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M_2 or first shear mode continental Rayleigh waves from Russian nuclear explosion of 30 October 1961

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ABSTRACT. M_2 or first shear mode continental Rayleigh waves excited by the Russian nuclear explosion are studied with reference to the continental structure. There is general agreement with crustal thickness of 45 km. The other aspects of the dispersion curve are also discussed with reference to previous works by others.

1. Introduction

A seismometric study of the above explosion was undertaken by the author (1962) using seismological data obtained from stations in India and Pakistan. The findings of the author were as follows —

Epicentre : Lat. 73½°N, Long. 62¼°E

Origin time : $08^h\ 33^m\ 33^s$ GMT

In the present communication it is proposed to study the first shear mode continental Rayleigh waves recorded by the vertical component of the Columbia type long period seismograph operating at Delhi. The constants of the instrument are as follows—

Seismometer free period $T_0 = 15 \cdot 0$ sec

Galvanometer period $T_g = 90 \cdot 0$ sec

The seismometer and galvanometer are both critically damped.

In a series of papers Sezawa and Kanai (1935a, 1935b, 1940) and Kanai (1948, 1951, 1955) computed dispersion curves and particle motion of M_2 or Sezawa waves for a single layer crust and made attempts to identify them on seismograms. But the credit of providing exceptionally clear data on higher mode surface waves is due to Oliver and Ewing (1957, 1958). The subsequent studies of M_2 and higher mode waves excited by natural earthquakes were undertaken by Oliver, Dorman and Sutton (1959) and Kovach (1959). Theoretical studies of Sezawa and Kanai were limited to single layer crust resting on semi-infinite substratum. It was Nagamune (1956) who made a theoretical study of M_2 waves in a medium with double surface layer.

The observations on M_2 waves are very rare because these short period waves are likely to be attenuated quickly in non-uniform structure of the crust. According to Oliver and Ewing (1957), the condition at the focus, depth etc might also be important in exciting higher mode waves. It was quite natural that surface and shallow disturbances like nuclear explosions might excite the higher mode waves more effectively. The M_2 or first shear mode Rayleigh waves excited by nuclear explosions were studied by Pomeroy (1963) from the long period records of Agra (India) and Upsala (Sweden) Press-Ewing seismograph. Subsequently, Tandon and Chaudhury (1963) have observed M_2-waves in their detailed study of seismic waves on account of 3 Russian nuclear explosions during August-September 1962. The nuclear explosion of 30 October 1961 has, however, the highest yield and accordingly the waves were expected to be better developed. Hence it is intended to make a study of the M_2-waves in relation to the structure of the crust. The path from Novaya Zemlya to Delhi (India) is primarily continental.

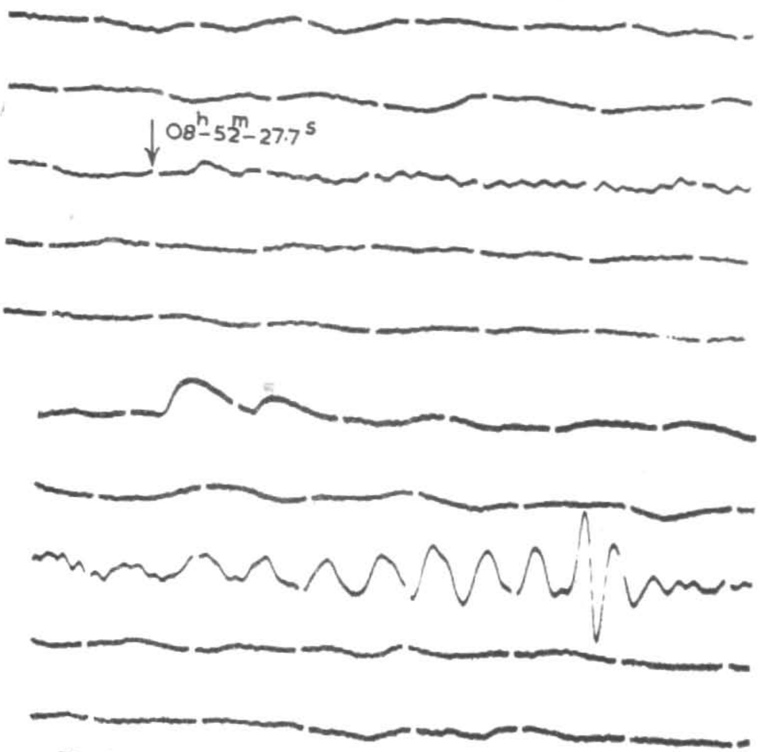

Fig. 1. Sections of Press—Ewing seismogram of 30 October 1961

2. Study

It would be seen from the record reproduced in Fig. 1 that the higher mode Rayleigh waves were well exhibited in the record. The background was fairly quiet, although microseisms having periods smaller than the periods of surface wave under study were present. But the amplitudes of surface waves were much larger than the amplitudes of the background microseisms. Accordingly it was not very difficult to pick up wave periods and their group velocities. The dispersion data of M_2-waves were obtained in the usual way and they are plotted in Fig. 2, showing the theoretical dispersion curve of Dorman's case 8043-336/03800 which takes into account a sedimentary layer. There is general agreement between the theoretical dispersion curve and observed dispersion of M_2-waves. The waves of period shorter than 7 seconds have not been observed. The north-south component is, in this case, nearly along the direction of propagation and should have recorded the M_2-waves but no use could be made of the record on account of the oscillatory background and diminished amplitudes. The explanation for the diminished amplitudes of the M_2-waves in the north-south component was provided by Pomeroy. The instruments operating at Delhi were previously at Agra and Agra records were used by him for the study of M_2-waves in relation to the structure of the crust between Novaya Zemlya and Agra.

The observations of the present author agrees well with those of Pomeroy and Tandon and Chaudhury as far as the usual branch of the M_2-wave dispersion curve is concerned. Tandon and Chaudhury have, however, observed a new dispersion curve with higher periods and higher values of group velocities. According to these authors the dispersion curve has both inverse and normal dispersion

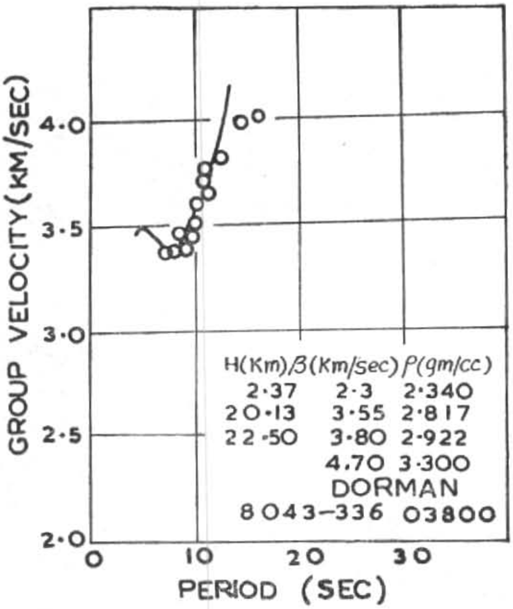

Fig. 2. M_2 dispersion curve

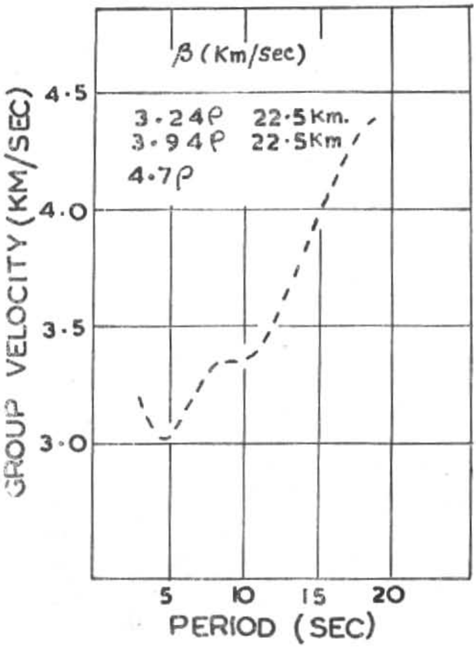

Fig. 3. M_2 dispersion curve
(Nagamune's case II)

with a minimum of group velocity of 4·1 km/sec at a period of 35 seconds. Neither the present author nor Pomeroy could observe any group velocity higher than 4 km/sec with higher wave periods. The authors attributed this new dispersion curve due to M_2-waves by stating that with higher contrast of velocity of shear waves in the crustal layering as in Nagamune's case I, longer period waves are possible and that the theoretical dispersion curve of Nagamune's case I shows waves of inverse dispersion in the period range of 17 to 33 seconds with a minimum group velocity of about 3·0 km/sec at 33 seconds. It may be pointed out in this connection that Nagamune's case I with high rigidity contrasts in layer is not applicable in the case of continental crust mantle system. Nagamune's theoretical dispersion curve case II for 45 km crust with contrast of shear wave velocity more appropriate to continental crust mantle system is shown in Fig. 3. The flattening of the group velocity curve and perhaps another minimum at a velocity of 4·4 to 4·7 km/sec at roughly a period of 20 seconds as suggested by Oliver and Ewing (1958) when the effect of gradient of velocity in the mantle and the curvature of the earth is taken into account might explain the existence of channel waves of S_a and S_n type as observed by Caloi (1953) and Press-Ewing (1954, 1955) from the stand point of normal mode theory.

The shorter period surface waves near the minimum of the group velocity of M_2-waves (Fig. 2) were not observed. The reason may be due to the fact that the propagation of short period waves is strongly affected by the variations and inhomogeneities present in the upper crustal layer through which these waves travelled. The L_g wave is a short period surface wave and the propagation of the phase could be explained from the consideration of the normal mode theory and the larger amplitudes of the L_g waves could be explained by stationary value at the minimum of the group velocity curve of M_2-waves. The absence of shorter period waves near the group velocity minimum is in accord with the observations of the author (1961) on the absence of L_g waves due to earthquakes originating from regions to the north of the Himalayas.

3. Conclusions

The above study leads to the following conclusions —

1. The higher value of crustal thickness of 45 km from Novaya Zemlya to Delhi is probably justified by the mountain ranges with deeper roots persent along the path.

2. The shorter period waves of L_g type or higher modes like the second shear mode are absent in the records presumably due to non-uniformity in the crustal section of the path.

3. Higher mode waves are better excited when the source is artificial like the atmospheric nuclear explosion.

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