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# Phase velocity of Rayleigh Waves over the Punjab

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(*Received 7 December 1967*)

ABSTRACT. From the records of Long-period Vertical component seismographs of identical characteristics at Delhi, Dehra Dun and Bhakra, the phase velocity of Rayleigh Wave has been computed. The waves extended from a period of about 17 sec to about 50 sec. The observed dispersion was compared with plausible theoretical models and it is seen that in the area of study the crustal thickness is about 40 km inclusive of 5 to 6 km of sediments.

## 1. Introduction

Surface wave dispersion studies are at present being used extensively for getting the average structure of the crust. The method is particularly useful in regions which are either not easily accessible or where there is a lack of observatories. Of the methods used, the phase velocity dispersion has been found to be more sensitive as well as more amenable to interpretation in the light of theoretical calculations. First used by Press (1956, 1957), the method has been applied in later studies by a large number of workers particularly Press (1960), Ewing and Press (1959), Oliver, Kovach and Dorman (1961), Brune and Dorman (1963), Luosto (1965) etc. A similar attempt has been made here for the study of the Punjab region. For this purpose, long period (vertical) seismographs of the Press-Ewing type ($T_0 = 30$ sec, $T_g = 100$ sec) were specially installed at Dehra Dun and Bhakra. These seismographs were set to the same operating characteristics as the one operating at Delhi under the WWNSS Scheme. This network constituted a tripartite array and was used to study the phase velocity of Rayleigh waves.

## 2. Data and method

The records for more than a year during 1965 and 1966 from the three stations were scrutinised and only those which gave clear trains of waves at all the three observatories were used. Particulars of the earthquakes selected are given in Table 1. An index map showing the wave paths from these earthquake epicentres to the tripartite network is shown in Fig. 1.

Of the three stations constituting the tripartite network, Dehra Dun (30·19°N, 78·03°E) and Bhakra (31·25°N, 76·25°E) are located on the southern foothills of the Himalayas, whereas Delhi is at the northeast tip of the Aravalis. The intervening space is filled with recent sediments. Fig. 2 shows this area together with the tectonic features as recently published by the Geological Survey of India. It may be seen from Fig. 2 that the thickness of the sediments is of the order of 3 km near the foothills of the Himalayas.

The method used for the calculation of the phase velocities was by the correlation of phases at the three stations. For this purpose, as mentioned earlier, only those events which gave clear trains of Rayleigh waves were selected. The peaks were correlated with reference to their amplitude characteristics, periods and wave form. A few typical cases of phase correlation are shown in Figs. 3, 4 and 5. After correlating the waves, the arrival times of crests and troughs were measured and these were plotted against the wave numbers for the three stations. The difference in the arrival times as well as the periods were then measured from these smoothed curves. Any effect of either observational errors or of small perturbations in the wave trains was thus reduced. In Fig. 6, a typical arrival time *versus* wave number curve is shown.

Phase velocities were calculated by the standard tripartite formula on the assumption of a plane wave front and of a uniform crust under the tripartite network. The calculations were also checked with the help of a nomogram prepared for the tripartite network.

During the progress of the work it was noticed that in the case of waves approaching from the north and therefore crossing the Himalayan mountain ranges, the wave trains were not regular. Even on occasions when the wave could be correlated, the results were found to be inconsistent. It is apparant that the close proximity of the Himalayan mountains was responsible for this effect. A more detailed study of these records may throw light on the structure of the crust and upper mantle under the Himalayas.

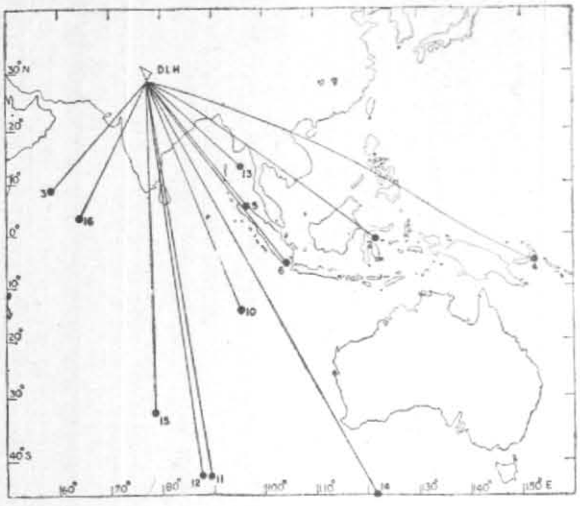



**Fig. 1. Map showing the epicentres of earthquakes and the great circle paths**

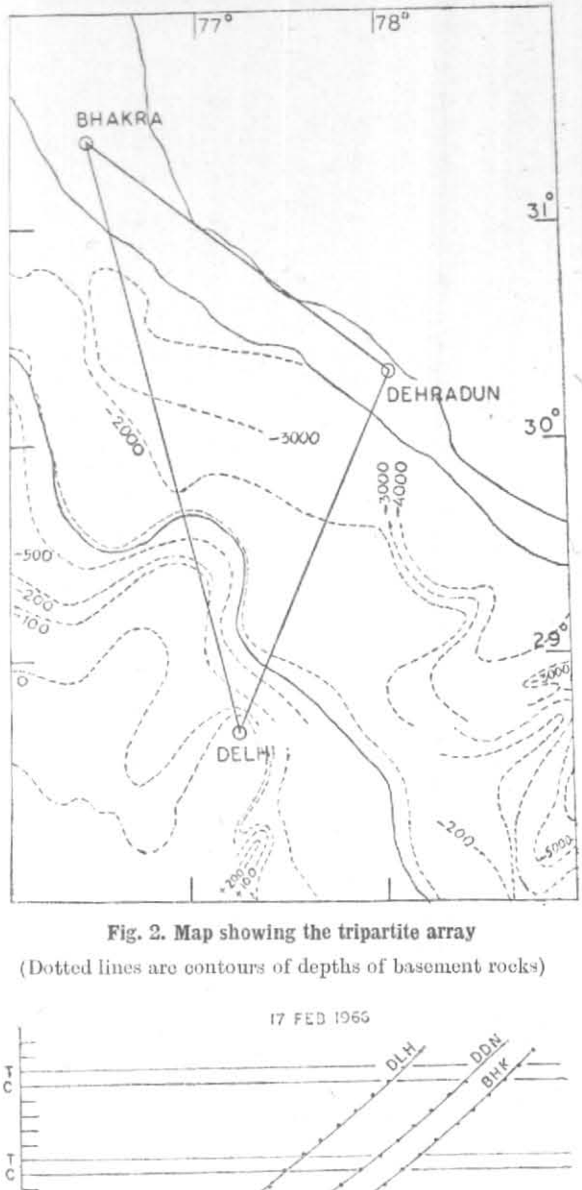



**Fig. 2. Map showing the tripartite array**

(Dotted lines are contours of depths of basement rocks)

Fig. 3

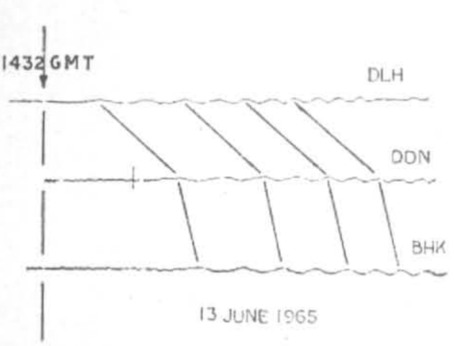



Fig. 4

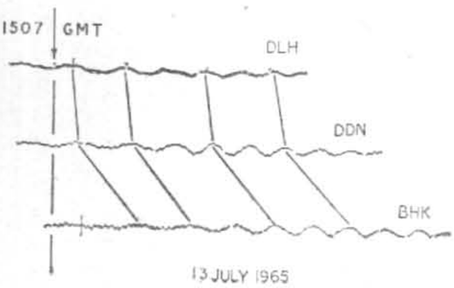
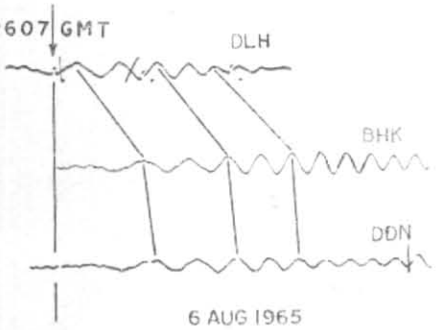



Fig. 5




**Figs. 3–5. Typical records showing correlations of waves at the three stations**

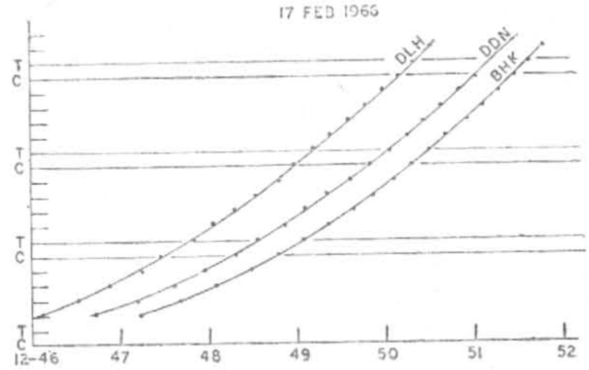



Fig. 6

The selected list of events studied in this paper does not include any of these.

### 3. Results and discussions

The phase velocities obtained have all been plotted against periods and shown in Fig. 7. The periods range from about 17 sec to about 50 sec and the velocities from 3·3 km/sec to 4·1 km/sec. It will be seen that the observed points

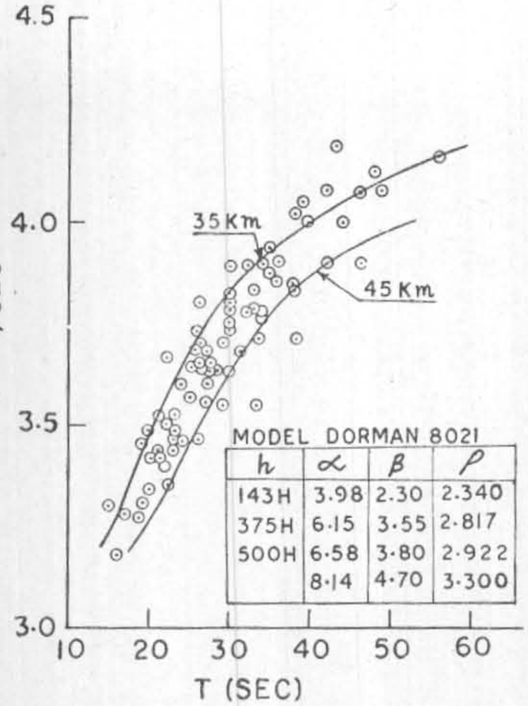


Fig. 7. Rayleigh wave dispersion (Punjab plains)

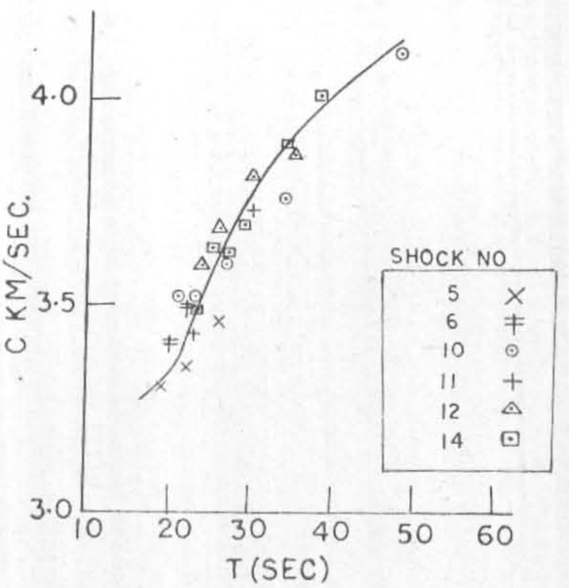


Fig. 9. Dispersion data for earthquake waves arriving along the leg Delhi—Bhakra

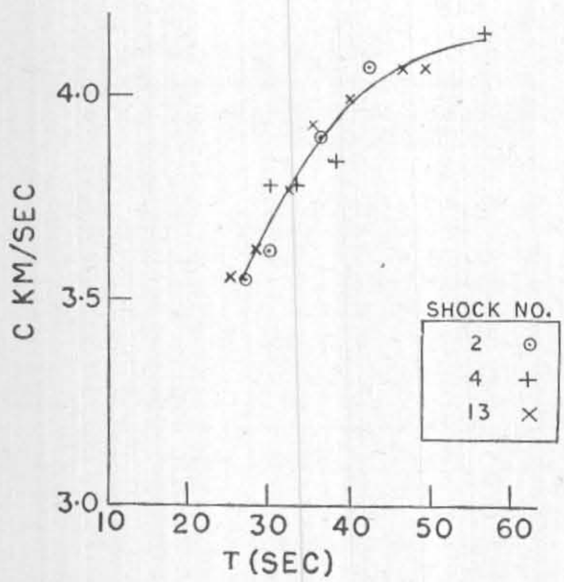


Fig. 8. Dispersion data for earthquake waves arriving along the leg Dehra Dun—Bhakra

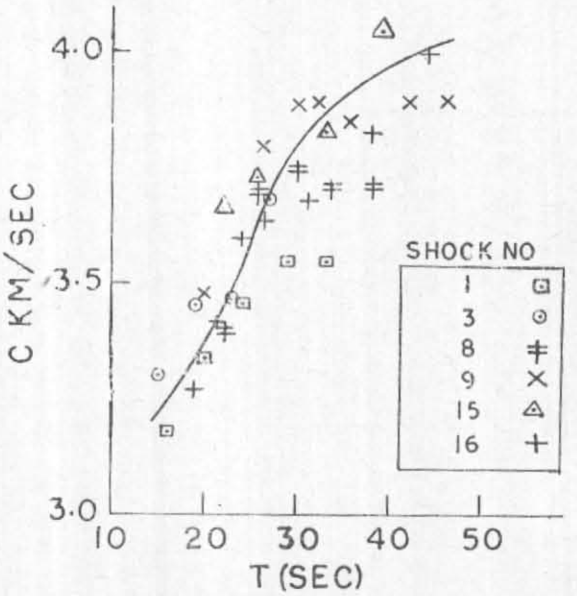


Fig. 10. Dispersion data for earthquake waves arriving along the leg Delhi—Dehra Dun

have a scatter of about $\pm$ 0·1 km/sec about the mean curve. Nearly all the observed points, however, lie between the two theoretical curves corresponding to Dorman's model 8021 for crustal thicknesses of 35 and 45 km. The comparison leads to the conclusion that in the area of study the crustal thickness is about 40 km inclusive of 5 to 6 km of sediments.

In order to find out whether there is any inhomogeniety within the tripartite area and if so whether it is possible to detect it, the results were plotted separately according to the direction of approach of the waves. According to Knopoff, Mueller and Pilant (1966) waves approaching from a direction close to one of the sides of the triangle would give the phase velocity

TABLE 1

| Date | Origin time (GMT) | Epicentre Lat. (°) | Epicentre Long. (°) | Depth of focus (km) | Mag. (CGS) |
|---|---|---|---|---|---|
| 13 Jun 1965 | | | | | |
| 13 Jul 1965 | 14 41 07·9 | 1S | 121·5E | 96 | 5·6 |
| 6 Aug 1965 | 05 54 01 | 8·8N | 58·5E | 33 | 4·1 |
| 12 Aug 1965 | 12 57 09·7 | 5·3S | 152·2E | 41 | 5·9 |
| 17 Aug 1965 | 10 35 04·1 | 5·3S | 96·2E | 33 | 5·3 |
| 21 Aug 1965 | 15 04 17·6 | 5·9S | 104·2E | 33 | 5·5 |
| 9 Sep 1965 | | | | | |
| 5 Oct 1965 | | | | | |
| 10 Oct 1965 | 17 25 44 | 59·1S | 24·8W | 53 | 5·7 |
| 31 Oct 1965 | 17 24 06·4 | 14·2S | 95·2E | 33 | 5·4 |
| 1 Dec 1965 | 15 23 02 | 42·1S | 89·1E | 33 | — |
| 1 Dec 1965 | 17 09 06·4 | 42·0S | 87·9E | 33 | 5·2 |
| 5 Jan 1966 | 17 21 28·4 | 13·2N | 95·5E | 37 | 5·3 |
| 7 Jan 1966 | 20 17 14 | 62·6S | 155·6E | 33 | 5·8 |
| 17 Feb 1966 | 11 48 00·8 | 32·2S | 78·9E | 33 | 6·4 |
| 15 Aug 1966 | 10 20 42·2 | 3·8N | 64·0E | 37 | 5·6 |

features of that side. Thus Figs. 8, 9 and 10 should give the features corresponding to the three legs Delhi-Dehra Dun, Delhi–Bhakra and Dehra Dun–Bhakra. It is seen that in the case of Dehra Dun–Bhakra and Delhi–Bhakra the scatter of the points is not much, whereas in the case of Delhi–Dehra Dun there is a considerable amount of scatter. It is, however, not possible to detect any appreciable difference in the mean curves. It is, therefore, presumed that there are no large variations in the crustal thickness beneath the array.

In a recent paper, Chaudhury (1966) has studied the crust across the Gangetic basin and one of the curves computed by him is the phase velocity curve. He has used Brune's method and assumed either integral or half-integral values for the initial phases as suggested in the paper. He has not confirmed the values by correlation of waves at another station lying on the great circle. Nevertheless, the results obtained by him and the present results agree fairly well and lend support to each other.

The phase velocities over the Delhi-Lahore profile have been computed by Gabriel and Kuo (1966) by making use of records from earthquakes lying on the great circle passing through these stations. They also found that when the waves approached from the northwest crossing the mountain ranges, the phase velocities obtained were different from those obtained when the waves approached from the southeast. Their results show higher phase velocities for periods less than about 30 seconds compared to those of the present study. Considering the number of earthquakes studied and the scatter of the results obtained, it is difficult to make any comments on the divergence of the results obtained. A further study using a large number of earthquakes may give the answer in this case.

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