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THE THREE COMPONENTS OF MICROSEISMIC DISTURBANCE AT KEW OBSERVATORY

Discussion of the Records for 1932

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Discussion of the Records for 1932

§ 1—INTRODUCTION

Investigations of the microseisms recorded at a large number of observatories during a single month, January, 1930 (1)(2)* have shown that the observatories could be classified roughly according to the local geological structure as follows :—

(a) " Rock " where A_H/A_Z, the ratio of the horizontal to the vertical amplitudes of the microseisms, does not vary with the period of the oscillations. The observed ratio (0·7) is the value for simple Rayleigh waves in a medium with Poisson's ratio 0·25.

(b) " Consolidated " with the horizontal and vertical amplitudes approximately equal, and the ratio A_H/A_Z diminishing slightly as the period increases.

(c) " Weak " where the horizontal amplitudes are much greater than the vertical, and A_H/A_Z varies considerably with the period.

Abisko, Kew and de Bilt were selected as typical observatories for these groups respectively, but with only few observations and a small range of periods in a single month, further information regarding the variations of A_H/A_Z with period was required for observatories on " consolidated " and on " weak " formations. The de Bilt tabulations of microseisms for the three components from 1923 to 1929 have been employed in the latter case(3), but no tabulations suitable for the former were available. To provide such data the three components of the microseisms at Kew have been tabulated for the year 1932.

The comparison of the three components at Kew also yields material from which the merits of the different components for routine tabulations can be considered. For Kew, and previously for Eskdalemuir, the measurements have been taken from the records of the N–S component for four hours daily (0h, 6h, 12h, and 18h)† ; they refer to the most prominent microseisms during an interval of 30 minutes centred at the hour, the period being the mean for a group of 3 to 12 oscillations, and the amplitude, the mean for the largest three consecutive oscillations. There is no international agreement governing these tabulations, but such data as have been published are generally either for the above four hours or for one hour (7h) daily. Details of the tabulations for a number of observatories are set out in Table I. Tabulations are being continued at Upsala and at Strasbourg as well as at Kew.

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*The numbers in brackets refer to the bibliography on p. 10.

†The Eskdalemuir tabulations are given for four hours daily from January 1, 1913 ; the data published for the two earlier years (1911–2) only include daily values of amplitude and period.

TABLE I—TABULATIONS OF MICROSEISMS AT CERTAIN OBSERVATORIES

Observatory	Type of seismograph	Component	Hours Tabulated (G.M.T.)	Interval for selection of microseisms	Years
				minutes	
Pulkovo .. (i)	Galitzin	N–S, E–W, Z.	0, 6, 12, 18	±15	1913
Irkutsk .. (i)	,,	N–S, E–W.	,, ,, ,, ,,	,,	,,
Taškent .. (i)	,,	,, ,,	,, ,, ,, ,,	,,	,,
Eskdalemuir (ii, iii)	,,	N–S.	,, ,, ,, ,,	,,	1913–24
Kew.. .. (iii)	,,	,,	,, ,, ,, ,,	,,	1926 et seq.
Upsala .. (iv)	Wiechert	,,	7	,,	1921 et seq.
Hamburg .. (v)	,,	N–S, E–W.	7	±10	1909–24
,, .. (v)		Z.	7	,,	1919–24
de Bilt .. (vi)	Galitzin	N–S, E–W.	6	±15	1917–29
,, .. (vi)	,,	Z.	6	,,	1923–29
Uccle .. (vii)	,,	N–S, E–W.	0, 6, 12, 18	,,	1914–22
Göttingen .. (viii)	Wiechert	N–S, E–W, Z.	7	,,	1907–09
Strasbourg .. (ix, x)	Galitzin	N–S, E–W.	0, 6, 12, 18	,,	1920 et seq.

The tabulations of the world survey of microseisms during January, 1930, included each available component for 57 observatories at the hours of the synoptic observations (1h., 7h., 13h., and 18h., G.M.T.), the measurements being taken from a group of waves within 5 minutes of the hour.

The figures following the name of each station indicate the source from which the data have been obtained, as follows :—

(i) B. Galitzin. *C. R. Comm. Sism., Petrograd*, **7**, 1919, pp. 97–184.
(ii) *London, Brit. meteor. magn. Yearb.*, 1913–21.
(iii) *London, Obs. Yearb.*, 1922 et seq.
(iv) *Upsala, Obs. séism.*
(v) H. Mendel, Die seismische Bodenunruhe in Hamburg und ihr Zusammenhang mit der Brandung, Hamburg, 1924.
(vi) *Utrecht, Seism. Reg.*
(vii) *Brussels, Bull. sism.*
(viii) B. Gutenberg, *Beitr. Geophys., Leipzig*, **11**, 1912, pp. 314–53.
(ix) J. Lacoste, *Trav. Sci. Sect. Séism. Un. géod. int. Toulouse*, **7**, 1932, pp. 16–35.
(x) *Strasbourg, Ann. Inst. Phys. Globe.*

The results now obtained indicate that there would be some advantages in tabulating from the vertical component rather than from a horizontal component. It is unfortunate that with vertical seismographs generally less reliable than the horizontal instruments, this component cannot be taken for all observatories. These tabulations could not have been made at Eskdalemuir, or for the earlier years at Kew, owing to the unsatisfactory operation of the vertical seismograph. The difficulties were overcome in 1927 when the steel spring was replaced by one made of elinvar, and the subsequent recording has been very satisfactory.

§ 2—DATA FROM KEW FOR 1932

In the comparisons between the microseisms of the three components at Kew the tabulations for the N–S components have been taken from the *Observatories' Year Book* ; those for the other components have been prepared specially for this investigation. The latter measurements were made recently by the author, the former about two years ago by W. J. Craxford, of the Kew staff. Thus the E–W and Z tabulations are more closely comparable than the N–S and E–W or the N–S and Z. Discrepancies between the two sets of tabulations might arise from a number of causes, such as :—

(a) Personal equation of tabulator. The recorded amplitudes are measured to 0·1 mm., but systematic errors amounting to several tenths of a millimetre may arise from the setting of the measuring scale or from estimation of the turning points of the oscillations.
(b) Differences between the width and intensity of the traces.
(c) Inaccuracies in the graduations of the celluloid scale used for the routine tabulations.*

*It may be remarked that this scale has since been replaced by one on glass.

The differences may be taken as representative of those likely to occur between the tabulations of different observatories, and are probably less than the "error of sampling" which affects all the measurements.

The computations of ground movements which correspond with the recorded amplitudes followed the usual procedure(4). The constants of the seismographs, and the magnifications for simple harmonic waves of period 3 seconds to 10 seconds, are given in Table II. In the case of the vertical instrument the constants and

TABLE II—KEW OBSERVATORY. SEISMOGRAPH CONSTANTS AND MAGNIFICATIONS, 1932

(*a*) *Seismograph Constants.*

Component	N-S		E-W		Z	
Dates	Jan. 1–Sept. 6	Sept. 6–Dec. 31	Jan. 1–Sept. 5	Sept. 5–Dec. 31	Jan. 1–Sept. 7	Sept. 7–Dec. 31
Free period of galvanometer (sec.) ..	24·7	24·7	24·8	24·8	13·0	13·0
Free period of pendulum (sec.) ..	25·0	25·1	24·9	25·1	12·6	12·8
Equivalent pendulum length (cm.)	11·8	11·8	11·8	11·8	36·0	36·0
Distance from galvanometer to chart (cm.)	112·2	112·3	109·8	110·2	112·8	112·5
Damping constant	+0·01	0·00	+0·02	+0·01	+0·02	+0·07
Transmission factor	15·26	15·60	14·83	14·61	114·5	109·7

(*b*) *Magnifications for Different Periods.*

Period (sec.)	N-S		E-W		Z	
	Jan. 1–Sept. 6	Sept. 6–Dec. 31	Jan. 1–Sept. 5	Sept. 5–Dec. 31	Jan. 1–Sept. 7	Sept. 7–Dec. 31
3	135	140	130	125	310	295
4	175	180	165	165	380	365
5	215	220	205	200	430	420
6	250	255	235	235	465	450
7	280	285	265	260	475	465
8	305	310	290	285	475	470
9	325	335	310	305	465	460
10	340	350	325	325	445	440

the magnification depend upon the position of the pendulum. The constants shown in Table II are those for the normal position. The pendulum is maintained between 2 milliradians above and 1 milliradian below the normal, so the errors in the magnification due to changes in the pendulum position do not exceed 1 or 2 per cent.(5), and may be neglected.

The monthly and yearly means of amplitude and period for the three components, together with the monthly maximum amplitudes, are shown in Table III.

§ 3—COMPARISON OF THE THREE COMPONENTS

The annual means of amplitude and period (Table III) are practically identical for the three components, but the monthly values are not so concordant.

The largest difference between the mean periods occurs for August, the values for the E–W and Z components being 4·7 sec., and that for the N–S, 5·4 sec. The amplitudes in summer are very small, and when magnified about 400 times by the vertical seismograph only amount to one or two tenths of a millimetre on the record. With the horizontal instruments only half as sensitive to these waves as the vertical,

TABLE III—MICROSEISMS RECORDED AT KEW OBSERVATORY, 1932

Month 1932	N—S Component				E—W Component				Z Component			
	Mean amplitude	Mean period	Maximum amplitude	Time of maximum amplitude	Mean amplitude	Mean period	Maximum amplitude	Time of maximum amplitude	Mean amplitude	Mean period	Maximum amplitude	Time of maximum amplitude
	μ	sec.	μ	d. h.	μ	sec.	μ	d. h.	μ	sec.	μ	d. h.
Jan. .	2·3	6·5	5·8	11 0	2·0	6·5	5·8	15 12	2·2	6·5	5·9	15 12
Feb. .	0·6	5·9	1·9	6 6	0·5	5·8	1·5	1 12	0·6	6·2	1·3	29 18
Mar. .	1·4	5·9	5·1	5 18	1·0	6·1	3·8	26 12	1·1	6·1	5·1	5 18
Apr. .	1·2	6·0	3·7	9 12	1·0	6·2	4·3	9 12	1·1	6·2	4·8	9 12
May .	0·3	4·7	1·5	13 12	0·3	4·8	1·2	12 12	0·3	4·9	1·3	24 0
June .	0·1	5·0	0·6	1 0	0·2	5·0	1·4	15 18	0·1	4·8	0·9	15 18
July .	0·2	4·6	0·7	2 12	0·3	4·6	1·4	2 18	0·2	4·6	1·1	2 18
Aug. .	$0·0_3$	5·4	0·5	31 18	0·1	4·7	0·7	4 18	0·1	4·7	0·4	31 0
Sept. .	0·8	5·1	3·3	21 0	0·9	5·0	2·2	22 0	0·6	5·2	2·4	21 0
Oct. .	1·0	5·4	4·4	20 18	1·2	5·5	3·0	30 6	0·9	5·7	2·9	30 6
Nov. .	1·3	6·1	4·8	27 6	1·5	6·0	5·9	26 18	1·7	6·3	5·8	23 6
Dec. .	2·0	6·5	6·4	31 12	2·2	6·5	6·3	31 18	2·0	6·6	5·7	31 18
Year .	0·9	5·6	—	—	0·9	5·6	—	—	0·9	5·7	—	—

the oscillations are frequently too small to be recognised in the seismograms. The August mean periods were based upon 19 measurements of the N–S component, 45 of the E–W and 124 of Z. Thus the N–S mean, derived only from the hours with the larger amplitudes, is larger than that for Z which was obtained from all the hours.

The mean amplitudes of the N–S and E–W components were the same (to the nearest 0·1μ) in May ; the N–S component was apparently the greater from January to April, and the E–W from June to December. The largest differences between these components were 0·3μ (January) and 0·4μ (March). These differences are possibly due to slight over-estimation of the N–S amplitudes. The tabulations of the E–W component for the whole year were made in a few days, but the N–S microseisms were tabulated regularly throughout the year. There is therefore more risk of a slight change in the standard of tabulation for the N–S component, especially between the months at the beginning and end of the year. The mean amplitude of Z was 0·2μ less than either of the horizontal components in September, and 0·2μ greater in November.

In April the maximum amplitudes of N–S, E–W and Z were all recorded at 12h on the 9th. In each of the other months the N–S and E–W maxima occurred at different times, but in 7 of these months, the Z maximum agreed with one or other of the horizontal components. The amplitudes and periods of the microseisms during January, and from November 21 to December 21, are plotted in Figs. 1 and 2. The curves show that the three components agree closely although the accuracy of the measurements is not sufficient to distinguish between disturbances which are very nearly equal ; there were three disturbances of this kind in November, giving the tabulated maxima at 6h on the 23rd, 18h on the 26th, and at 6h on the 27th, for the Z, E–W and N–S components respectively.

The first stage in examining the variation with period of the ratios between the amplitudes of the components (A_N, A_E and A_Z respectively,) was to determine whether the ratios A_E/A_Z for different periods in January, 1932, agreed with those of January, 1930. The ratios A_E/A_Z during January, 1932 were accordingly tabulated for different periods and it was found that the medians were 1·0 for periods 5·0–5·9 sec., $0·9_5$ for periods 6·0–6·9 sec. and 7·0–7·9 sec., and $0·8_5$ for periods 8·0–8·9 sec. ; thus the results are very nearly the same as those from the earlier investigation (1·0, 0·9, 0·9 and 0·8 respectively).

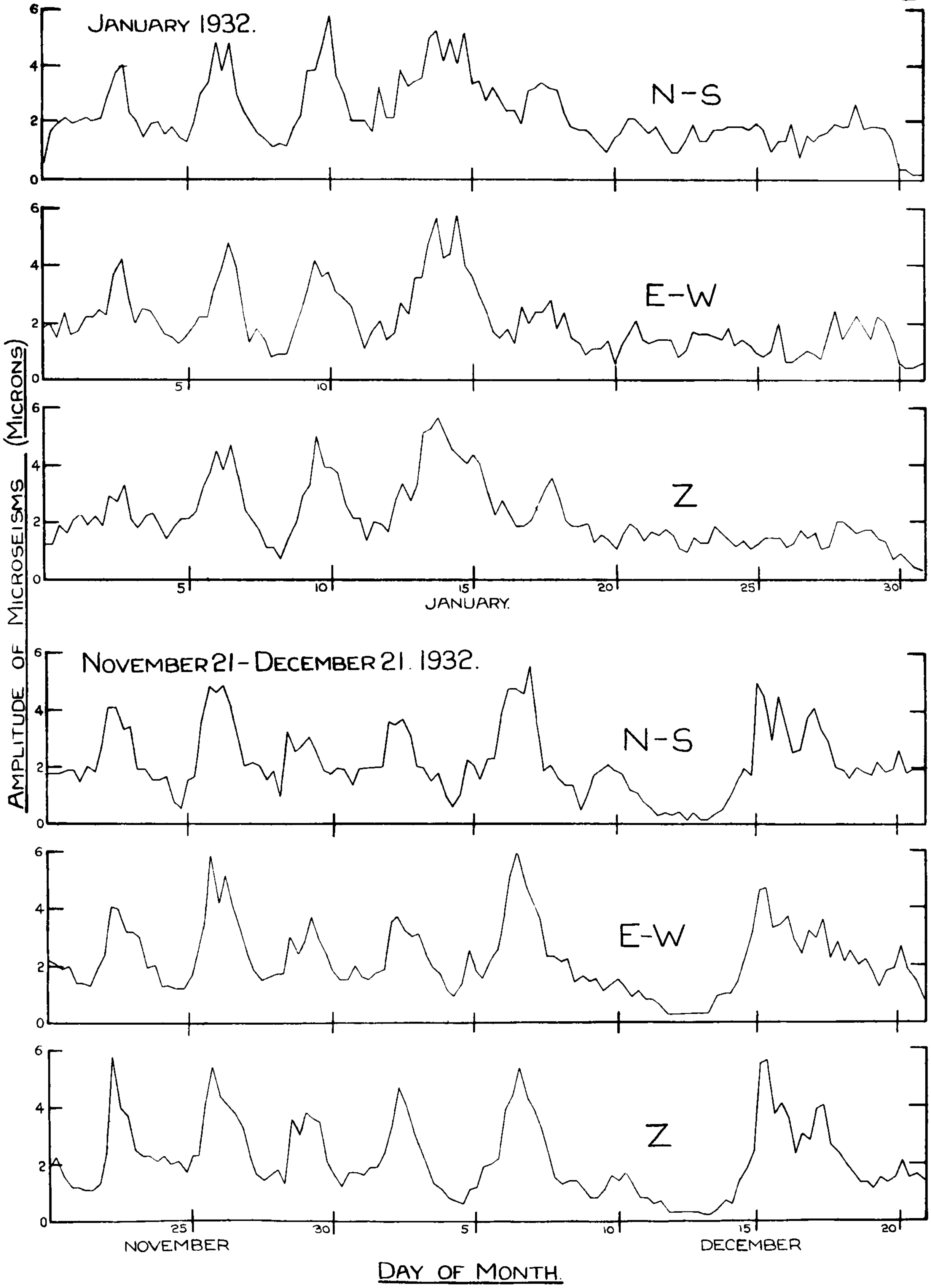

FIG. I — KEW OBSERVATORY — AMPLITUDE OF MICROSEISMS.

(1803) Ps 5019 2780, 625, + 1/256p [illegible]

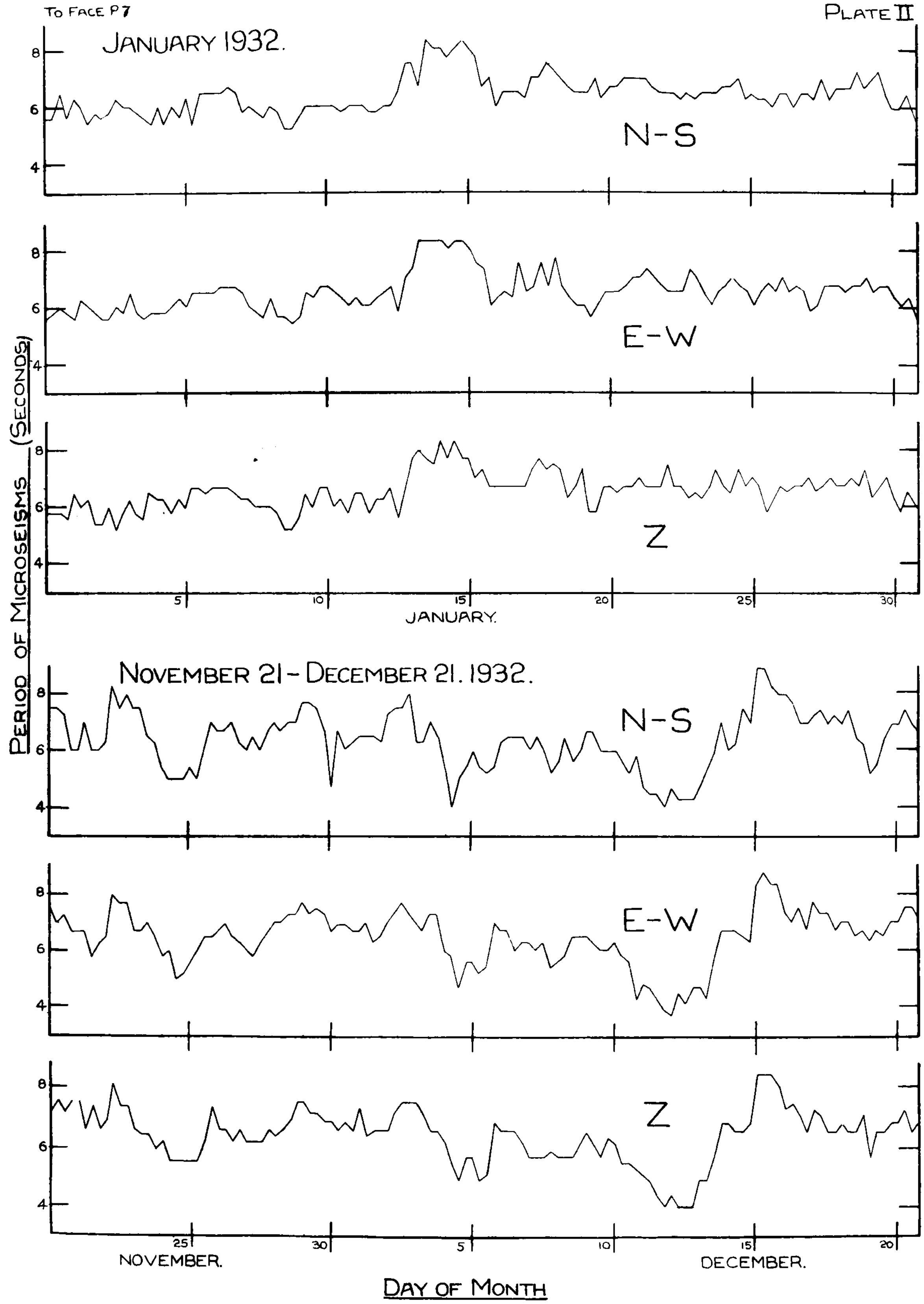

FIG.2-KEW OBSERVATORY PERIOD OF MICROSEISMS

Since the accuracy attained in comparison of the components from the individual observations depends upon the size of the oscillations, the ratios between two components with very small amplitudes would be misleading. The comparisons for 1932 have therefore been restricted to the occasions when the amplitudes of all the components were not less than 1μ. The ratios, A_E/A_N, A_N/A_Z and A_E/A_Z were classified according to the Z period, and the medians given in Table IV were computed for each group. For amplitudes of 1μ the ranges of the recorded

TABLE IV—MICROSEISMS RECORDED AT KEW OBSERVATORY DURING 1932 WITH AMPLITUDES ON ALL THREE COMPONENTS NOT LESS THAN 1μ

Medians of A_E/A_N, A_N/A_Z and A_E/A_Z for different periods.

Period of Z Component	Number of Values	A_E/A_N	A_N/A_Z	A_E/A_Z
sec.				
4·5—4·9	12	0·9	1·35	1·25
5·0—5·4	10	1·0	1·15	1·15
5·5—5·9	44	1·0	1·15	1·1
6·0—6·4	67	0·95	1·1	1·05
6·5—6·9	133	0·9	1·1	1·05
7·0—7·4	79	1·0	1·0	1·0
7·5—7·9	51	0·95	1·0	0·95
8·0—8·4	10	1·0	0·8	0·8
8·5—8·9	4	1·0	0·8	0·85

oscillations are about half a millimetre on the horizontal components and about one millimetre on the vertical; consequently errors of measurement of a tenth of a millimetre may lead to an error of about 30 per cent. in the ratio of horizontal to vertical amplitudes. For the larger amplitudes the error is smaller, and the error of the medians varies inversely as the square root of the number of values. The medians of A_N/A_Z and of A_E/A_Z are plotted against the period in Fig. 3. The straight line on the diagram has been drawn to pass smoothly between the medians of A_E/A_Z which have been obtained from more than 10 values; the departures of the medians from this line are small for periods from 5 to 8 sec., but become larger for the longer or shorter periods which were recorded less frequently.

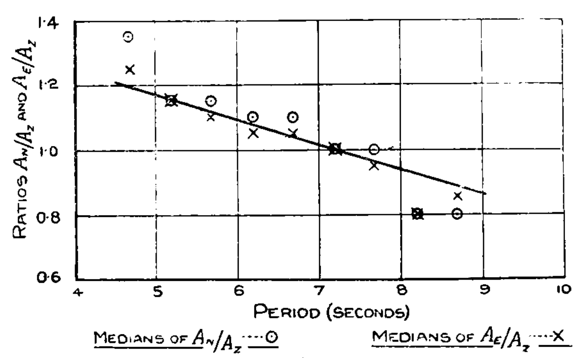

FIG. 3.—VARIATIONS OF A_N/A_Z AND A_E/A_Z WITH PERIOD. KEW, 1932.

The results of the comparisons are that within the accuracy of the tabulations :—

(a) The amplitudes of the microseisms recorded at Kew by the two horizontal components are equal for all periods.

(b) The ratio of horizontal to vertical amplitudes diminishes from about 1·2 for microseisms of period 4½ sec. to 0·85 for periods of 9 sec.

§ 4—REDUCTION OF THE RECORDED AMPLITUDES TO "STANDARD" AMPLITUDES

In the survey of the microseisms recorded during January, 1930, allowance was made for the effects of local structure by reducing the amplitudes to standard conditions. "Standard" amplitudes were defined as the surface amplitudes for simple Rayleigh waves in granite with energy equal to that of the microseisms. An approximate reduction factor of 1½ was then obtained for the horizontal movements at Kew. More accurate values of the horizontal and vertical reduction factors are available from the values of A_H/A_Z for different periods found in the preceding section.

The method depends upon the theory of Rayleigh waves through granite covered by a superficial layer. The horizontal and vertical displacements of such waves, u, w, have been compared with those of simple Rayleigh waves in granite having the same energy, u_R, w_R. Values of u/u_R and of w/w_R, for thin layers of limestone, sandstone and clay upon granite, are plotted against the corresponding ratios of u/w in Fig. 4. The ratios of u/w vary from 0·68 to 1·35. The relation between u/u_R or w/w_R and u/w does not depend upon the composition of the superficial layer. In the former case it is approximately linear and may be expressed by the equation :—

$$u/u_R = 1{\cdot}00 + 1{\cdot}85\ (u/w - 0{\cdot}68)$$

With $u_R/w_R = 0{\cdot}68 = 1/1{\cdot}47$, the corresponding relation between w/w_R and w/u is :—

$$w/w_R = 1{\cdot}00 + 0{\cdot}17\ (1{\cdot}47 - w/u).$$

The equations are graphed in the diagram, but it must be emphasised that the formulæ break down if the wave length is less than about 15 times the thickness of the layer.

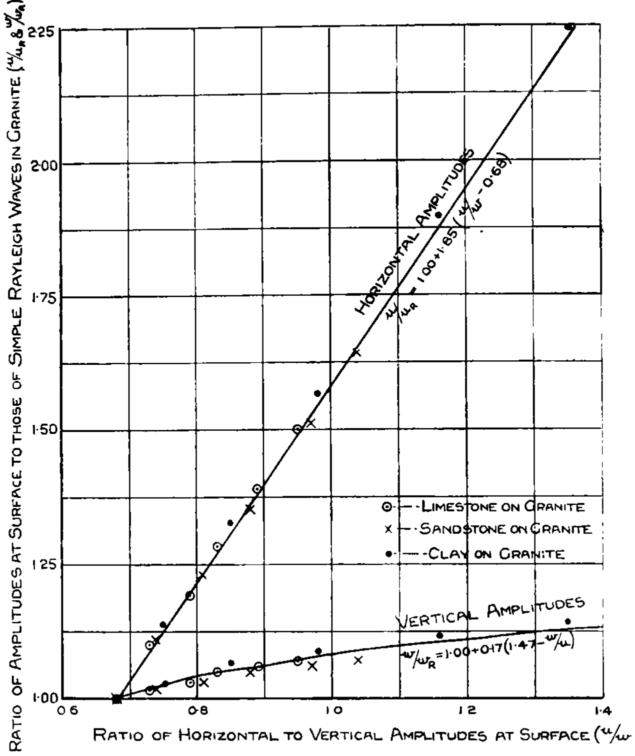

FIG. 4.—RELATION BETWEEN SURFACE AMPLITUDES AND RATIO OF HORIZONTAL TO VERTICAL COMPONENTS.

These formulæ for u/u_R and w/w_R may be combined with the linear relation between u/w and period from Fig. 3. The relation between the period (T_P) and the factor for reduction of the amplitudes at Kew to the standard conditions becomes $u/u_R = 2{\cdot}60 - 0{\cdot}14\ T_P$ for the horizontal components and $w/w_R = 1{\cdot}15 - 0{\cdot}01\ T_P$ for the vertical component.

Table V shows the mean standard amplitudes of the three components, computed from the mean amplitudes and periods for each month. The "standard" amplitudes of the horizontal components are less than those of the vertical, and except during months when the amplitudes are very small, the ratio A_H/A_Z is approximately the theoretical value for simple Rayleigh waves. When allowance is made for the effect of the weaker superficial strata at Kew, the mean amplitudes during 1932 are reduced from 0·9μ to 0·5μ in the case of the horizontal components and from 0·9μ to 0·8μ for the vertical component.

TABLE V—MEAN AMPLITUDES OF MICROSEISMS AT KEW DURING 1932 REDUCED TO "STANDARD" CONDITIONS

Component	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	μ	μ	μ	μ	μ	μ	μ	μ	μ	μ	μ	μ	μ
N—S	1·4	0·3	0·8	0·7	0·2	0·1	0·1	0·0	0·4	0·5	0·7	1·2	0·5
E—W	1·2	0·3	0·6	0·6	0·1	0·1	0·1	0·1	0·5	0·7	0·9	1·3	0·5
Z	2·0	0·6	1·0	1·0	0·3	0·1	0·2	0·1	0·5	0·8	1·6	1·9	0·8

§ 5—ADVANTAGES OF THE VERTICAL COMPONENT FOR ROUTINE TABULATIONS

The comparisons of the three components during 1932, have shown that on the average the differences between the two horizontal components are so small that there would be no advantage in tabulating from the E–W as well as from the N–S. On the other hand tabulations of the vertical component would be more valuable

To face p. 9

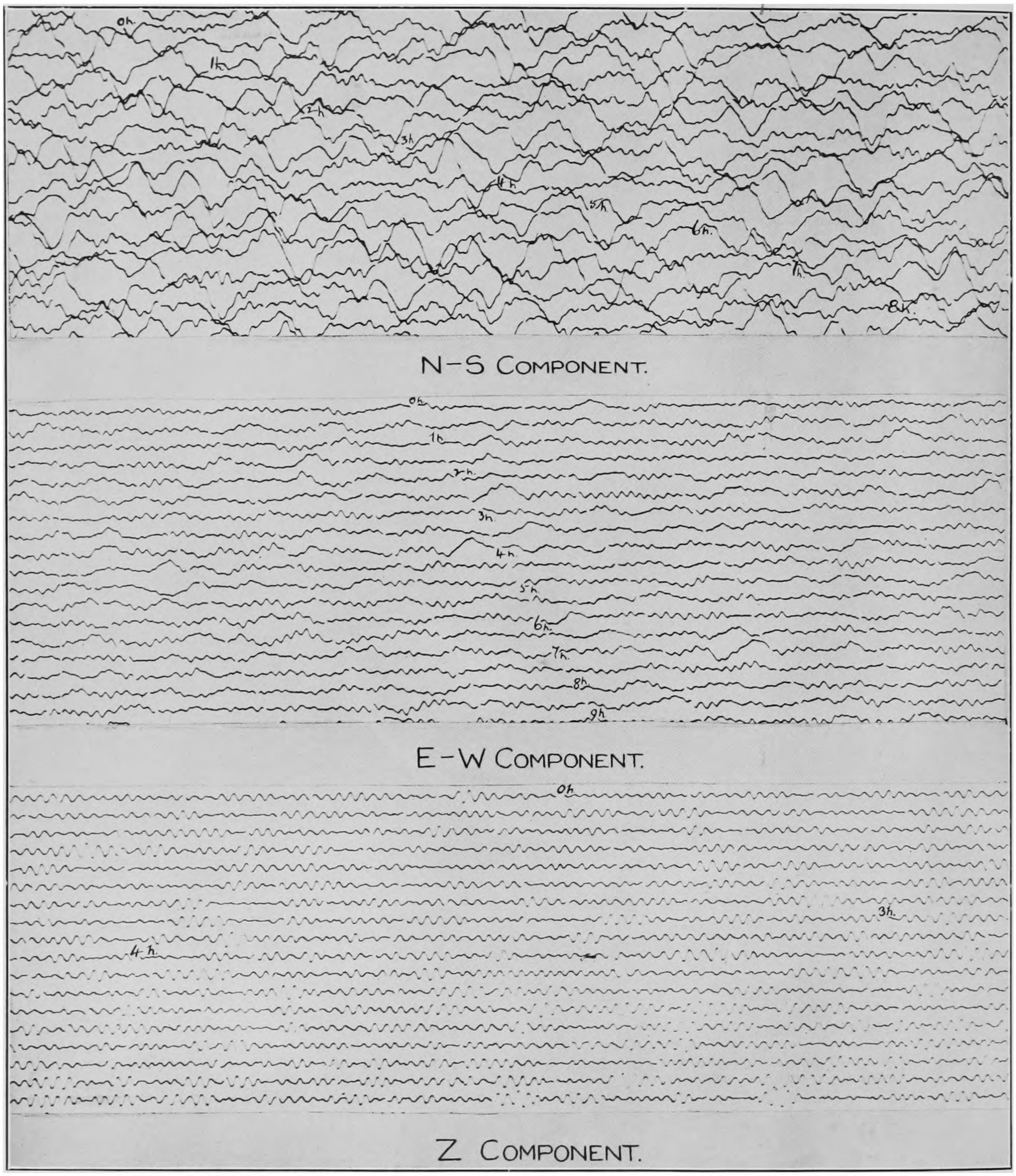

FIG. 5. KEW OBSERVATORY. PORTIONS OF GALITZIN SEISMOGRAMS, JANUARY 10, 1932, SHOWING MICROSEISMS AND THE EFFECT OF VERY STRONG LOCAL WIND

than those of the horizontal components for the following reasons :—

(a) For Rayleigh waves the motion is in the direction of propagation and in the vertical. Thus the Z seismograph gives a complete record of the latter component of the motion ; the former is recorded partly by the N–S and partly by the E–W, and it is difficult to determine what proportion of the horizontal motion is recorded by either instrument considering that waves from different directions are superposed (6).

(b) Theory and observation agree in demonstrating that the effect of the local geological structure, and the variation of this effect with the period, is very much smaller for the vertical than for the horizontal component.

(c) The Z seismograph at Kew has a higher magnification than the N–S or E–W for oscillations with the period of microseisms. The amplitudes to be scaled from the records are larger and the errors of tabulation are of less importance ; further there is no uncertainty in the monthly means owing to frequent occurrences of amplitude 0·0 mm. and indeterminate period.

(d) Freedom from wind disturbance. The horizontal seismographs at Kew, especially the N–S, show large irregular disturbances during local strong winds but the vertical instrument does not (7). Sections of the records showing these disturbances on the morning of January 10, 1932, are reproduced in Fig. 5. Obviously the selection of the largest microseisms during an interval of 30 minutes from the disturbed horizontal records is extremely difficult, and tabulations for the vertical component would be more reliable.

It will be noticed that while (c) and (d) arise from local or instrumental characteristics, (a) and (b), being due to the geophysical properties of the microseismic waves, are general and apply to all observatories. It is therefore desirable that, wherever possible, the routine tabulations should be taken from the vertical rather than the horizontal components. A change will be made in the component from which the microseisms at Kew are tabulated and the data from the beginning of 1935 will be taken from the vertical component. The results obtained for 1932 have shown that, within the accuracy of the measurements, the annual means of amplitude and period are equal for the three components, and accordingly the value of the data for determining secular variations will not be impaired by the change from the N–S to the Z component.

§ 6—SUMMARY

The microseisms recorded during 1932, by the N–S, E–W and Z components of the Galitzin seismograph at Kew Observatory have been tabulated for four hours daily. The mean amplitudes and periods of the three components for the whole year are approximately equal (0·9μ and 5·6 sec.). The amplitudes of the two horizontal components are nearly equal for all periods, but the ratio of horizontal to vertical amplitudes diminishes from about 1·2 for microseisms of period $4\frac{1}{2}$ sec. to 0·85 for periods of 9 sec. ; this variation is consistent with the hypothesis that the microseisms may be regarded as Rayleigh waves through granite covered by a superficial layer. The yearly mean amplitudes of the simple Rayleigh waves with energy equal to that of the microseisms are 0·5μ in the horizontal and 0·8μ in the vertical components.

The vertical is more reliable than either of the horizontal components for tabulations of the microseisms, since there are no uncertainties due to changes in the direction of travel of the waves, and effects of the local geological structure are smaller. There are additional advantages at observatories where the vertical seismograph has a larger magnification for these oscillations, and where the horizontal instruments are disturbed by local strong winds. Hitherto the routine tabulations of microseisms for Kew Observatory have been obtained from the N–S component, but the vertical is being adopted from the beginning of 1935.

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