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One dimensional seismic velocity structure beneath Western Nepal

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ABSTRACT

An attempt has been made to study the velocity structure of western Nepal. Arrival time data of local earthquakes occurring in that region were used to derive the model. A three layered velocity model both for the P- as well as S-wave velocity has been estimated. The compressional wave velocities in the first, second and the third layers have been estimated to be 5.53 km/sec, 6.29 km/sec and 8.13 km/sec respectively. Similarly the corresponding S-wave velocities are 3.18, 3.62, 4.66 km/sec respectively. The model for the Western Nepal and that for the Centre-East Nepal are almost same. The crust and the mantle beneath west and centre-east are homogeneous.

INTRODUCTION

Velocity model is required for a variety of purposes, such as the localization of earthquakes, understanding of the composition of the crust and the interpretation of tectonics.

Earthquakes may occur over a variety of depths and epicentral locations. Arrival time data of a set of local earthquakes recorded by local seismic stations provide us information on the path they traverse through. The earthquakes have independent hypocenter parameters but depend on the same velocity model used to calculate travel times for all events. Since the parameters used to describe the model are common to all events, the set of arrival times from the collection of discrete event carries information on local velocity structure. Systematic departures of observed and calculated arrival times reflect the model inaccuracies and may provide information to correct or improve the velocity model.

MAIN OBJECTIVES AND STUDY AREA

The main objectives of this study are to determine a one-dimensional velocity structure for western Nepal and to compare with the initial model.

The study area lies in Western Nepal (Fig. 1). It lies between the latitudes 27° N and 31° N and between the longitudes 79.5° E and 84.5° E.

PREVIOUS WORKS

A strong need was felt since the beginning of the installation of seismic station in Nepal in 1978. To accomplish this need, the first attempt was made by Pandey (1981). Quarry blast data were used to derive the velocities. He could estimate the P-wave velocity in the first layer to be 5.58 km/sec and the S-wave velocity is 3.05 km/sec.

Using local earthquake data Pandey (1985) derived a three-layered velocity model for central and eastern Nepal (Fig. 2 and Table 1). This model is used in routine localization of earthquakes in Nepal.

Maskey (1996) estimated a four-layered P-wave velocity model for Nepal. Minimum Apparent Velocity Method (MAV) method was utilised in this study.

DATA

Local earthquakes (Fig. 3) which occurred in the Western Nepal in 1997 are utilized in this study. The figure shows that the western part is more active than the eastern part of the study area. The E-W section shows most earthquakes have shallow depth (10-25 km).

The criteria for the selection of the earthquakes is such that the earthquakes are recorded at least by three stations and the number of P-wave arrivals and S-wave arrivals are at least 3 and 2 respectively. In total, 380 local earthquakes and

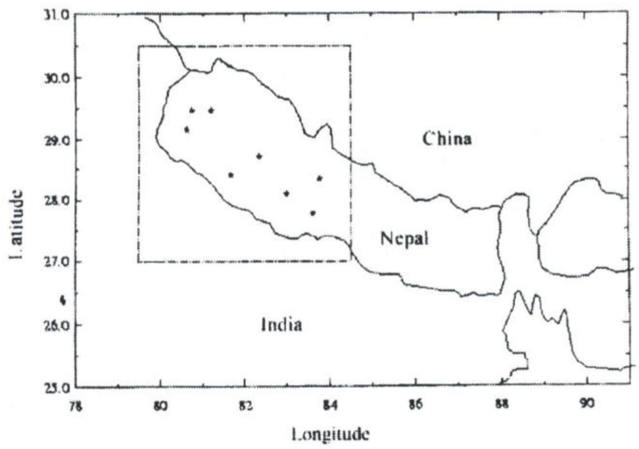


Fig. 1: Location map of the study area (rectangular) and seismic stations (stars).

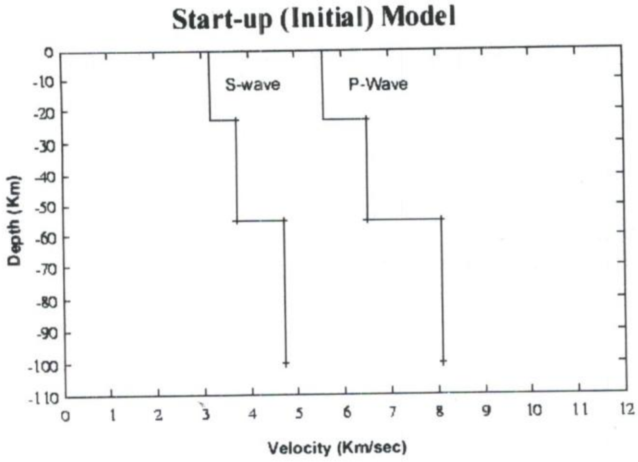


Fig. 2: Start-up Model (Pandey 1985).

Table 1: The start-up model (Pandey 1985).

Layer No.	P-wave velocity (Vp) (km/sec)	S-wave velocity (Vs) (km/sec)	Depth to the top (m)
1	5.6	3.17	0.0
2	6.5	3.71	23.0
3	8.1	4.73	55.0

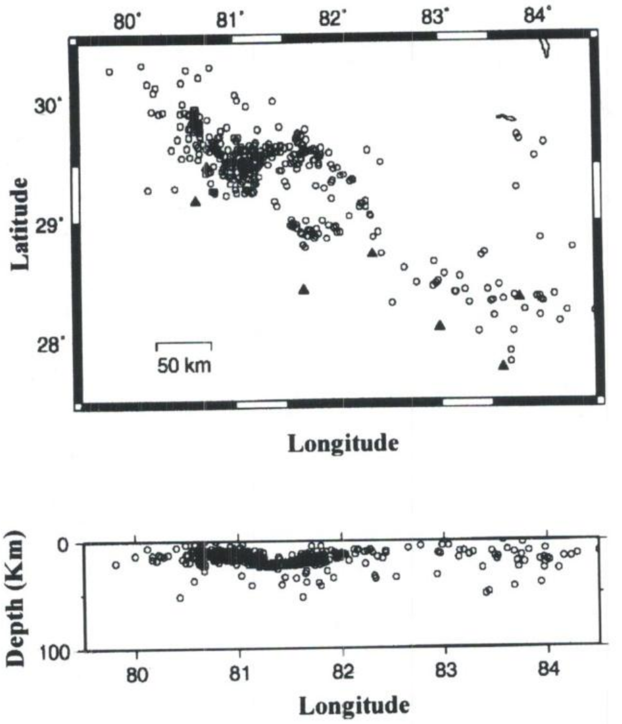


Fig. 3: Local earthquakes utilized in the study. Notice that most earthquakes have shallow depth.

their P- and S-arrivals at eight stations (Fig. 1) are used. Although there are very few earthquakes below 55 Km depth yet the space is reasonably represented by the rays (Fig. 4). The rays are traced using software written by T. Sato. The software utilizes shooting method. The other requirements are a priori start-up model and the locations of the stations (Table 2).

The hypocenter parameters and arrival time data of the earthquakes were used from the local earthquake bulletin of National Seismological Centre (NSC), Department of Mines and Geology, Nepal. The model currently used for the localization of local earthquakes in routine works in Nepal is used as the start-up model (Fig. 2 and Table 1).

THEORY

In general the travel time function is a highly nonlinear function of the hypocenter parameters and the velocity model parameters. Yet, a quasi-linear system of equations can be written using a first-order expansion. For a set of ***q*** total earthquakes recorded at ***p*** stations, the arrival time for the ***i***th event at the ***j***th station is

$$\mathbf{T}_{ij} = T_{ij}(x_{1i}, x_{2i}, x_{3i}, x_{4i}, \mu_1, \ldots, \mu_l) \qquad (1)$$

$$i = 1, \ldots, q \qquad j = 1, \ldots, p$$

where x_{1i} ..... are the hypocenter parameters and μ_{1i} .... are the aggregate of possible parameters describing the model.

A quasi-linear equation relating small changes of the hypocenter and model parameters is

$$\Delta T_{ij} = \sum_{k=1}^{4}\left(\frac{\partial T_{ij}}{\partial X_{ki}}\right)\Delta X_{ki} + \sum_{k=1}^{l}\left(\frac{\partial T_{ij}}{\partial \alpha_k}\right)\Delta \alpha_k \qquad (2)$$

where $\Delta T_{ij} = T_{ij} - T_{ij}^{0}$ $\quad \Delta X_{ki} = X_{ki} - X_{ki}^{0}$ $\quad \Delta\alpha_k = \alpha_k - \alpha_k^{0}$

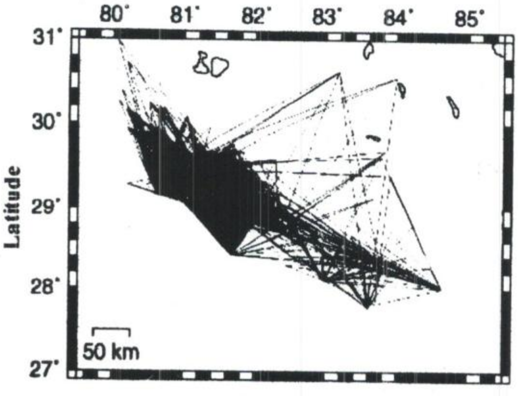
The quantities X_{ki}^{0} and α_k^{0} are points in hypocenter and model space where the partial derivatives are evaluated.

The quantity ΔT_{ij} is then associated with *O–C*, the observed minus calculated arrival time, the residual calculated assuming an initial set of solution parameters.

The equation (2) can be written in the compact matrix notation

$$A\Delta x = \Delta t \qquad (3)$$

where A is an *n* x *m* coefficient matrix whose elements are the partial derivatives of travel time with respect to the unknowns, which are the hypocenter parameters (latitude, longitude, depth and origin time) and the velocity parameters. Δx is the *m* x *1* solution vector and its elements are the aggregate of hypocenter and model corrections, and Δt is the vector of *O – C* residuals based on the start up model.



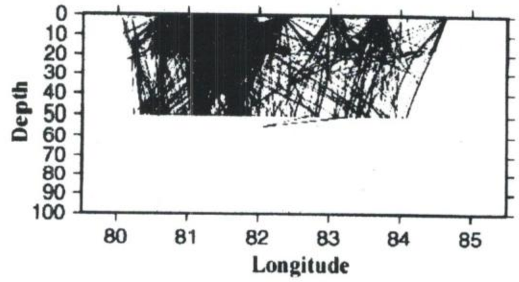


Fig. 4: Ray tracing for P-waves. The rays show how they represent the space.

Table 2: List of the stations used in the study.

Station Name	Latitude (Degree, N)	Longitude (Degree, E)	Height (km)
GKN	28.003	84.637	1.478
PYU	28.100	82.988	1.867
KOL	27.767	83.605	1.830
DAN	28.348	83.765	2.500
BAY	29.474	81.201	3.050
GHA	29.177	80.627	2.450
GJR	29.483	80.742	2.934
HAR	28.418	81.674	1.230
MEG	28.713	82.341	2.740

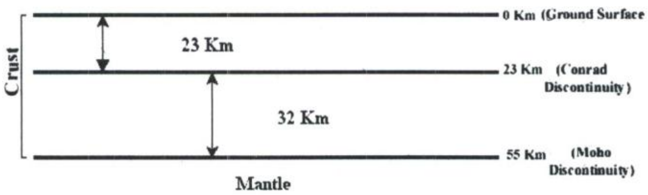


Fig. 5: Division of the space beneath the study area. The sapce is divided into three layers.

Since there are more observations than the parameters to be determined in (3), an exact solution is normally not available. Least Squares method is utillized to solve the solution in which the functional

$$s = (A\Delta x - \Delta t)^T (A\Delta x - \Delta t)$$

is minimized for some set of parameter estimating Δx.

METHOD

The space beneath the study area is divided into three layers (Fig. 5). The thickness of the first layer is 23 km. That of the second layer is 32 km and the third layer is halfspace. Velocity is constant within these layers and it is allowed to vary in the vertical direction when rays pass from one layer to the other.

Hypocenters are calculated for the used earthquakes based on the arrival time data and the initial model. The initial uncertainties of the hypocenter parameters are given by the standard deviation of the hypocenter parameters based on the initial model. The uncertainty for the origin time is 0.6±0.6 sec. Similarly for the latitude, longitude and depth the uncertainties are 0.05±0.05, 0.04±0.04 degrees and 2.5±2.5 km respectively. For all the stations the station corrections are assumed to be zero. Its uncertainty is assumed to be 0.15 sec.

The simultaneous inversion method is applied to the arrival time data. The program is written by T. Sato. The linearized inversions were iterated six times and the convergence was achieved, in general, in the fourth iteration (Fig. 8). The initial standard deviation of the travel times (SDTR) varied from 0.6 to 0.8 sec for the initial models. After convergence it reduced to 0.20 sec. The corresponding residuals for the P- and S-arrivals are 0.2 and 0.25 sec respectively.

RESULTS

In the final model (Fig. 6) the P-wave velocities in the first; second and the third layer are 5.53, 6.29, and 8.13 km/sec respectively. Similarly, the corresponding S-wave velocities are 3.18, 3.62, and 4.66 km/sec in their order.

CONCLUSION

The final model for the Western Nepal is almost similar to Pandey (1985) model (Fig. 7) which is adopted here as the initial model. The P- and S-wave velocity in the mantle (>55 km depth) are almost same. The P-waves in the first and the second layers are little smaller than those in the initial model. The S-wave velocity in the first layer is comparable to that in the initial model but in the second layer it is relatively smaller.

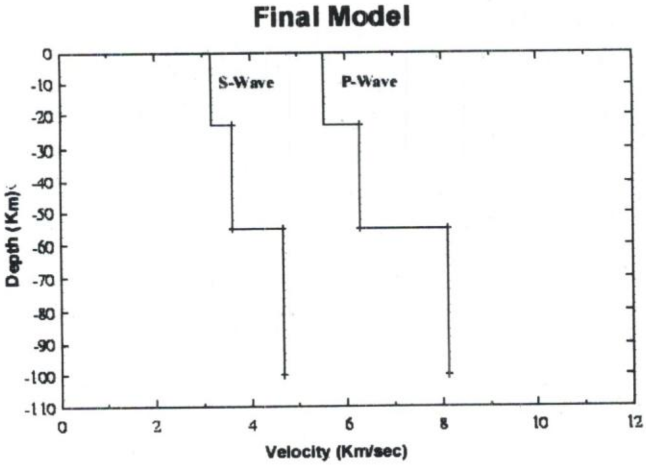


Fig. 6: The final model that is achieved after one-dimensional inversion.

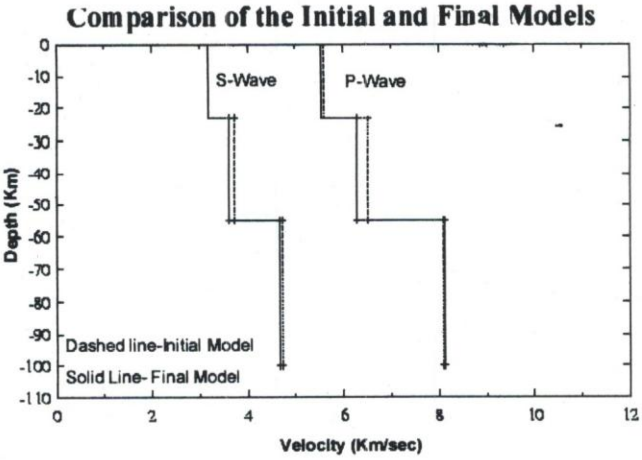


Fig. 7: Comparison of the start-up (Initial model) and the final model. The initial model (dash-line) and the final model (solid-line) are similar.

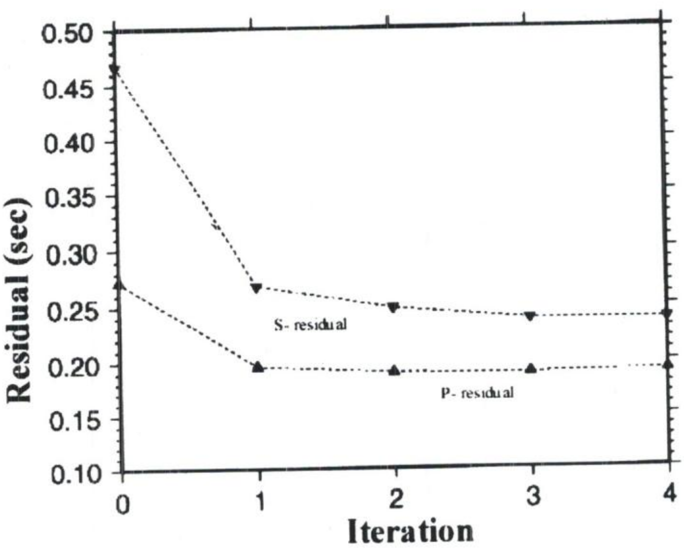


Fig. 8: The figure shows how the residual decreased in the iterations.

The mantle beneath the study area and the Centre-East Nepal has similar property. The first and the second layers depict probably the lateral heterogeneity beneath the study area and the Centre-East Nepal and it is rather low. The result implies that the crust as well as mantle beneath Western and Centre-East Nepal are homogenous.

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