CHAPTER 5

S-WAVE VELOCITY MODELLING OF RFs USING NEIGHBOURHOOD ALGORITHM METHOD

This chapter briefly explains the procedures followed for deriving the models by inverting the receiver functions to obtain the shear wave velocity structure in the crust of SGT. Discussion over the individual models is also included with the comparison of the synthetic RF and the true RF.

5.1 PERSPECTIVE

From the arrival time of different phases and multiples receiver functions are derived and using H-k stacking method the preliminary information i.e. depth of Moho discontinuity and the Poisson’s ratio as well as Vp/Vs are obtained. The time related receiver function has to be converted to depth related section to model the velocity structure beneath the station. Inversion techniques can play a major role in this transformation. Receiver function has a non-linear relation with shear wave velocity. This relation decides the inversion technique and its modifications. The effects of linearization and non-uniqueness of receiver functions are studied by Ammon et al. (1990). Shibutani et al. (1996) obtained the crustal velocity structure by inverting the data using a non-linear genetic algorithm. A fully nonlinear, derivative free, direct search algorithm called Neighborhood Algorithm (NA) was proposed by Sambridge. 1996a,b. In this study the same technique is used for the inversion of receiver functions.
5.2 PARAMETERS USED IN NEIGHBOURHOOD ALGORITHM INVERSION METHOD

Non-uniqueness and nonlinearity are said to be the two main problems with receiver function inversion (Ammon et al. 1990). Ammon et al. (1990) showed that the use of a linearised inversion technique often produces final models that depend on the starting model.

In order to avoid these problems associated with the inversion of receiver functions the NA method was adopted to seek a good fit to receiver functions by varying the crustal structure beneath a receiver. Sambridge (1999a) showed that this method performed well for a nonlinear wave form fitting problem. This method requires minimum tuning and that is one of the advantages of this method over such methods as simulated annealing and genetic algorithms. NA is controlled by just two parameters. Ranking of data misfit is the other advantage so that any type of user defined misfit measure can be employed and the complexities due to scaling of misfit function can be avoided.

Parameters for a six layered model are assumed. The crust is divided into six horizontal layers; a sediment layer, basement layer, upper crust, middle crust, lower crust, and uppermost mantle. For each layer four parameters have to be assumed and a total of 24 parameters has to be assigned. Thickness of the layer, S velocity at the upper boundary, the S velocity at the lower boundary and Vp/Vs ratio in the layer are the model parameters in each layer. The velocity in each layer is represented as a linear connection of the velocity at the upper and lower boundaries. In practice, this is approximated by a number of thin constant velocity layers, and we allow for reflection and transmission at each interface. This method is simple and flexible but requires high computational cost compared to those methods with fewer layers.
Impulse response of an incident P wave is calculated at the base of the receiving station in forward modeling using the phase-adaptive reflectivity method. It is given by the following expression,

\[ \omega_0^{rac} = W_F[I - R_{0J}^1 R_F]^{-1} T_{0J}^1 \]  

(5.1)

where \( W_F \) is the amplification factor for displacement at the free surface, \( R_F \) is the free-surface reflection matrix, \( T_{0J}^1 \) represents transmission from the base of the uppermost mantle layer to the surface, and \( R_{0J}^1 \) represents reflection for the zone between the surface and the base of the uppermost mantle layer. \( V_p \), the P wave velocity in each layer is calculated from the S velocity \( V_s \). The ratio \( V_p/V_s \) is also calculated in each layer. The density (\( \rho \)) is coupled to the P velocity using the following expression,

\[ \rho = 2.35 + 0.036(\alpha - 3.0)^2 \]  

(5.2)

Source equalisation is then performed for both the data and synthetic responses using the water-level deconvolution by preserving the relative amplitudes of the radial and vertical components.

The misfit between the observed and synthetic receiver functions is calculated using an Lp norm misfit measure, given by the following relation,

\[ M_p = \left[ \frac{1}{N_d(S)} \sum_{n=1}^{N_d} \sum_{t=1}^{T} \left| u_n^{obs}(t) - u_n^{syn}(t) \right|^p \right]^{1/p} \]  

(5.3)

where \( N_d \) is the number of observations for a particular receiver, \( u_n^{obs} \) and \( u_n^{syn} \) are observed and synthetic receiver functions, \( S_n \) is the signal to noise ratio for each observation.
ratio for the nth observed receiver function, and \( (S) = N_s^{-1} \sum_n S_n \) is the average signal to noise ratio.

The NA control parameters (ns and nr) have to be tuned for each specific problem. Sambridge (1999a) used parameters of ns = 20 and nr = 2 for receiver function inversion after a few trials. After performing a number of synthetic tests with a limited range of control values for the parameters are selected. Based on these tests the chosen values are, 200 for the parameter ns, with a value of 2 for the parameter nr. The NA is then initiated by generating 50 random models in parameter space, and the same number of models are generated at each subsequent iteration by re-sampling the 25 Voronoi cells within which the lowest current misfits are attained. The algorithm proceeds.

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**Figure 5.1a** Cross section AA’ connecting TRVM, KOD, HSR and KGF
for 500 iterations, and we take the best fitting model found within this number of iterations as our estimate of the crustal structure beneath the receiver.

The values given for these parameters are not only related to the regional geology but also for the minimum misfits. After running the 500 iterations the program gives a final model for each run. Figure 5.1a and 5.1b represents two cross sections AA’ and BB’ as shown in the Figure 4.15. AA’ dissect the study area from south to north connecting the stations TRVM, KOD, HSR and KGF. It trends from SGT to Dharwar Craton and can show the difference in crustal distribution across the terrains. While BB’ starts from Madurai Block (KOD) and trends to north east by touching the stations CSM, CPT and MMT in Madras Block. Figures 5.1a and 5.1b are drawn using the final model data for each stations obtained from the lowest misfit model after running the program.

![Cross section BB’ connecting KOD, CSM, CPT and MMT](image)

**Figure 5.1b** Cross section BB’ connecting KOD, CSM, CPT and MMT
5.3 MODELS WITH THEIR SYNTHETICS

Receiver functions obtained were inverted using NA for different ranges of values for parameters. Results were then merged and arranged according to the misfit values. Thus the variance of the results for each inversion run will be evident. Merged models for all of the inversion runs and the waveform fits are given for each of the station in Figures 5.1-5.12. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines. The comparison of recorded RF stack with the corresponding synthetic RF calculated from the best model is also shown in the figures.
5.3.1 Station TRVM

Figure 5.2(a) S-wave velocity model for TRVM derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (black) for the station TRVM with the corresponding synthetic RF (blue) calculated from the best model.
Figure 5.3(a) S-wave velocity model for KOD derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (black) for the station KOD with the corresponding synthetic RF (blue) calculated from the best model.
5.3.3 Station PCH

Figure 5.4(a) S-wave velocity model for PCH derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station PCH with the corresponding synthetic RF (red) calculated from the best model.
5.3.4 Station CSM

Figure 5.5(a) S-wave velocity model for CSM derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station CSM with the corresponding synthetic RF (red) calculated from the best model.
5.3.5 Station PLM

Figure 5.6(a) S-wave velocity model for PLM derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station PLM with the corresponding synthetic RF (red) calculated from the best model.
5.3.6 Station CPT

Figure 5.7(a) S-wave velocity model for CPT derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station CPT with the corresponding synthetic RF (red) calculated from the best model.
5.3.7 Station MMT

Figure 5.8(a) S-wave velocity model for MMT derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station MMT with the corresponding synthetic RF(red) calculated from the best model.
5.3.8 Station MDRS

Figure 5.9(a) S-wave velocity model for MDRS derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station MDRS with the corresponding synthetic RF (red) calculated from the best model.
5.3.9 Station RNP

Figure 5.10(a) S-wave velocity model for RNP derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station RNP with the corresponding synthetic RF (red) calculated from the best model.
5.3.10 Station TRP

Figure 5.11(a) S-wave velocity model for TRP derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station TRP with the corresponding synthetic RF (red) calculated from the best model.
5.3.11 Station HSR

Figure 5.12(a) S-wave velocity model for HSR derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (blue) for the station HSR with the corresponding synthetic RF (red) calculated from the best model.
Figure 5.13(a) S-wave velocity model for KGF derived using neighbourhood algorithm. The best models are shown in yellow and green with the overall best model as a red line. The rest of the models are shown in grey with the parameter space explored bounded by black lines.

(b) The comparison of recorded RF stack (black) for the station KGF with the corresponding synthetic RF (blue) calculated from the best model.
5.4 DISCUSSION

Shear wave velocity models are shown in the Figures 5.1-5.12 along with the comparison of stacked receiver function with their synthetics. In all of the synthetic tests a Gaussian filter of width 2 is used with a water level parameter of 0.001. Overall the fit of the predicted receiver function to the original receiver function is good, though there are noticeable discrepancies. In most of the models Moho is identifiable and in many cases a low velocity structure is also noticeable. The Moho indicating in the model is comparable with the result obtained from the H-k stacking method.

Parameters were changed several times to get a model with lesser misfit value and a matching synthetic. For TRVM station a low velocity layer (LVL) is evident from a depth of 16km and it extends up to 30km. At a depth of 35km S-wave velocity increased > 4km/s and it points the Moho discontinuity. Meanwhile the upper crust beneath this station carries a higher value for S-wave velocity. There the value reaches up to 3.6km/s. The model carries a misfit value of 0.788. Similarly for KOD and PCH low velocity layer can be seen in the model. In this low velocity layer S-waves travel with a minimum value of 3.0km/s. In the station KOD there is a shallow LVL from a depth of 10km from the surface while for PCH, LVL starts from the depth of 20km. Vs increases ≥4.5km/s beneath the station PCH.

Shear wave velocity structure of the station CSM is quiet normal except a hike in the velocity at a depth of 10km. Sudden increase in velocity to 4.5km/s from 3.9km/s at a depth of 35km indicates the Moho beneath the station. Meanwhile the result of H-k analysis shows a crustal depth of 39km. But the variance of the value obtained for Moho depth for CSM was high with a value ±2.9 because of low quality of data. Misfit value of the model is 0.899. In the comparison of RFs (original and synthetic), synthetic goes with the true at the first arrival, Ps and at multiples, though the amplitudes are not
exactly matching. In the case of CPT Moho is observed beyond 40km with an increase of velocity to 4.6km/s. The velocity model of MMT station has some ambiguities. But the RF of MMT justifies the model because in the RF of MMT there are two spikes immediately after the first arrival. The first spike reaches around 4 seconds and the second one reaches around 6 seconds. Similarly a sudden variation in velocity can be seen at two places in the model. First is at a depth of 32km and the other is at a depth of 46km. The model carries a misfit of 0.692 and the predicted RF almost matches with the true one with variations in amplitudes. Along the station MMT, MDRS is the other one which located at Phanerozoic sediment in Madras Block. A clear LVL is evident in the model from a depth of 20km, extending up to 34km in MDRS. At the depth of 34km a sudden change in velocity denotes the Moho. The model carries a misfit value of 0.740 but the multiples are displaced slightly from the true RF. The remaining station in Madras plate, RNP has a simple model without any LVL and the Moho can be observed at a depth of 34km. The model carries a misfit value of 0.748 and the multiples of synthetics are matching with the original RF.

A high velocity immediately below 5km from the surface is observed in the velocity model of the station TRP and the velocity decreases gradually from 4.2km/s to 3.6km/s within a depth of 20km. At a depth of 34km a velocity hike can be observed and denotes the Moho discontinuity. Similarly in the other two stations in Dharwar Craton i.e., HSR and KGF, immediate high velocity layer can be found. In both the cases the high velocity layer can be seen near to the depth of 10km from the surface. The model of velocity structure obtained by inverting the receiver function for the stations in Dharwar Craton shows a Moho at a depth of 34km.