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Preliminary results from very long period data collected by a broad band digital seismic station

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Abstract. Preliminary analysis of seismograms recorded by a wide band high dynamic range digital seismograph installed under a collaborative research programme between IPG, Paris and NGRI, Hyderabad, indicates that the crust and upper mantle structure below the Indian continent are characterized by high velocity up to a depth of 500 km. Both the group and phase velocities in the period range of 100–350s are found to be faster by 3–4% and 1–3% respectively compared with global models such as the preliminary reference earth model.

Keywords. Broad band; surface waves; group velocity; phase velocity.

1. Introduction

A broad band high dynamic range digital seismograph was installed in the seismological observatory of the National Geophysical Research Institute (NGRI), Hyderabad during January 1989, as part of a cooperative endeavour between NGRI, Hyderabad and the "Geoscope" programme initiated by CNRS, France at the Institute de Physique de Globe (IPG) Paris, towards delineating the deep structure of the earth generally and that of the Indian subcontinent in particular. Data from this global seismic network are also expected to help elucidate the dynamics of rupture processes during major earthquakes.

Surface Love and Rayleigh waves which penetrate the crust and upper mantle to varying depths depending upon their modes and wavelengths have been widely used to study the earth's outer layers including those of the Indian subcontinent. The latter studies (Gupta and Narain 1967; Gupta *et al* 1977a, b; Brune and Singh 1986; Singh 1987, 1988 etc.,) have however been limited to the crust, on account of the information limit imposed on available seismograms (6–60 s) by recording instruments, which typically consist of a sensor with 15 s natural period and galvonometer with 100 s period (WWSSN standard). The new wide band digital seismograph at NGRI, Hyderabad capable of recording very long period waves, of 1000 or longer period, therefore greatly extends the probing depth of surface waves to bring information from the deep structure of the Indian shield.

This paper presents results obtained from the analysis of long period (up to 350 s)

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surface waves recorded at Hyderabad in the wake of 7 selected moderate earthquakes and exposes the potentiality of this new seismic station in revealing the nature of a significant part of planetary upper mantle structure.

2. Instrumentation and data acquisition

The new installation at the NGRI seismological observatory at Hyderabad is equipped with a set of three component broad band streckeisen sensors. Following the force balance principle, the mass element of these sensors is maintained at a central (constant zero) position through a system of feedback forces, thereby vesting them with high dynamic range. The feedback forces which are applied electromagnetically through servo-controlled currents are in turn amplified and recorded in a digital form to provide a measure of the ground motion. Wielandt and Steim (1986) gave a detailed description of the working principle of these sensors. These have a dynamic range of more than 140 db and a flat velocity response in the period of 0·1 s to 360 s making it perfectly feasible to resolve waves with periods ranging from 3600 s to 0·1 s using a suitable digitizer.

The basic digitizer is a 16-bit A/D converter, which is transformed to 24-bit data by digital processing (Classen *et al* 1980). The data are sampled at intervals of 50 ms and passed through different filters before being recorded on a cartridge. The input data is divided into four different data streams. The first of these consists of very broad band data (VBB) sampled every 50 ms subject to fulfilling the trigger criterion based on a simple STA/LTA ratio. When this ratio exceeds a preset threshold, the trigger is declared, retrieving a 30 minute pre-event data which is prefixed to a 30-minute post-event data making a total of 1 h data length for the event recorded. The second stream captures long-period data (LP), sampled once every second and recorded continuously. The third stream consists of the broad band data (BRB) which is sampled once every 200 ms. This data channel is not recorded on the cartridge but prepared only for tele-transmissions. Finally, the very long period data (VLP) is continuously recorded at intervals of 10 s. This data file can also be tele-transmitted.

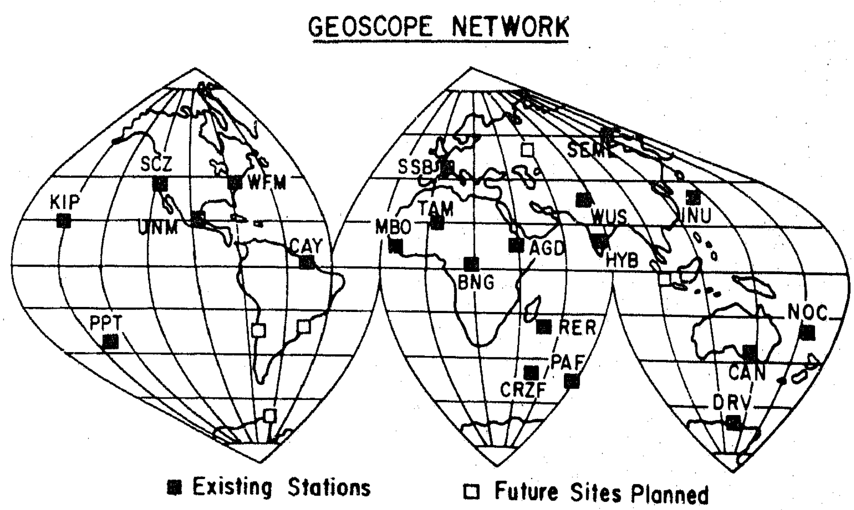

Figure 1. Network of seismological stations under geoscope project.

The Geoscope network today consists of 21 broad band digital seismic stations spread over the globe (figure 1). All these stations are equipped with 3 sensors (one vertical, and two horizontal). Data processing (filtering and computing STA/LTA etc.,) is done by a mini HP computer. Some of the stations are connected to the data processing centre of INSU, at St. Maur, Paris via telephone lines and others via a satellite. This data processing centre also collects daily information regarding the health of the station through a telephone line. Transmitted data include VLP histograms; position of the seismograph mass (maximum and minimum during the day); Omega time comparisons; and the number of events recorded during the day. It takes about 8 minutes to transmit the complete VLP data recorded during 24 hours and about 40 minutes for transmitting BRB data in respect of a single event. Therefore BRB data is not routinely collected except for events of magnitude (Ms) 7·0 and greater but can be obtained on special request for earthquakes of lower magnitude of (Ms) up to 6·0.

3. Data and analysis

Forty two earthquakes of magnitude (Ms) 6·0 and greater were recorded by the broad band seismograph at Hyderabad up to the end of December 1989. Of the 13 that had magnitudes greater than 6·5, we selected 7 earthquakes for analysis for long-period data. Particulars of these earthquakes are given in table 1. Their epicentral locations along with great circle paths are shown in figure 2. The data used in the present analysis for the determination of group and phase velocities are the very long-period data sampled at 10 s interval. A typical long period seismogram is shown in figure 3.

3.1 *Group velocities*

Fourier transform of the very long-period (VLP) data was obtained after tapering it by a Cones window function:

$$W(x) = 16x^2(1-x^2) \tag{1}$$

to ensure a quasi-similar normalized signal-to-noise ratio with respect to the record length. The fourier-transformed signal was then corrected for instrument response and an energy diagram constructed by moving window analysis, to determine the group velocities. The energy diagrams and group velocities obtained form the present study are shown in figures 4–10, together with velocities determined for the preliminary reference earth model (PREM) of Dziewonski and Anderson (1981) for comparison. These indicate that velocities are higher in the period range of 100–35 s in comparison with PREM by 3–4%. However, group velocities obtained from earthquakes located in the Western and Northern azimuth with respect to Hyderabad, indicate nearly similar velocities as that of PREM.

3.2 *Phase velocities*

Phase velocities were obtained using the computation technique developed by Romanowicz (1981). Accordingly,

Table 1. List of epicentral parameters and other related information used in this study

Date	Region	Origin time UTC h min s	Latitude in degrees	Longitude in degrees	mb	Ms	Depth	Strike	Dip	Mo	Half duration (seconds)
21/08/89	Ethiopia	01 09 06·63	11·874 N	41·870 E	6·3	6·2	16	281	45	5·3*10**18	6·3
04/09/89	Alaska	13 14 58·25	55·543 N	156·835 W	6·5	6·9	11	62	82	4·6*10**19	10·2
17/09/89	Caspian sea	00 53 39·77	40·203 N	51·749 E	6·1	6·1	51	292	36	2·2*10**18	4·8
07/10/89	Andreanof Is	15 48 29·06	51·314 N	179·028 W	6·1	6·7	20	62	71	1·8*10**19	9·0
18/10/89	California	00 04 15·24	37·036 N	121·883 W	6·5	7·1	19	235	41	2·5*10**19	11·0
27/10/89	Solomon Is.	21 04 51·82	11·022 N	162·350 E	6·1	7·0	25	161	82	2·9*10**19	12·0
29/10/89	Honshu	05 25 38·27	39·571 N	143·333 E	6·0	6.6	10	32	74	5·8*10**18	6·7

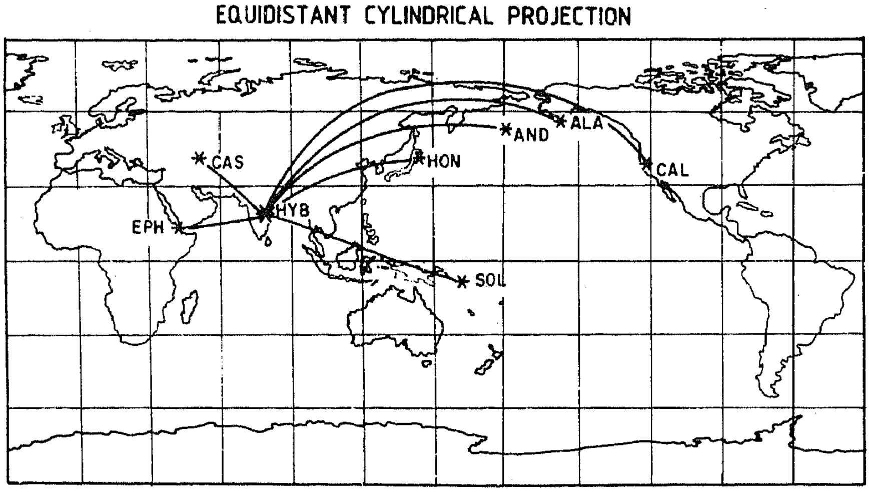

Figure 2. Epicentres and great circle paths for which group and phase velocities are estimated in the present study.

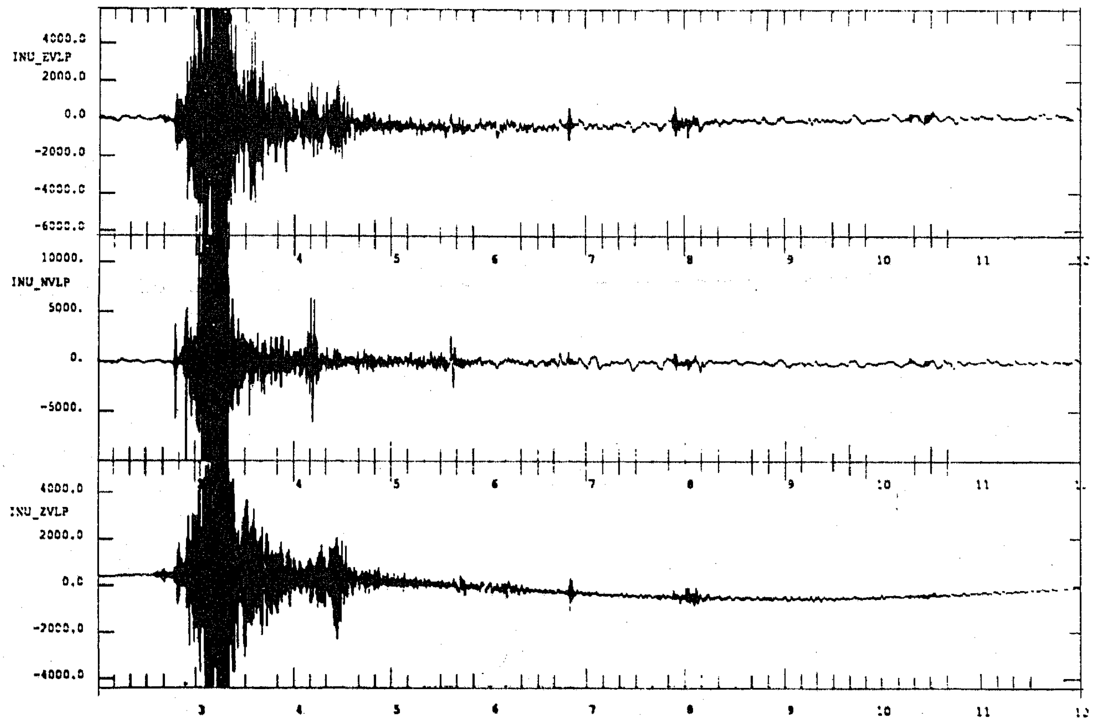

Figure 3. Typical very long-period seismogram. Units of x-axis are in hours.

$$U(\theta, \omega) = U_s \cdot U_p,$$

where U_s is the source spectrum; U_p is the propagation term

$$U(\theta, \omega) = (\alpha + i\beta) A_s \cdot \exp(-\eta X) \exp(i\varphi X), \tag{2}$$

$$\alpha = S_R M_{ZZ} + P_R (M_{YY} - M_{XX}) \cos 2\theta + 2 M_{XY} \sin 2\theta$$

$$\beta = Q_R (M_{XZ} \cos \theta + M_{YZ} \sin \theta).$$

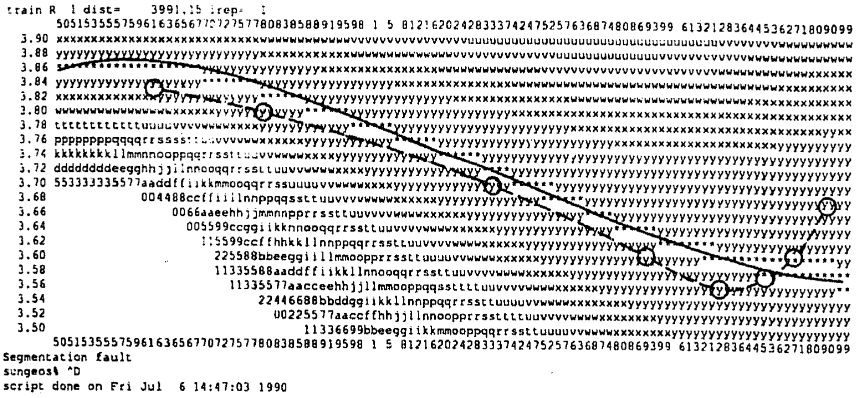

Figure 4. Group velocities obtained for the earthquake located at Ethiopia. The solid curve shows the group velocities obtained in the present study. Dotted curve shows the velocities for the PREM model.

Figure 5. Group velocities obtained for the earthquake located at Alaska (solid line) along with those of PREM model (dotted line).

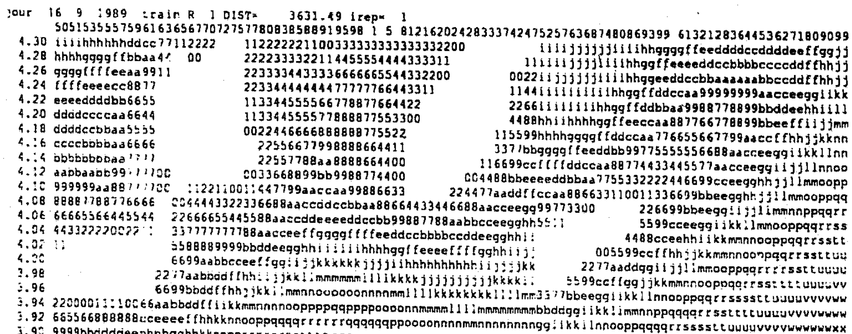

Figure 6. Group velocities (solid line) obtained for the earthquake located near Caspian sea compared with PREM model (dotted line).

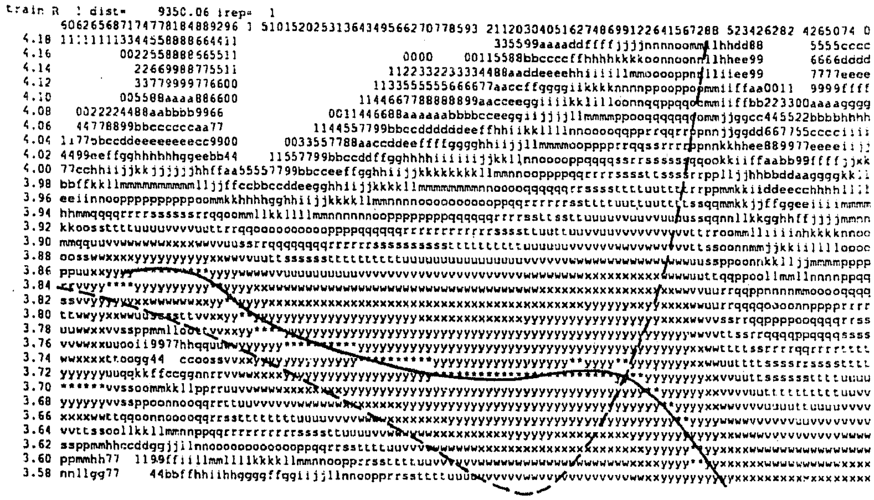

Figure 7. Group velocities (solid line) obtained for the earthquake located near Andreanof Is.

Figure 8. Group velocities (solid line) obtained from the data of the Californian earthquake (Lomaprieta).

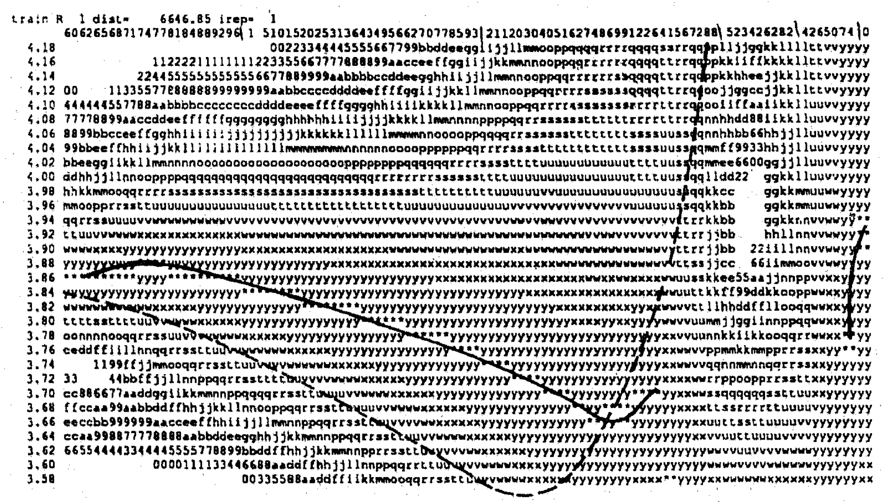

Figure 9. Group velocities obtained from the data of the earthquake located at Honshu region.

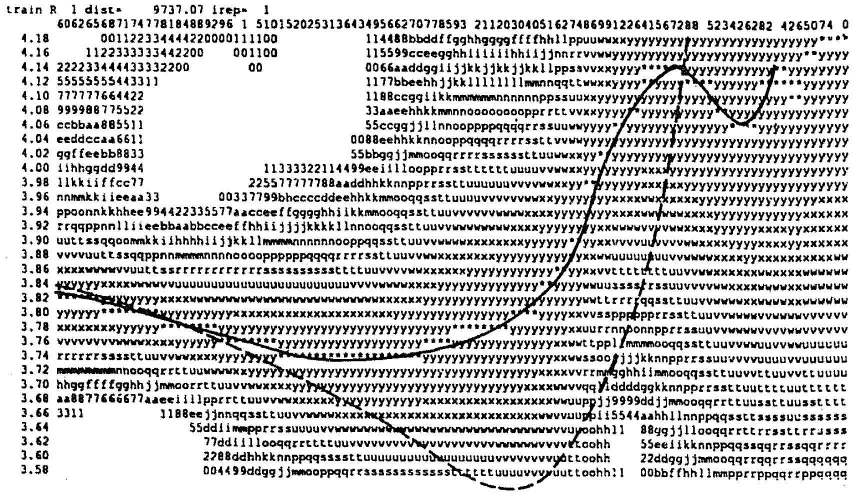

Figure 10. Group velocities (solid line) obtained using the data of the earthquake located near Solomon Island region.

U is the complex amplitude of Rayleigh wave, θ is the azimuth of the recording station measured counter clockwise from the source. These amplitudes are measured for each angular frequency ω and corrected for source instrument response and source time function. The function P_R, S_R, Q_R, are the stress motion eigenfunctions and are estimated for a given velocity model.

φ the phase in equation (2) is expressed as

$$\varphi = \frac{\omega X}{C} + N2\pi,$$

$$C = \frac{\omega X}{\varphi - N2\pi}.$$

Here C is the phase velocity, N an integer and X the epicentral distance.

The phase velocities obtained from this study are shown in figure 11 for comparison with those of PREM (dotted line). The velocities obtained for an integer value equal to 4, are nearer those for the PREM model. These velocities are considered as the most probable phase velocities for paths connecting the source and the station. It is notable that they are always higher than velocities expected for the PREM model. The source mechanism solutions used are either Geoscope moment tensor solutions obtained from the very long-period range 180–310 s data (Romanowicz and Guillemant 1984; Romanowicz and Monfret 1986) or the solutions obtained from IDA/IRIS, GDSN, GSN station long-period data using the technique developed by Woodhouse and Dziewonski (1984).

4. Discussion

Analysis of very long-period surface waves (up to 600 s) recorded at Hyderabad points to the existence of a high velocity structure underneath the Indian shield. Group velocities in the period range of 100–350 s in respect of 5 events are found to be

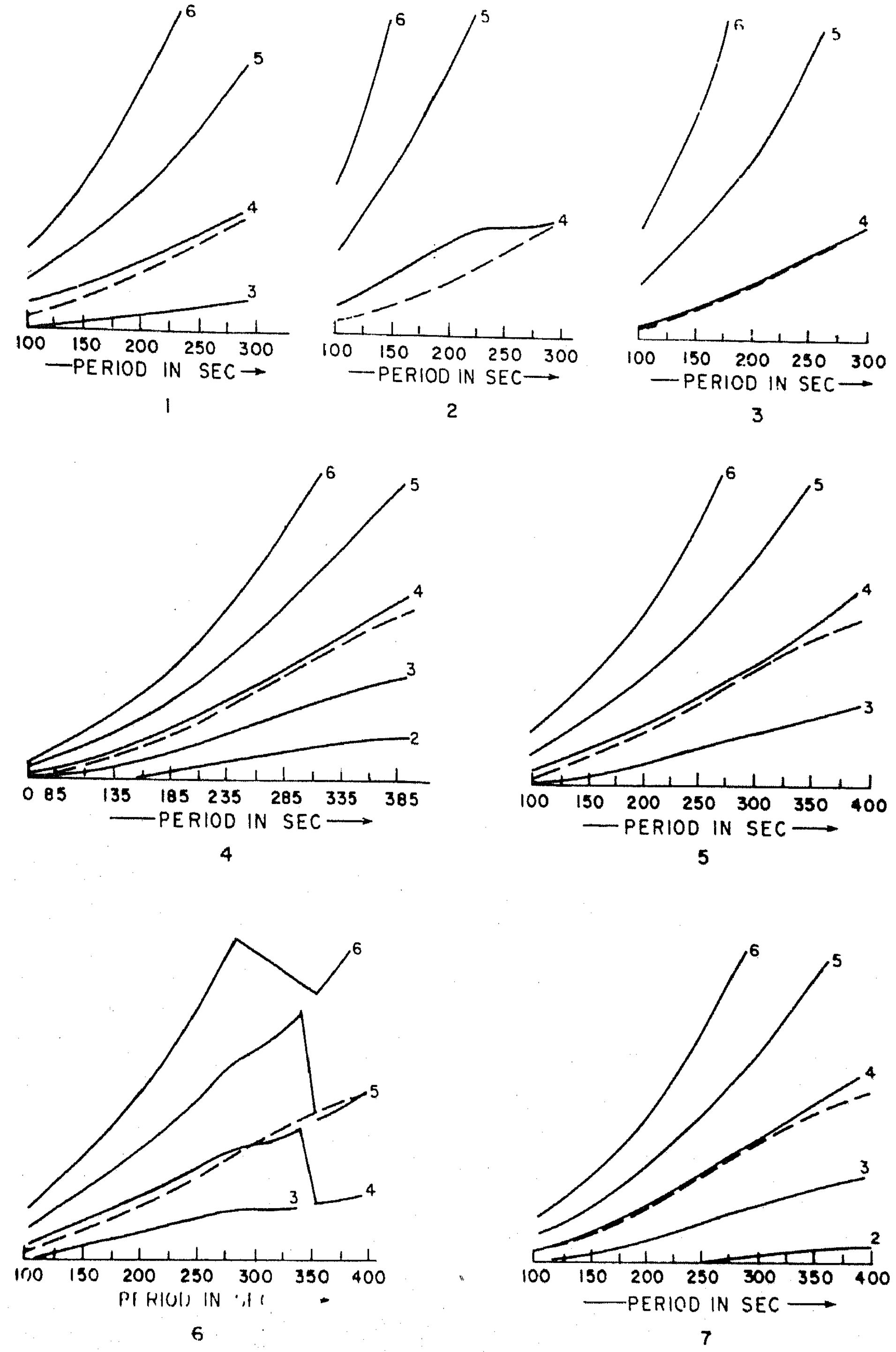

Figure 11. Phase velocities estimated in this study. Dotted line shows the velocities for PREM model. The epicentres are located at 1) Honshu 2) Caspian 3) Ethiopia 4) Alaska 5) Andreanof Is 6) Solomon Is 7) California.

higher than those estimated for the PREM model, by 3–4%, except for two earthquakes, one located (Ethiopia) west of the station yielding values similar to those estimated for the PREM model, and the other located in the Caspian sea region yielding a velocity about 1–6% lower (figure 6). However, phase velocities in all cases are found to be higher than those for the PREM model by about 1% and in one case, where the earthquake is located near the Caspian sea, by about 3%. The largely higher estimated group and phase velocities of surface waves recorded at Hyderabad from earthquakes located at different azimuths points to the possible existence of a higher velocity structure beneath the Indian continent at least within the depth range of 500 km. These results are broadly similar to those yielded by tomographic studies of the Indian shield (Iyer *et al* 1989; Ramesh *et al* 1990), which show a uniformly higher upper mantle velocity. The new results, however, expose the yet unutilized potential of VLP surface wave data in providing significant clues to the nature of the upper mantle beneath the Indian shield.

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