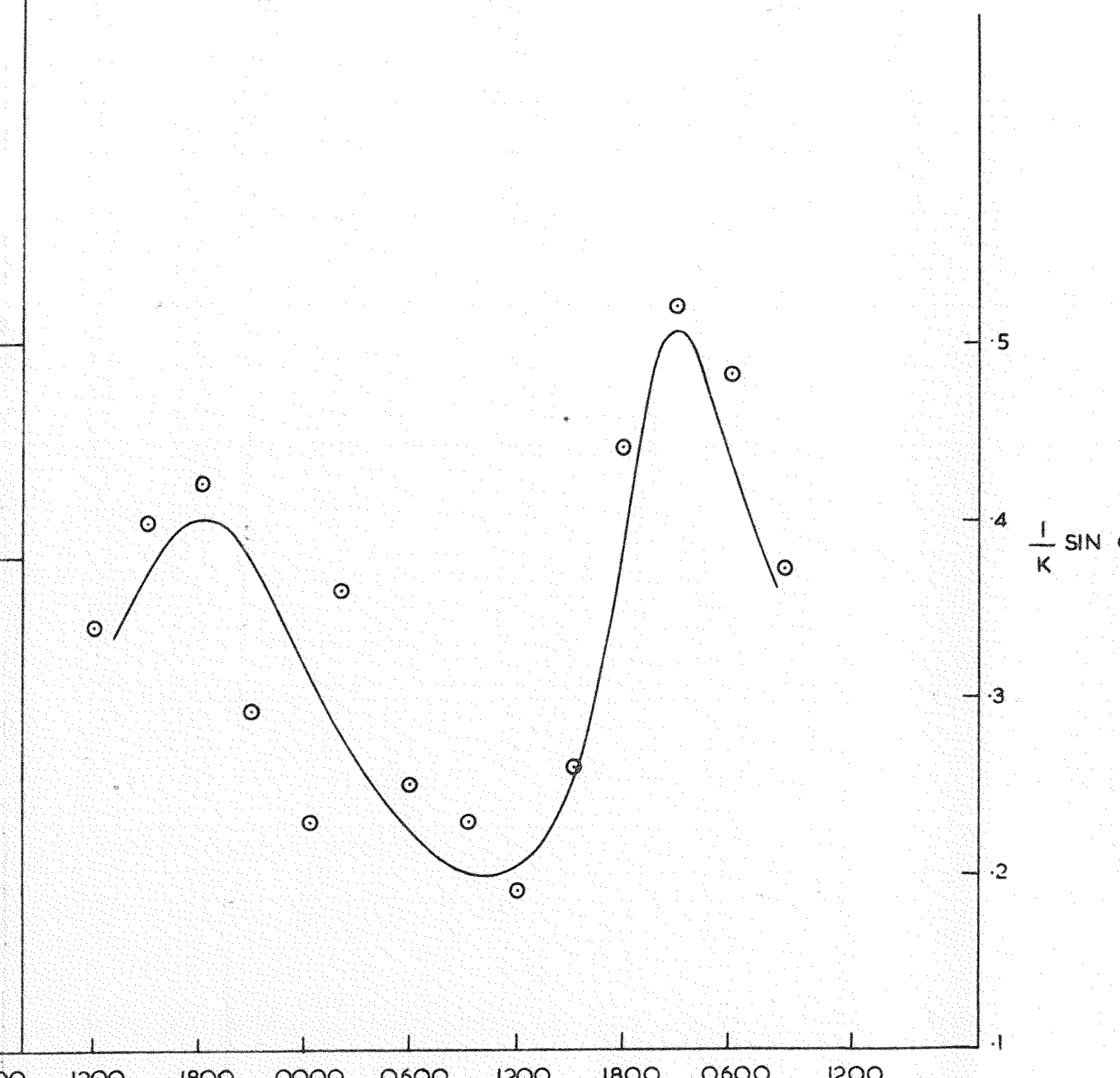
7. REFERENCES

(1) DARBYSHIRE, J. (1950) Proc. Roy. Soc. A, **202**, 439.
(2) DARBYSHIRE, J. (1954) Proc. Roy. Soc. A, **223**, 96.
(3) LEE, A.W. (1932) Mon. Not. R. Astr. Soc. Geophys. Suppl. **3**, 83-105.
(4) LEE, A.W. (1935) Proc. Roy. Soc. A, **149**, 183.
(5) LEET, L.D. (1934) Gerlands Beitr. Geophys. **42**, 232-245.
(6) LONGUET-HIGGINS, M.S. (1950) Phil. Trans. A, **243**, 1-35.
(7) PRESS, F. and EWING, M. (1948) Trans. Amer. Geophys. Un. **29**, 163-174.
(8) RAYLEIGH, Lord (1885) Proc. Lond. Math. Soc. **17**, 4-11.
(9) SCHOLTE, J.G. (1943) Versl. gewone Vergad. Akad. Amst. **52**, 669.
(10) STONELEY, R. (1926) Mon. Not. R. Astr. Soc. Geophys. Suppl. **1**, 349.
(11) TUCKER, M.J. (1952) J. Sci. Instrum. **29**, 321.



WAVE HEIGHT (ARBITRARY UNITS)
10
0
STORM POSITIONS (ACTUAL)
6. 2. 49. 1200 250°
7. 2. 49. 0000 270°
7. 2. 49. 1200 300°
8. 2. 49. 0000 315°
LT/RT
TAN Θ
LT/RT & TAN Θ
3·5
2·5
1·5
·5
1200 1800 0000 0600 1200 1800 0000 0600 1200 1800
6. 2. 49.
7. 2. 49.
8. 2. 49.

FIG 1.



1/K SIN Θ
·5
·4
·3
·2
·1
1200 1800 0000 0600 1200 1800 0600 1200

FIG 2.