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Sedimentary Rayleigh waves across the Gangetic basin— A preliminary study

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ABSTRACT. Rayleigh wave dispersion in range of periods of 5 to 15 seconds from a number of earthquakes has been studied for paths crossing the Gangetic basin. The results have been compared with theoretical models, mostly with a single layer. They indicate the variation of the depth of the low velocity sediments from one path to another within the basin.

1. Introduction

In an earlier paper Chaudhury (1966) presented the results on surface waves with periods exceeding twenty seconds across the Gangetic basin. These results indicated among others a thickness of about three kilometers of low velocity sediments at the top of the crust in the basin. The presence of such sediments is, however, known to show itself more prominently in its effects on surface waves of periods less than twenty seconds. Oliver and Ewing (1958) have discussed the effect of surficial sediments on such waves and have shown that some quantitative estimates of sedimentary layer thickness could be made from a study of the dispersion of these waves. Shurbet (1961) has used the method for an estimation of the thickness of sediments in the Mexican Geosyncline. In the present study a similar attempt has been made in respect of the Gangetic basin.

2. Data and method used

For this study the Long Period seismograph records of Delhi and Bokaro have been used. The Delhi instruments are of the WWSS (30-100) system and those at Bokaro are the Press-Ewing seismographs loaned during the IGY by the Lamont Geological Observatory and were operating roughly as the (15–80)–B system described by Brune, Nafe and Oliver (1960). The particulars of the earthquakes, records of which have been used, are given in Table 1. These have been taken from the USCGS epicentral cards.The location of the epicentres and the wave paths (assumed not to have undergone any refraction) are shown in the index map in Fig. 1. This map includes also the 500 and 1000 ft contours to show the extent of the basin involved in the paths. A few typical records are shown in Fig. 2 (a–h). Generally the vertical component records have been used, except in the case of earthquake No. 8 and earthquake No. 11. In these cases the east and north components records were used as those from the vertical components were either not available or not clear.

The periods of the waves studied ranged from about 15 sec to about 5 sec and the instrumental phase-shift correction, which is small at these periods, has not been applied. As the epicentral distances involved and the length of the wave trains on records were in most cases small, the periods of the waves were measured directly from peak to peak or trough to trough. The calculation of the group velocities were done on the calculated epicentral distances.

It may be seen from Fig. 1 that the wave paths traverse the Gangetic basin in different regions. Of those recorded at Delhi, the path from earthquake No. 1 traverses the southern margin of the basin from Bihar through Uttar Pradesh to Delhi, while those from earthquakes Nos. 2 to 6 cross the basin in the Punjab/Uttar Pradesh region. Similarly earthquake No. 8 recorded at Bokaro gives a traverse across the Bengal region; waves from earthquake No. 10 pass mostly across the northern margin of the Peninsular shield and those from earthquakes Nos. 7, 9 and 11 cross the basin in the Bihar region. The dispersion results in these different regions are given below.

3. Results and Discussions

The group velocity of Rayleigh waves from each of the earthquakes has been plotted against period and these are shown in Figs. 3 (a to k). To enable an estimation of the sedimentary layer thickness theoretical curves for a few models have also been included in the above figures. The models used are those of Haskell, Stoneley, Kanai (*cf.* Ewing, Jardetzky and Press 1957) and one calculated from CANSD (Brune and Dorman 1963). The details of these models are given in Table 2. The inferences regarding the thickness of low velocity sedimentary layer which could be drawn from a comparison of the observed results with the curves for the models are shown in Table 3. Except for Kanai's model, which differs from the others, the inferred layer thicknesses are fairly close to one another.

TABLE 1

Particulars of the earthquakes

Earth-quake No.	Date	Origin time (GMT) h m s	Epicentre Lat. (°N)	Epicentre Long. (°E)	Depth of focus (km)	Mag. (CGS)	Distance from Delhi or Bokaro (deg.)	Records used from
1	9 Apr 1963	00–03–35·6	22·2	85·6	33	—	10·0	Delhi
2	27 Nov 1963	21–10–39·9	30·8	79·1	33	5·1	2·7	,,
3	8 Feb 1964	11–54–23·1	29·0	82·2	33	—	4·6	,,
4	24 May 1964	00–00–50·2	30·1	82·1	33	5·1	4·5	,,
5	6 Oct 1964	20–19–34·1	29·3	80·9	27	5·1	3·3	,,
6	13 May 1965	10–51–15·5	29·8	80·5	33	5·1	3·1	,,
7	6 Oct 1964	20–19–34·1	29·3	80·9	27	5·1	7·0	Bokaro
8	18 Feb 1965	04–26–33·5	25·0	94·3	36	5·4	7·8	,,
9	18 Mar 1965	02–41–27·6	29·9	80·3	33	5·2	7·8	,,
10	24 Mar 1965	01–08–07·8	25·2	67·7	40	4·8	16·5	,,
11	1 Jun 1965	07–52–26·1	28·5	83·2	33	5·2	5·2	,,

TABLE 2

	Haskell (H)		Stoneley (S)			Kanai (K)		CANSD (Modified) (C)	⇾
	H	$\propto$	H_1	H_2	$\propto$	H	$\propto$	6 km	
α						3·464	6·00	3·84	
β	2·55	3·50	2·55	2·80	3·25	2·0	3·464	2·0	As in
ρ	ρ_1	$1{\cdot}11\rho_1$	ρ_1	$1{\cdot}075\rho_1$	$1{\cdot}283\ \rho_1$	ρ_1	ρ_1	2·3	CANSD
μ						μ_1	$3\ \mu_1$		

TABLE 3

Earth-quake No.	Region	Fraction of hilly path x	Inferred thickness (km) of sediments from Haskell	Stoneley	Kanai	CANSD	Recorded at
1	Southern margin of Gangetic basin	~	1	—	—	—	Delhi
2	Gangetic basin, Punjab	0·43	6	≈5	—	—	,,
3	Do.	0·33	7½	≈8	4	6	,,
4	Gangetic basin, Punjab/U.P.	0·58	≈6	≈5	3	<6	,,
5	Punjab/U.P.	0·2	8	7½	4	>6	,,
6	Punjab	0·42	≈6	≈5	3½	<6	,,
7	Bihar/U.P.	0·43	7½	≈6	4	≷6	Bokaro
8	Bengal	~	≈4	≈3	—	—	,,
9	Gangetic basin, Bihar/U.P.	0·5	6	6	≈3	<6	,,
10	Peninsular shield	~	3	3	—	—	,,
11	Gangetic basin, Bihar	0·35	9	8	4	>6	,,

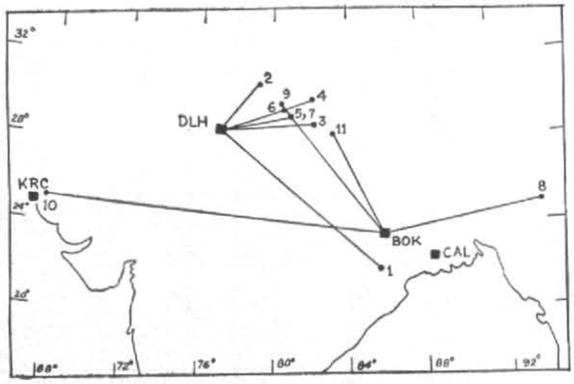


Fig. 1. Index map showing epicentres of earthquakes and wave paths

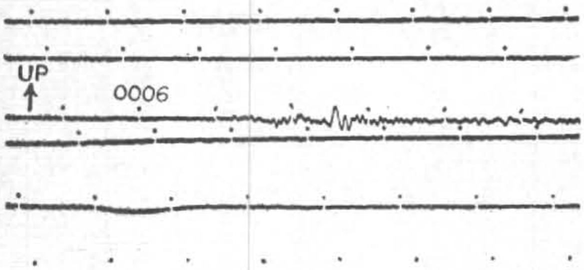


Fig. 2(a). Delhi record (vertical) of earthquake No. 1

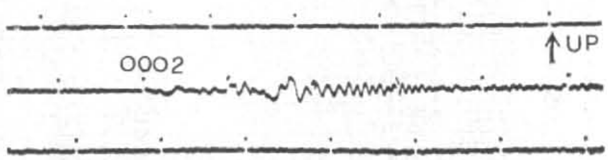


Fig. 2 (b). Delhi record (vertical) of earthquake No. 4

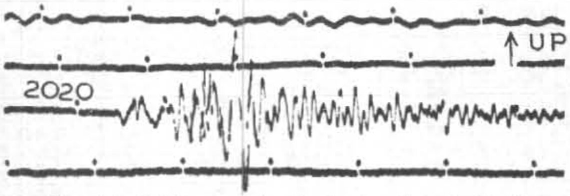


Fig. 2(c). Delhi record (vertical) of earthquake No. 5

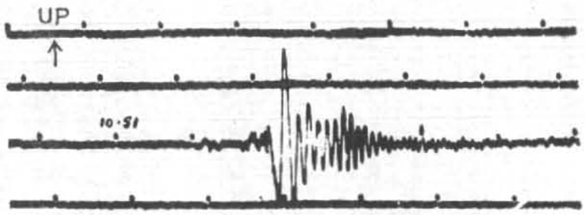


Fig. 2(d). Delhi record (vertical) of earthquake No. 6

Fig. 2(e). Bokaro record (vertical) of earthquake No. 7

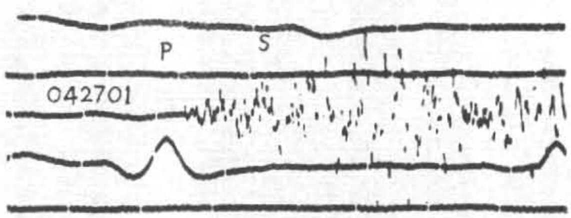


Fig. 2(f). Bokaro record (East-West) of earthquake No. 8

Fig. 2(g). Bokaro record (vertical) of earthquake No. 9

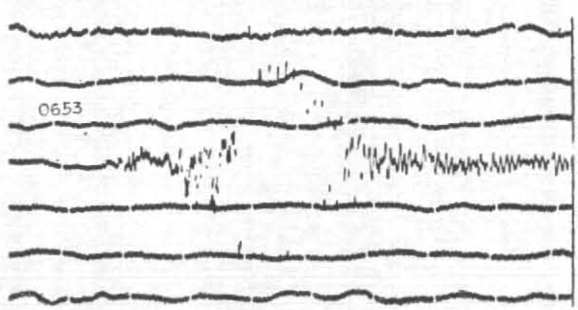
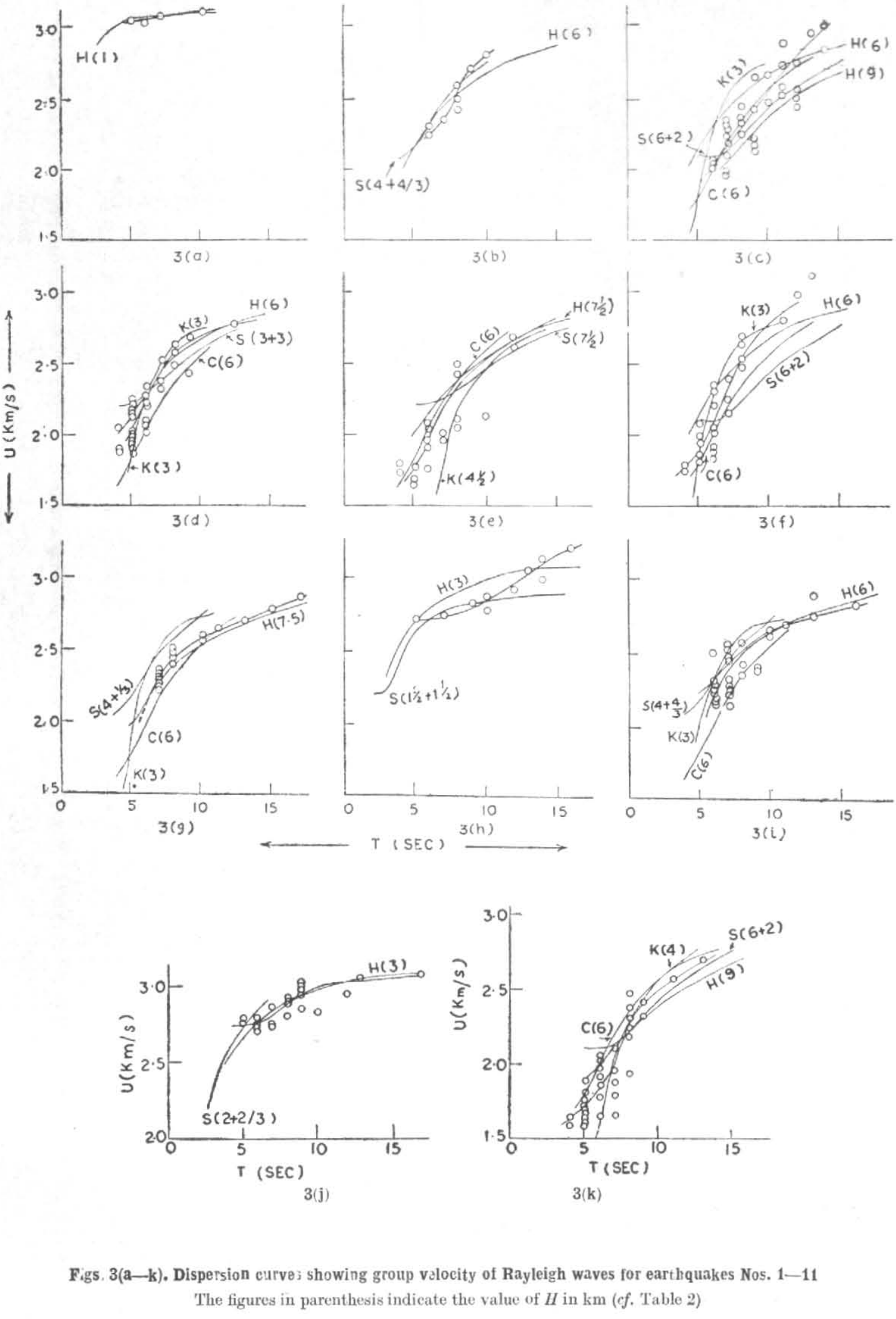


Fig. 2(h). Bokaro record (North-South) of earthquake No. 11



Figs. 3(a—k). Dispersion curves showing group velocity of Rayleigh waves for earthquakes Nos. 1—11

The figures in parenthesis indicate the value of H in km (*cf.* Table 2)

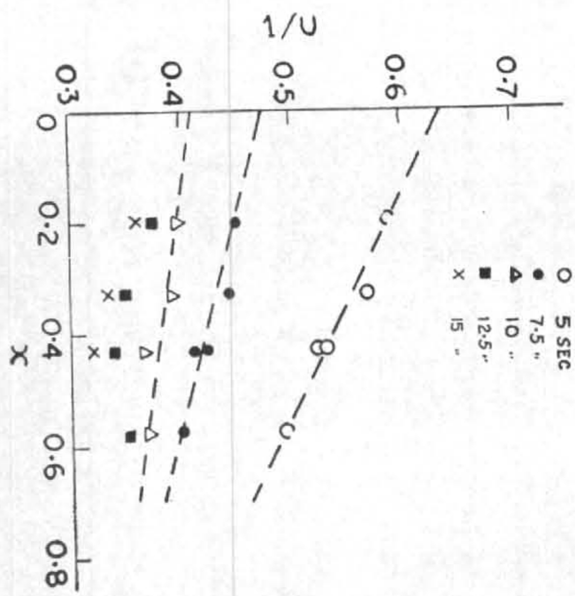


Fig. 4(a) — Punjab region

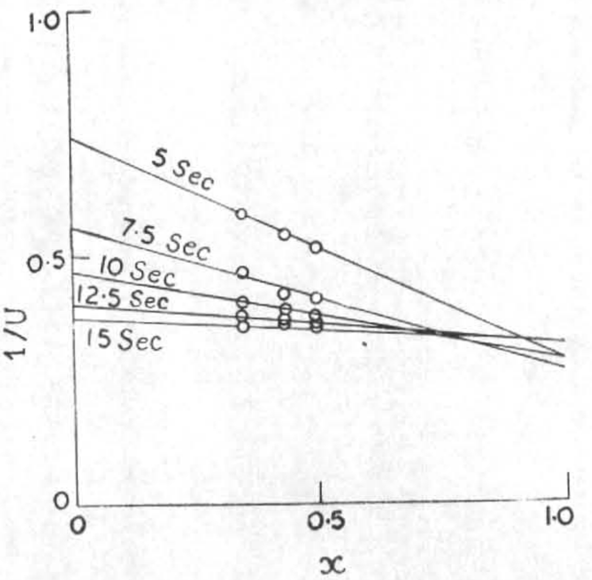


Fig. 4(b) — Bihar region

The results bring out the following —

(*i*) The low velocity sediments are thinner along the southern margin of the Gangetic basin.

(*ii*) The higher the percentage of hilly path, the lower is the average sedimentary layer thickness. This shows that the sediments over the hills and mountains are consolidated and have seismic wave velocities higher than those in the sediments over the low land.

(*iii*) The Bengal region is shallow compared to Gangetic basin in the Punjab and Bihar regions, and that in the Bihar region the sediments are thicker than in the Punjab. This latter point is clearly brought out by a comparison of the dispersion results from earthquakes Nos. 3 and 6 with those from earthquakes Nos. 11 and 7 respectively, having about the same fraction of mountain paths (taken as higher than 1000 ft). No definite estimation of the layer thicknesses can be made for the paths in the regions from these curves since, as can be seen, this depends on the model chosen as the standard. If Haskell's model with different layer thicknesses is taken as the standard, the average layer thickness comes to about 4 km in the Bengal region, slightly more than 6 km in the Punjab and about a quarter as much more in the Bihar region. On the other hand if Kanai's model is used, the respective thicknesses come to about half of the above values.

The above estimates give the average values for the paths including certain fractions of mountain paths. In an attempt to remove the effect of the mountainous portion of the path, it was assumed that the mountainous part and the basin part are each uniform across which the group velocities for any particular wave period are U_1 and U_2. If x is the ratio of the mountain path to the total path and U is the resultant group velocity for the path,

$$1/U = x\,(1/U_1 - 1/U_2) + 1/U_2$$

A plot of $1/U$ against x should, therefore, result in a straight line and enable the calculation of U_2 for any period. Thus it would be possible to draw a dispersion curve and get an estimate of the sedimentary layer thickness in the basin part. This has been done for earthquakes Nos. 2 to 6 recorded at Delhi and for Nos. 7, 9 and 11 recorded at Bokaro and are shown in Figs. 4 (a) and 4(b). The results for the Punjab/Uttar Pradesh region in Fig. 4 (a) while reflecting the effect of x on $1/U$ in the proper direction do not show very well the linear variation expected, particularly for periods of 12·5 sec and 15 sec. This could result, among others, from the effect of refraction and also from a variation of the properties over the area considered. For periods of 5, 7·5 and 10 sec, however, the points could be fitted to straight lines and these have been shown as dotted lines. Fig. 4 (b) for the earthquakes recorded at Bokaro, however, shows reasonable straight line fits. In this there are data only from three earthquakes and the fit as found could be misleading. Taking the results, however, the group velocities for the basin part for the different periods have been plotted against the periods and compared along with the results for the Punjab region, with the theoretical models in Fig. 5. The comparison

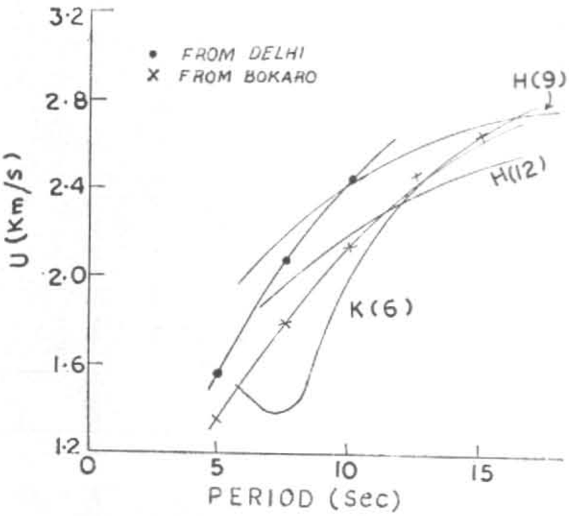


Fig. 5. Dispersion for the basin proper

shows that the slope of the theoretical curves of Haskell's model is less than that of the observed curves, indicating that the velocity in the sediments is less than assumed. On the other hand, Kanai's model with a lower velocity in the sediments gives a better agreement for the same reasons. The values of U_2 plotted in Fig. 5 do show that even for the basin part, the low velocity sediments over Punjab are thinner by about twenty per cent than that over Bihar. Haskell's model indicates that the low velocity sediments over the Bihar region of the Gangetic basin are 10-12 km thick and the thickness of sediments over the Punjab region is about 8–9 km. Kanai's model, however, gives the values at 6 and 4–5 km respectively. These are likely to give a nearer approximation to the true values in view of the better agreement of the model with the observations.

The thickness of sediments over the Gangetic basin has been estimated variously at different times and is still a matter of conjecture. Mithal and Srivastava (1959, 1965) have discussed the various observations on this aspect and have concluded that "the thickness of sediments is thought to vary upto 500 ft or more at the southern margins of the plains. Along the northern fringes at the foot-hill it may be 10,000 ft or more in the Punjab plain, 25,000 to 40,000 ft or more in Uttar Pradesh and Bihar, 4,000 to 12,000 ft or more in the Bengal basin......". It was also recognised that the floor of the Indo-Gangetic plain is gently sloping towards the Himalayas. The results from the present preliminary study of the dispersion of the shorter period Rayleigh waves are in broad agreement with these.

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