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Evaluation and Comparison of the Crustal Structure of the Indus Block up to Kutch Region and Saurashtra Region using ga Inversion of Surface-wave Dispersion

KEYWORDS: Dispersion, Genetic Algorithm (GA) inversion, Crustal Structure of Kutch and Saurashtra

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ABSTRACT *We have computed Group velocities of the fundamental mode Rayleigh wave using an earthquake of MW 5.2 (Lat: 39.50˚N, Long: 73.81˚E). This earthquake was recorded at seven stations of Saurashtra region and eight stations of Kutch region by seismic network of Institute of Seismological Research, Gujarat (India). The period of observed group velocity data ranges from 6 to 60 sec for Saurashtra and 6 to 68 sec for Kutch. The dispersion curves have been inverted for crustal structure using Genetic Algorithm (GA) inversion; it gives the average crustal structure along the path. We have evaluated crustal structure of the Indus block up to Saurashtra and then up to Kutch. The thickness of crust up to Saurashtra is 43.61 km with S-wave velocity of 4.53 km/sec and thickness of crust up to Kutch is 44.91 km with S-wave velocity of 4.46 km/sec whereas previous study of Indus block up to Bhuj (Kutch) indicates 44.19 km thick crust with 4.39 km/sec S-wave velocity. According to these results, it is inferred that the crust of the Kutch region is thicker than that of Saurashtra region.*

Introduction

The Trans-Aravalli Block is one of the three blocks of the Indian peninsula; the two other being Bundelkhand block and the South Indian block, suturing of which has formed the Indian peninsula (Qureshy & Iqbaluddin, 1992). On the basis of topography and geology Balakrishnan (1997) has divided Indian subcontinent into several crustal blocks. He called the Trans Aravalli block, whose major part lies in Pakistan, the Indus block.

According to Biswas (1987) the Saurashtra arch, the extension of the Aravalli range across the western continental shelf subsided along the eastern margin fault of the Cambay basin during Early Cretaceous. It formed an extensive depositional platform continuous with the Kutch shelf, for the accumulation of thick deltaic sediments. A part of Saurashtra arch was uplifted as a horst during the main tectonic phase in the late Cretaceous. (The Saurashtra horst is the uplifted part of a WSW-plunging basement arch which divides the western continental margin into a northern Kutch-Saurashtra shelf and a southern Bombay- Kerala shelf. The arch forms the southern limit of the Jurassic sedimentation of the Indus shelf basin.)

For evaluation of crustal and lithospheric structure of the Indian subcontinent, the observed surface wave dispersion data have long been used by Bhattacharya (1981, 1991, 1992) and Suresh et al (2008). Lithospheric structure of Indus block is evaluated by Suresh et al. (2008) up to Bhuj (Kutch). While in this study we have evaluated crustal structure of Indus block up to Kutch and Saurashtra through inversion of group velocity of fundamental Rayleigh wave using a genetic algorithm.

Data

Here, we have taken an earthquake of M_W 5.2 (of 13th October 2008 and located in China-Kyrgyzstan Border region). Epicentre and recording stations are shown in Fig. 1. Surface wave was recorded by broad band seismographs at seven stations of Saurashtra and eight stations of Kutch. The seismographs at Kutch and Saurashtra consist of a three component seismometer CMG3T connected to a Guralp CGM-DCM recorder. Using the seismograph response, the digital data were converted to ground displacements that were further converted to vertical, radial and transverse components with known back azimuth of the epicentre. Group velocities were obtained through frequency-time analysis (FTAN) following Bhattacharya (1983), which is shown in Fig 2 and 3. The vertical components are used to obtain the fundamental mode Rayleigh-wave group velocity.

Inversion

Most geophysical modelling problems are traditionally solved using local optimization techniques which often find solutions that are only locally optimum (Sambridge & Drijkoningen, 1992; Lomax & Snieder 1995) and success can depend strongly on the choice of a starting model, on many occasions such a starting model is difficult to ascertain. Here, Genetic algorithm, a non-linear, guided, global search technique is used, which efficiently searches a large model space, finding solutions that are globally optimal (Yamanaka H & Ishida H, 1996; Bhattacharyya J et al., 1999).

The GA starts with random initial set of 120 potential values for each of the waveform parameters, within an initially specified range of acceptable values. These model values are then coded as genes, which in turn are combined to form specific models or chromosomes for each member of the initial population of given potential solution. These models are ranked from the best to worst, according to a fitness function. This is obtained from the cross-correlation function computed between each synthetic and the recorded seismograms. Here we have taken 120 random initial set of population, where we have created a new population with two elite members, 94 members through crossover, and 24 members by mutation. The elite member replaces the worst models in the current generation with the best individuals of the previous generation, so that the best individuals are not lost. We accept the model if the misfit value is less than 1 (< 1). It means that average difference of the observed and theoretical group velocity is within a corresponding standard deviation of the observed data. The same process is repeated various times. We have prepared the list of 100 accepted solutions, having misfit value between 0.12 and 0.16, the observed group velocities have been compared with the theoretical dispersion curves which is shown in Fig. 2.

Thickness, S-wave velocity and Vp/Vs ratio are considered as a model parameter in our nine-layer structure model having 23 variable parameters of the structure. Five layers out of nine layers form the crust. The density in each layer has been kept constant because it has the least effect on the dispersion curve. We have also considered ranges of thicknesses for layers 1–4, 6, and 7; for the fifth layer, being the lowest layer of the crust, we considered the range of depth of the bottom of this layer, and this range corresponds to that of the crustal thickness. The sub-crustal region down to 220 km has three layers, and the region below 220 km is a half-space with the same velocities and density as in the preliminary reference earth model (Dziewonski & Anderson 1981). We have fixed the depth of the bottom of the eighth layer at 220 km.

So,

Thickness of Fifth layer = Crustal thickness – Sum of the top four layers (1)

Thickness of Eighth layer = 220 km – Sum of the thickness of the top seven layers (2)

The resultant model with mean and standard deviation is shown in tables 2 and 3. Using equation (1) and (2) we get fifth and eighth layer thickness with mean and standard deviation for each 100 solutions. The mean and standard deviation for Vp is obtained using Vs and Vp/Vs ratio. The thickness of crust up to Saurashtra is 43.61 km and S-wave velocity is 4.53 km/sec and thickness of crust up to Kutch is 44.91 km and S-wave velocity 4.46 km/sec.

Results and Discussion

The crustal structure of Indus block up to Saurashtra and Kutch has been evaluated with standard deviation given in tables 2 and 3, respectively. The total thickness of crust found is 43.61 km with S-wave velocity below the crust equal to 4.36 km/sec up to Saurashtra. In case of Kutch, the total thickness of crust is 44.91 km with S-wave velocity below the crust equal to 4.46 km/sec. Suresh et al. (2008) have evaluated the crustal structure of Indus block up to Bhuj (Kutch). According to him the crust is 44.19 km thick with 4.39 km/sec S-wave velocity below the crust. This indicates that the crustal thickness in Saurashtra is less as compared to Kutch but the S-wave velocity is nearly same below the crust.

Top two layers show the sediment thickness. We have found 5.51 km thick sedimentary layer in Kutch. While in case of Saurashtra the total sedimentary layer thickness is 4.67 km. This infers less sedimentation in Saurashtra as compared to Kutch. This is because in early Cretaceous period the sedimentation in Kutch and Saurashtra was same but, during the main tectonic phase in the late Cretaceous, a part of Saurashtra arch was uplifted as a horst, and hence sedimentation is less in Saurashtra.

Conclusions

In this study, the crustal structure of Indus block up to Saurashtra has been obtained through inversion of surface-wave dispersion data using genetic algorithm. The thickness of crust up to Saurashtra is 43.61 km; with S-wave velocity of 4.53 km/sec and of crust up to Kutch is 44.91 km, with S-wave velocity of 4.46 km/sec. The thickness of top two layers i.e. sedimentary thickness is 4.67 km for Saurashtra and 5.51 km for Kutch.

Data and Resource Section

Seismograms used in this study were recorded by the observatories of the Institute of seismological Research (ISR), Gandhinagar (Gujarat), India.

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Table 1 Nine-Layered Structure with Search Space of the Solutions

Layer Number	Thickness (km)	Depth of the bottom	Density (gm/cm3)	Vs (km/sec)	Vp/Vs
1	1–2	—	2.00	1.80–2.30	1.70–1.82
2	3–5	—	2.30	2.40–3.20	1.70–1.82
3	8–12	—	2.65	3.30–3.60	1.70–1.82
4	13–17	—	2.90	3.60–3.90	1.70–1.82
5	—	36–48	3.05	3.70–4.00	1.70–1.82
6	30–40	—	3.37	4.30–4.62	1.70–1.82
7	50–60	—	3.36	4.30–4.62	1.70–1.82
8	—	220	3.35	4.30–4.62	1.70–1.82
9	∞		3.44	4.64	1.8448

Table 2 Structure parameter of Indus block with standard deviations for Kutch

Layer Number	Thickness (km)	Density (gm/cm3)	Vs (km/sec)	Vp/Vs	Vp (km/sec)
1	1.02±0.02	2.00	2.002±0.197	1.7908±0.0131	3.584±0.197
2	4.49±0.20	2.30	3.165±0.027	1.7243±0.0256	5.457±0.095
3	10.15±1.34	2.65	3.342±0.065	1.7336±0.0302	5.792±0.110
4	14.34±1.16	2.90	3.701±0.067	1.7726±0.0233	6.560±0.166
5	14.90±2.13	3.05	3.823±0.055	1.7665±0.0266	6.754±0.163
6	35.80±3.06	3.37	4.461±0.085	1.7891±0.0074	7.982±0.152
7	59.39±0.51	3.36	4.617±0.085	1.7234±0.0218	7.958±0.103
8	79.90±3.91	3.35	4.423±0.097	1.7208±0.0166	7.611±0.193
9	∞	3.44	4.64	1.8448	8.56

Table 3 Structure parameter of Indus block with standard deviations for Saurashtra

Layer Number	Thickness (km)	Density (gm/cm3)	Vs (km/sec)	Vp/Vs	Vp (km/sec)
1	1.01±0.01	2.00	2.158±0.173	1.7734±0.0252	3.824±0.273
2	3.66±0.64	2.30	3.156±0.047	1.7444±0.0350	5.506±0.161
3	9.12±0.97	2.65	3.457±0.043	1.7258±0.0235	5.966±0.113
4	14.88±1.32	2.90	3.814±0.087	1.7398±0.0290	6.634±0.131
5	14.93±3.28	3.05	3.850±0.088	1.7480±0.0279	6.731±0.199
6	34.75±3.42	3.37	4.358±0.074	1.7695±0.0211	7.711±0.120
7	58.81±1.35	3.36	4.598±0.026	1.7552±0.0296	8.069±0.145
8	82.83±4.20	3.35	4.479±0.098	1.7351±0.0236	7.771±0.218
9	∞	3.44	4.64	1.8448	8.56

Figure Legends

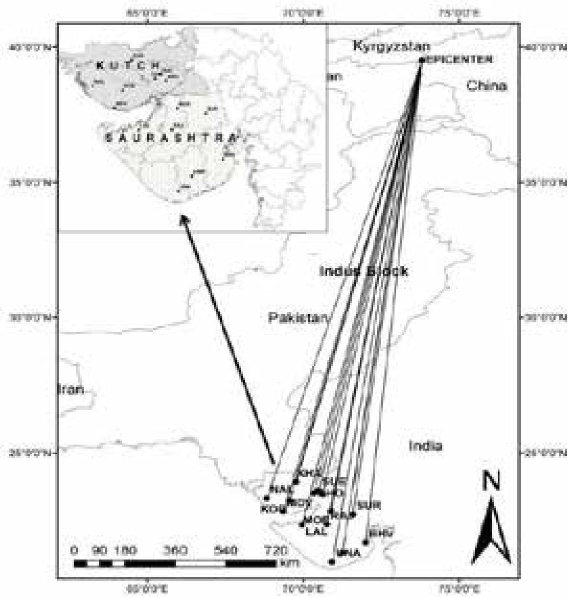

Fig.1 Location of epicentre and recording stations

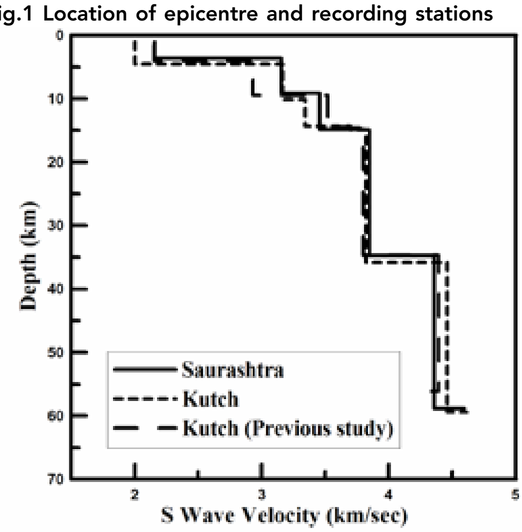

Fig.2 Comparison of S-wave velocity of Indus block up to Saurashtra and Kutch with the previous study up to Kutch (Bhuj).

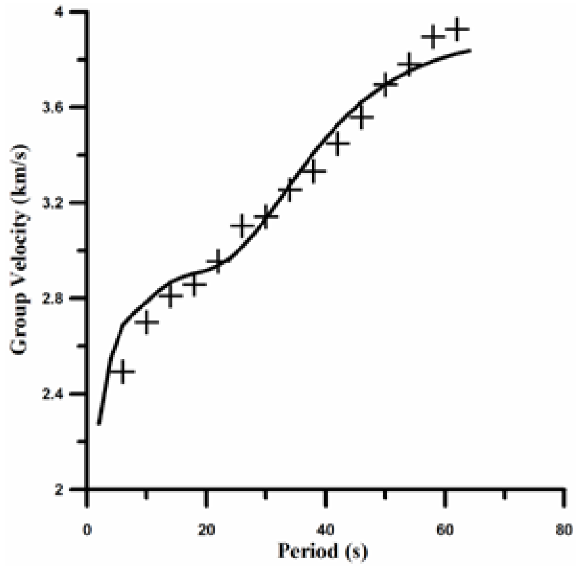

Fig.3 Comparison of observed (+) and theoretical (-) group velocity data for Kutch

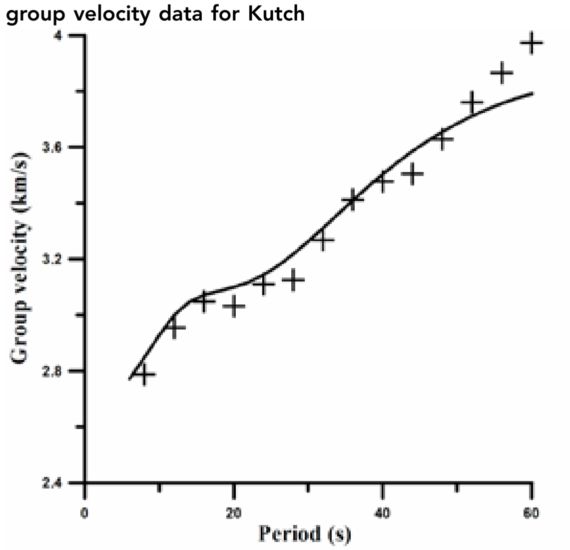

Fig.4 Comparison of observed (+) and theoretical (-) group velocity data for Saurashtra

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