Surface wave dispersion and crustal structure in Asia

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ABSTRACT. Dispersion of surface waves of Rayleigh type due to two earthquake shocks in the Arctic region was studied from the seismograms of Shillong. From the study of the dispersion curves it was concluded that the average crustal thickness was of the order of 45 km for the Asian path from Arctic to Shillong.

Surface waves of the Rayleigh and Love type have been widely used for determining the crustal structure of the different regions of the world. Oliver (1962) has summarised the observations on the seismic surface waves having periods between one second and one hour with velocities of 1 km/sec, to about 8 km/sec. The basic data for the surface wave method of determining the crustal structure of a region is a dispersion curve derived directly from seismograms. The dispersion curve consists of a plot of points of observed group velocity *versus* wave period. Many investigators, beginning with Love (1911), have shown in the past that this dispersion is a natural consequence of the layering in the crust. Comparison of observed dispersion with theoretical curves for different crustal models leads to a choice of that model, which has the best fit with the actual observations. If the observations cover a broad range of periods and if the crust is fairly simple and homogeneous between the epicentre and the seismograph station, the theoretical model can be expected to give fairly a good indication of the average properties of the crust.

In 1963 through the co-operation of the United States Coast and Geodetic Survey, three components of Press-Ewing long period type seismometers were installed in the Central Seismological Observatory at Shillong. These instruments form a matched system with a seismometer period of 30 secs, and galvanometer period of 100 secs. The magnification is around 3000 for a period of 30 secs. Long period seismic waves at fairly long distances are generally well recorded by these seismographs. This has given us an opportunity to study the crustal structure of the regions which have not hitherto been much widely studied. In the present communication, it is proposed to study the average crustal thickness of the region from Arctic to Shillong from a study of the dispersion data of Rayleigh type of surface waves originating from two earthquake shocks in the Arctic region.

The records of the earthquakes which have been used in this study are due to the shocks of (1) 4 September 1963 and (2) 25 August 1964. According to U.S.C.G.S., the epicentre of the shock No. 1 was near the east coast of Baffin Island (Lat. 71°·3 N, Long. 73°·1 W), h about 33 km, $H = 13^h\ 32^m\ 12.3^s$ and magnitude 6·1 and for the shock No. 2, epicentre was east of Soveranaya Zemlya (Lat. 78°·2 N, Long. 126°·6 E), h about 50 km, $H = 13^h\ 47^m\ 20.6^s$ and magnitude 6·1. Both the shocks were well recorded in the seismograms of Shillong (Lat. 25° 34′N, Long. 91° 53′ E). The dispersion of Rayleigh waves could be measured from the seismograms with great precision because of the long path travelled by the waves. The epicentral distance for the shock No. 1 was 9110 km and that for the shock No. 2 6033 km. These were a few of the largest paths, the structure of which are primarily continental over which surface waves have so far been recorded by the Shillong seismographs. The epicentral distance being very long the results obtained were rather independent of small errors in the determination of epicentral distances and origin times. Fig. 1 is an index map showing the position of the epicentres at Baffin Island (path 1) and Soverenaya Zemlya (path 2) and station Shillong. It may be seen from Fig. 1 that a portion of path 1 is water covered. Oliver, Ewing and Press (1955) from a study of Lg phase has shown that most of the water covered portion of path 1 has got a continental structure.

The observed Rayleigh wave dispersion data as obtained from the seismograms were compared with the theoretical Rayleigh wave dispersion curves (Fig 3) computed by Dorman for continental path. The following symbols have been used.

β = Shear wave velocity, ρ = Density and H = Layer thickness in km.

The dispersion curves for the Rayleigh waves were determined by graphical methods by plotting crests and troughs observed on the seismograms. The surface wave portion of the seismograms for one shock has been shown in Fig. 2 as an example. The group velocity dispersion data for the Rayleigh waves thus obtained are presented in Table 1 for shock No. 1 and in Table 2 for

Fig. 1. Index map showing wave-paths of the observed earthquakes

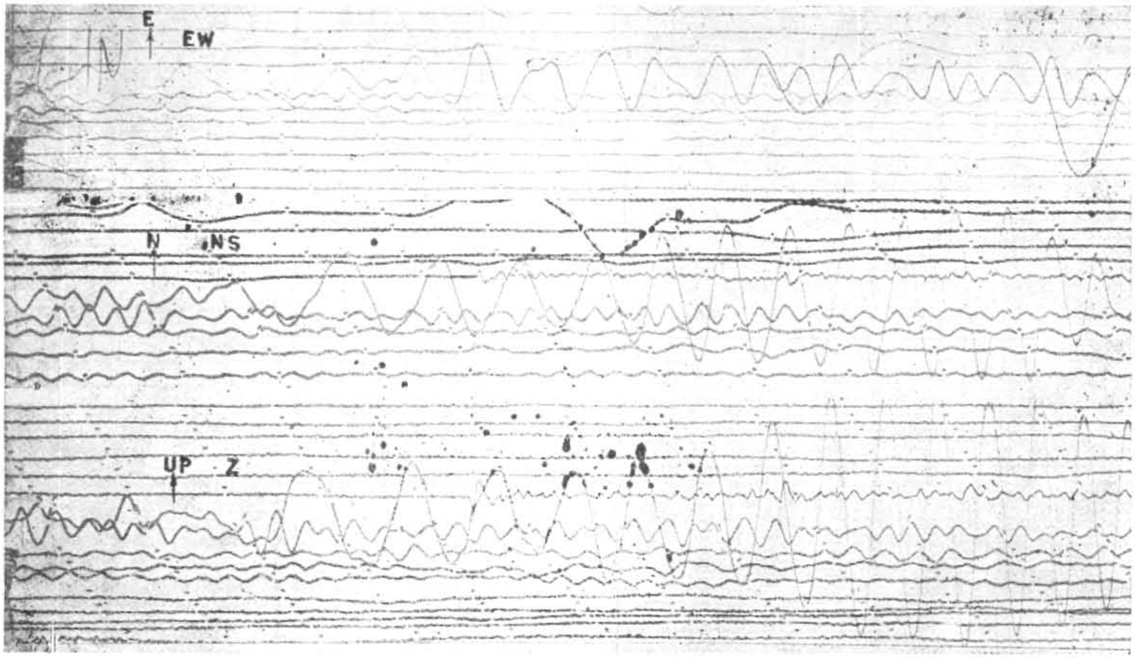

Fig. 2. Part of the ultra-long period seismograms (E-W, N-S, and Z) recorded at Shillong of the earthquake of 4 September 1963 showing the surface waves

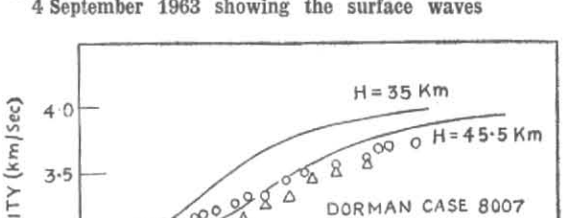

Fig. 3. Rayleigh wave dispersion, Arctic to Shillong continental path

o — Observed dispersion data from 4 September 1963 earthquake
△ — Observed dispersion data from 25 August 1964 earthquake
Continuous lines corresponds to theoretical curves

TABLE 1

Period (secs)	Group velocity (km/secs)	Period (secs)	Group velocity (km/secs)
20	3·04	42	3·43
23	3·07	43	3·44
25	3·08	46	3·50
28	3·11	51	3·57
30	3·14	56	3·64
32	3·20	57	3·62
35	3·27	58	3·69
37	3·32	59	3·67
40	3·37	64	3·71

TABLE 2

Period (secs)	Group velocity (km/secs)	Period (secs)	Group velocity (km/secs)
23	2·89	39	3·16
24	2·92	40	3·20
25	2·94	41	3·23
27	2·96	44	3·27
29	2·98	47	3·31
31	3·02	48	3·35
33	3·05	49	3·40
34	3·10	51	3·50
36	3·13	56	3·55

the shock No. 2. These have been plotted in Fig. 3 together with the two theoretical curves for two different crustal thickness corresponding to Dorman case 8007. These theoretical curves were computed for a two layered crust overlying a infinite half space with velocities, thickness and densities as indicated in the figure. The values for thickness, velocities and densities were chosen by Dorman as representatives of the values obtained from seismic refraction measurements in the continental crust, and from the values obtained from gravity measurements.

An inspection of the group velocity period curves for Rayleigh waves shows that, the observed points obtained from the records of earthquake No. 1 are below the theoretical curve in the period range 40-64 seconds, while the points are above the theoretical curve for the period range 20-40 sec. The departure in the higher period range can be attributed to the fact that longer period Rayleigh waves are appreciably affected by a velocity gradient in the mantle (Press and Ewing 1955). The slightly higher values of group velocities in the period range 20-40 seconds points to a crust whose thickness is slightly less than 45 km. It may also be seen that the group velocity values on account of the earthquake No. 2 are below the theoretical curve for a crustal thickness of 45·5 km for the entire range of periods from 23-56 secs. This suggests a crustal thickness of a little more than 45 km. The departure from the theoretical curve has increased with the increase of period. This again can be accounted for, by the velocity gradient in the mantle.

The lower value of crustal thickness as suggested by the group velocity values from the earthquake No. 1 may perhaps be attributed to the fact that a small fraction of path No. 1 (about 500 km) which constitutes about 5 per cent of the total path is non-continental in nature and for which no correction has been applied. In addition the portion of the path in the Arctic region is likely to have a smaller crustal thickness as compared to the continental Asian portion of the path.

From a study of the Rayleigh wave dispersion data from the above two earthquakes it may be concluded that the crustal thickness for the Asian path from Arctic to Shillong across U.S.S.R. and China is of the order of 45 km. The mean elevation of the path is about 1 km. Although data from deep seismic refraction measurements are not yet available for the region, but considering the fact that quite a large area of the region under study is covered by high plateau of Mongolia and Tibet, the author's estimation of the average crustal thickness seems to be quite appropriate. This estimate is also in good agreement with the values arrived at by Shechkov (1964). Shechkov after a sudy of the Euro-Asian crustal structure from the dispersion data of Rayleigh and Love waves has indicated a crustal thickness of greater than 40-45 km in southwest Mongolia.

The above observations are also in good agreement with the observations made by Kovach (1959). Kovach estimated the crustal thickness for an Euro-Asian path, across China and U.S.S.R. to be about 45 km from a similar study of Love and Rayleigh wave dispersion from the records of Upsala, Sweden. The author's conclusions are also in good agreement with that of Tandon and Chaudhury (1963), who using data from Russian Nuclear Explosions recorded by Long Period Press-Ewing seismographs estimated the crustal thickness for the Asian path between Novaya Zemlya and Delhi from a study of the fundamental Rayleigh and M_2 waves. Saha (1965) has also arrived at similar conclusions regarding the average crustal thickness between Novaya

Zemlya and Delhi from a study of M_2 waves from nuclear explosions.

Data for more earthquakes could not be incorporated in the present study as earthquakes with epicentres in the Arctic region, and having sufficiently large magnitude, exhibiting a good dispersion of surface wave in the Shillong seismograms are rather rare. As such the author had to satisfy himself with data from two earthquakes only.

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