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A REVIEW OF RESEARCH ON MICROSEISMS

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ABSTRACT

This paper reviews the various problems of research on microseisms, and also the methods of obtaining seismograms. Direction finding techniques are outlined, and possible origins of microseisms are suggested. The surf and wind theory of microseisms are compared. Mention is also made of some recent theories of microseisms. The paper shows how the subject of microseisms is closely connected with that of swell and storm prediction, a problem of interest to Defence Scientists and Meteorologists.

Introduction

It is noticed that there is a background oscillation on seismographs which is not due to any particular earthquake. This background oscillation is due to microseisms. The shaking of the earth due to microseisms is quite small, the amplitude being usually of the order of a few microns. The period of these microseisms is usually between 2 seconds and 10 seconds. If seismographs with sufficient magnification for suitable periods are used, noise of less than 2 sec. period or larger than 10 sec. periods is also observed but this is not of much interest. Noise of short period is associated with local vibration of trees and the seismic pillar or due to wind, rain, waterfalls, traffic etc. Microseisms of very large period (10 to 30 second) are due to frost, temperature fluctuations, groups of sea waves in shallow water or gusts of wind as variously suggested in the literature.

For the study of microseisms, often specially sensitive arrangements are made. Electromotive force from an electro-magnetic transducer is amplified by a suitable wideband amplifier and is recorded photographically or on pen and ink recorder, (see any text-book on Seismology). The recorder is the most costly part of the equipment especially when many components of ground motion are to be studied. A record of microseism often shows a phenomenon like beats.

Problems of Research

Records of microseisms are studied and the periods, and amplitude, are correlated with meteorological phenomena like atmospheric lows, pressure gradients and sea waves by statistical analysis. Often some experimental direction finding techniques are applied and possible sources of microseisms in weather charts at different times in these directions are studied for finding the explanation of the microseisms. Also some workers have concentrated on the study of various components of microseismic vibrations in order to know more about the nature and propagation of these waves.

It has not been difficult to correlate existence of a known storm or swell with increase in microseismic intensity but attempts to find the direction of the storm from microseismic records have not been completely successful. It is this problem which is of great interest to both the Defence Scientists and Meteorologists. Also one can very easily collect records from various observatories of some particular microseismic storm and then try to discover their relationship with meteorological parameters as indicated in available charts, or study the variation of microseisms from station to station in order to discover any geological discontinuities and crustal blocks. It is well known that amplitudes do depend on local ground conditions as well as proximity of faults. One could also construct a few seismographs with ease and obtain one's own records. Propagation of these waves in various regions needs also to be clarified by obtaining actual data as well as by extension of the theory.

Direction finding Techniques.

Direction finding is attempted in three ways. In one method (Ramirez 1940) three seismographs are placed at the corner of a triangle and from phase difference at these instruments the direction of arrival can be determined. In the second method relative magnitude of the N. S. & E-W component gives the direction (uncertainty of 180°). A modification of this method is Lee's (1935) statistical method. Phase difference between the components are variable, but certain values predominate in accordance with the theory for pure Raleigh waves approaching from adjacent directions.

A third variation (Bungers 1939) of the same would be to regard the usual beats to be due to simultaneous arrival from two different directions which are given by the sides of a parallelogram enclosing the horizontal ground motion diagram.

These direction finding techniques regard the waves as very simple in nature. Actually it is not easy to isolate Rayleigh waves from distortional Love waves on the surface. Direction finding from horizontal pendulums will on the whole be incorrect; directions obtained from vertical or from any components suffer from side and layer reflections of the waves during propagation. Since what we observe is a complex interference pattern, its direction of progress may have very little to do with direction of origin. In this connection the author was led to these conclusions from his work on direction finding at Washington D. C. Reference should be made to work of Kohler at Jena during war years where seismic direction finding techniques were investigated in detail in order to locate machinery and gun batteries for German war effort. Phases in the midst of a record had no relationship worth the name with the direction of approach. Only binaural intensity effect was recommended by him. This can be applied very conveniently to microseisms provided the stations are on the same Geological foundation. An interesting observation may be mentioned that while recording seismic waves from shots, the traffic on a near-by road was recorded like regular beats, also gusts of wind showed beats. It appears that beats appear not because of two directions of origin but due to either spurts of activity at perhaps one general moving source or due to reflections. An additional evidence for the spurious nature of the two directions would be disagreement between simultaneous determination of such directions at different stations.

Possible origin of Microseisms

From correlative studies and directions of approach following origins of microseisms have been suggested.

Microseism Type	*Origin and Location.*
1. 2 to 4 second period.	Cold fronts and wind at the coasts. Pressure gradient, over land, (Gassman) shaking of forests and buildings. Observations in the Eastern U.S., Europe, New Zealand, etc. A Wide-spread phenomenon.
2. Period greater than 4 seconds mostly around 6 secs.	A. Pressure gradient over Germany, Russia, Scandanaland :— via ; Greece. B. Pressure lows over oceans, Cyclones, Monsoon Storms :-- Italy, India Southern U. S., Caribbean, U. K., France China, Japan. C. Surf :— Scandanavia, California, Morocco, Philippines.

At one time there used to be energetic controversies between supporters of different theories of origin. But now geophysicists have realised that as in other geophysical phenomena, the explanation is bound to be very complex and it will vary with geographical location. There is perhaps room for all these sources. There should be more emphasis now on work regarding limitation of zones where any one or more agents are decisive. There is also not complete understanding regarding mechanism of transfer of energy from the wind or waves to the crust.

The surf and wind theory

The earliest theory of origin is associated with the names of Wiechert and Gutenberg. The correlation between surf and microseisms in Scandanavia, Gottingen, Hamburg, and Potsdam in Germany led them to regard surf against the Norwegian shield as a possible source of microseisms. Belenseifer (1939) found agreement regarding both intensity and period with surf at Sylt (an Island off Denmark) for some prominent microseisms. Repetti has observed similar correlation for Philippines. Byerley has found support for surf theory for microseisms at Berkley. Debrach has given data for Morocco.

Recent papers by Bath of Sweden support surf as the main contributor to microseismic energy. He has also discussed the effect of wind and pressure gradients over land and across the coast line of Norway. Strongest microseisms arise when wind blows across the coast line producing surf as well. He also discusses the 11 year period in microseismic intensity as due to shifting of cyclone tracks. There is marked semiannual variation in microseisms in Northern Europe with a low in summer. Bradford regards pressure effect over land as important for observations in Alaska. His conclusion is that type and intensity of cyclonic depression are dominant factors in microseismic propagation. Critikos (1931) finds that land winds from North are more effective for Greece than sea and surf. Gutenberg (1931) made a detailed study of records at some North American Stations and concluded that microseisms were most pronounced when surf at Canadian coast was favourable. Don Leet at Harvard also favours large pressure gradient especially across a coast line as chief factor in the generation of microseisms.

Some Early Theories

Bannerji long ago studied and explained microseisms on Indian records of monsoon origin as coming from the atmosphere's pumping effect over the ocean. Ramirez (1938) has shown that there is a lack of direct relationship between microbarometric and microseismic waves. Ghersi from records obtained in Italy correlated microseisms with pressure effects in the cyclone chimney when blowing over the ocean. According to him there is also strong dependence of microseisms at Shanghai on typhoons. Gherzi and Bannerji think of some direct action of the winds over the ocean bottom.

Bannerji has been predicting arrival of storm at the coast line from microseismic records few hours earlier. In case microseisms are generated at the storm base as claimed in these observations, larger range of prediction can be reached by making instruments more sensitive.

Recent work

At present there are quite a few teams of scientists working on these problems. In U. S. A. some work is being done by the Navy. But this work was led into premature application on account of reported results of Gilmore and Ramirez at St. Louis. A chain of triangle stations for tracking pressure lows across the Atlantic was established. But recent work of Kammer and Dinger has pointed out the need of further research and reassessment of the method.

Recently Prof. Gutenberg and his students at Pasadena have begun a scientific study of microseisms as opposed to just a statistical study of records. They have already set up basic experiments on microseisms, namely experiments that will distinguish between various types of waves in microseisms like Love waves and Rayleigh waves.

Press and Ewing at Columbia have given a theory for microseisms. They believe that microseisms owe their origin to a Stoneley type wave (Airy Phase) that travels from the storm centre over the ocean partly in the earth's crust and partly in the ocean. This is transformed into Rayleigh wave at the coast line. The group velocity for these waves shows a minimum with period at about 6 seconds. Some experimental data by Katz was given for some microseismic storms at New York which could be explained on this hypothesis as well as on the pressure gradient across coast basis as argued by Leet.

The sea waves have oscillations of few microns at the bottom, and when these persist for large areas these might transfer some motion to the basement. A more elegant theory for this interaction between waves and the sea bottom has been given by Longuit

Higgins. He also explains the repeated observation that often strong microseisms have period half that of the ocean waves. There is a second order pressure term in case of standing waves that is in phase over large areas and has double the frequency of the waves. Darbyshire in U. K. and others have marshalled data in support of this theory for the U. K. They also notice the time lag of required order between microseisms and arrival of associated waves at the cost. Bernhard's earlier data for microseisms at Strasbourg and swell at Morocco also supports this. Becker (1949) in Germany and Jones in New Zealand also favour such an origin of microseisms.

Effect of crustal Blocks.

Possibly all the various theories described above are true to a certain extent. There are well known exceptions to each theory even in the same general geographical area. For example Whipple and Lee pointed out that equal storms did not give equal microseismic intensity at U. K. stations. Or some storms on the ocean glaringly forget to excite microseisms. Sometimes one has large microseisms even though surf conditions are unfavourable. Such exceptions need special study. The effect of geological blocks in the upper crust has to be investigated in detail. It is well known that when there are strong microseisms in the Caribbean, the amplitudes are nill at Florida.

As early as 1921 Gutenberg has pointed out that the propagation of microseisms in Europe is clearly affected by boundaries of major geological units. For example, microseisms originating near Scandanavia are propagated far into Asia without much loss of energy, but their amplitudes decrease considerably in southerly direction where surface layers of different geological age and with different elastic constants are crossed by the waves. Similarly, microseisms are propagated across large parts of the United States with ease. On the other hand, records of microseisms produced by hurricanes in the Caribbean area and recorded at the stations of the United States Navy show that the amplitude of the microseisms decreases rapidly from one island to another. In the Pacific the station at Guam of the Microseismic Project of the United States Navy records microseisms from typhoons with their centre far away in the area of Japan. Japanese scientists have pointed out that typhoons in that area are accompanied by large microseisms at the stations along the east coast of Japan, but only by insignificant microseisms on the west coast of Japan. There is some indication that typhoons moving westward south of Guam produce relatively irregular and small microseisms at Guam until they cross the Andesite Line near the Caroline Islands. Thus far, in all instances where the microseisms are propagated over long distances without much loss of energy, stations and sources are on the same geological unit. On the other hand, where amplitudes of the microseisms decrease rapidly with distance there is some evidence that they have crossed one or more discontinuities separating areas with different seismic velocities. Faults need not reduce appreciably the amplitudes of microseisms as long as velocities on both sides of the fault zone are approximately the same, and as long as the fault zone is narrow as compared with the wave-length. Study of the decrease of amplitudes of microseisms based on more extended data can be expected to give more information on boundaries of distinct units of the Earth's crust.

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Effect of superficial layers.

Several papers especially by Lee have appeared regarding effect of superficial layers of sand or clay on the amplitudes of microseisms; such studies would explain marked differences observed sometimes in the intensity at neighbouring stations.

Compexity of origin.

Geophysical phenomena are characterised by great number of variables and single explanation for all areas on the surface of the earth cannot be expected. It is clear that whenever observations are made near rocky coasts in N. W. Europe, N. E. America, Philippines etc. the origin is surmised to be the wind or surf conditions at the coast. When observations are conducted in Japan, Chinese and Indian coastal areas, Southern Europe, S. E. United States, New Zealand, or U.K., Barometric lows over oceans, become more important. Microseisms in Switzerland, Russia, Greece, Alaska and to some extent Sweeden and Finland are also correlated with pressure gradients over land. For steep coast line with high cliffs and perhaps a fault line close to the coast on the ocean side, the pressure gradient effects on coast become more prominent. It is still controversial as to the mechanism of production of microseisms under lows over ocean. There is evidence in U. K. that microseisms are of period half that of prevalent waves. On Indian coast during monsoon storms periods were quoted as of the same order. More data on this point will decide whether only one explanation given by Longuit-Higgins or by Ewing and others is more reasonable or whether both hold, but become significant only in different areas.

One can imagine that on development of a proper direction finding technique, it would perhaps be possible by means of microseisms to track stroms. Or one might learn about surf conditions in distant coasts by this means.

Importance to the Navy.

The origin of microseisms is but imperfectly understood at present. In case, in India, microseisms come directly from beneath the storm centre, it would be possible to foretell the incidence of storms at the coast days ahead since the storm travels at about 20 to 30 miles an hour while the microseisms travel at more than a mile per second. This would also afford an imporant aid in knowing meteorological conditions in southern Central Indian Ocean which is not accessible to other modes of routine observation so far.

In case the stronger microseisms come from swell at a coast, by patient peace-time study, conclusions can be arrived at, which would help in charting surf at distant coasts during an emergency. One could still surmise indirectly though, the meteorological conditions in distant oceanic areas.

Thus the subject of microseims is closely connected to that of swell and storm prediction.

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