1-D VELOCITY MODEL FOR WAPDA TARBELA MICROSEISMIC NETWORK IN TARBELA AND NORTHERN AREAS, PAKISTAN

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ABSTRACT

A new 1-D velocity structure model is proposed for Microseismic Monitoring system (MSMS) of WAPDA Tarbela Dam Project in Northern Areas of Pakistan. It is expected to serve for routine high accuracy earthquake hypocenter location and to work as a reference model for the tomographic studies. We perform a series of simultaneous inversion of P and S waves' velocity structure and hypocenter location using VELEST and the arrival time data obtained in site during the period from March 2010 to March 2012.

The new velocity model has the additional boundaries at 23 km and 110 km and higher velocities in the lower crust in comparison with the currently used velocity model and shows a better consistency with the existing studies, although the analysis of hypocenter relocation using these models show that they are equivalent in terms of the residual: its RMS and the distribution throughout the available epicentral range from 0 km to 450 km.

The lack of the shallow events determined within 20 km from any station causes the possibility of a hidden surface layer of low velocity that can be a subject for future study. The new model is expected to improve the accuracy of the routine hypocenter determination and to make it possible to perform 3-D seismic tomography for the Northern Areas of Pakistan in the future.

Keywords: Simultaneous Inversion, P and S velocity structure, RMSs

1. INTRODUCTION

The Directorate of Seismology WAPDA, Tarbela Dam Project, is responsible for monitoring seismic activity around the Tarbela Dam Project and the projects which are in the feasibility study phase in the Northern Areas of Pakistan. The Directorate has been recording microseismic data around the Tarbela Dam Project since 1973. Due to the recent renewal of the network, we have to improve the existing velocity model for the determination of hypocenter parameters of earthquakes in and around the extended network of Northern Areas Microseismic Monitoring System (MSMS). Also the appropriate velocity model is important for different tasks, such as reliable routine hypocenter determination, seismic tomography of the area, moment tensor inversion etc.
In the present study, we determined a 1-D velocity model with station corrections by analyzing data from MSMS, WAPDA Tarbela. We used the program VELEST (Kissling 1988, 1995; Kissling et al., 1994).

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2. TARBELA NETWORK

The new network consists of 19 field stations. Each field station consists of a short period seismometer (SS-1, Kinemetrics) and an accelerometer (Episensor, Kinemetrics): both of them have three components, and a digital data logger (Q330S, Kinemetrics) synchronized with GPS timing system. Previously our area of interest was about 160 km in radial distance from the SWM station near Tarbela Dam Project. Initially Directorate of Seismology Tarbela, installed 10 field stations, and after two years we added 9 more station. With this extension of the micro-seismic monitoring network to the Northern areas of Pakistan, the area of seismic activity monitoring has increased longer than 350 km (Figure 1). The field data are sent to the central recording and processing system based in Tarbela Dam Project via V-SAT communication and then processed and stored by Antelope software (Kinemetrics).

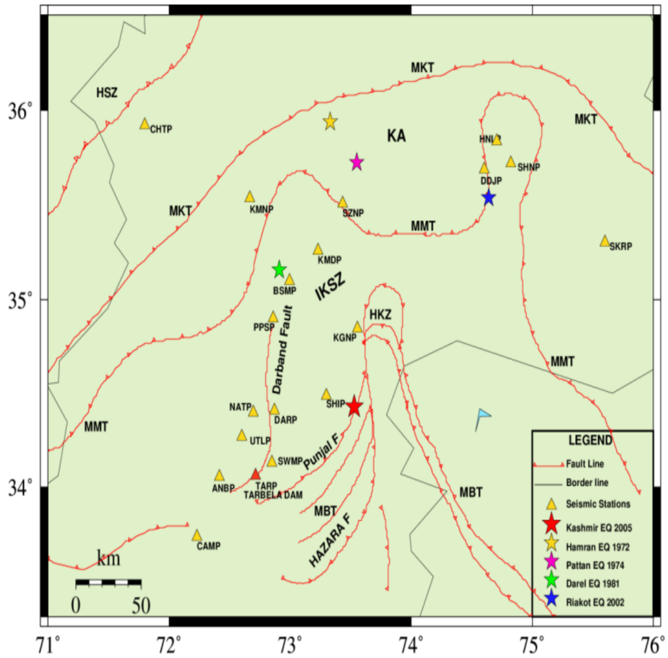


Figure 1. Location of field stations and major tectonic structure in and around the study; Area. HSZ: Hindu Kush Seismic Zone, KA: Kohistan Arc, MKT: Main Karakorum Thrust, MMT: Main Mantle Thrust, MBT: Main Boundary Thrust, IKSZ: Indus Kohistan Seismic Zone, HKS: Hazara Kashmir Syntax, Star denotes the epicenter of the 2005 Kashmir earthquake.

3. DATA

The Catalogue of earthquake parameters is generated with Antelope software by the Directorate of Seismology Tarbela Dam Project. For the present study, we have data from March, 2010 to March, 2012. The number of events which have been analyzed by seismologists in Tarbela, is in total about 600. We at selected 400 that have the RMS of the arrival time residuals less than 1sec (RMS<1sec) . from the catalog made in Tarbela network. This number is reduced to 387 during the analysis due to the constraints used below: the epicentral distance to the reference station less than 450 Km; more than three arrival time data is available under this constraint.

For the analysis explained below we used arrival times of P and S waves at different stations that belong to MSMS. Figure 4 shows the wadati diagram for the an event in March 31,2012 gives a reference value of the ratio Vp/Vs 1.75. The mark of data are fitted well the line and shows the accuracy of the timing system.

4. ANALYSIS

We have selected DARP station as a reference station in this study, because this is on hard rock and then may not have a strong site effect, and have obtained the maximum number of phase arrivals. The minimum focal depth is set to 0 km and the maximum epicentral distance is set 450Km from the reference station. We used upper most layers as negative, because the VELEST program takes sea level as zero; however, the seismic stations are installed at maximum 2200 meters above sea level. We prohibit introducing newly, so called low velocity layers in the simultaneous inversion of the hypocenters and velocity structure.

4.2. Search for the Optimum Velocity Model

Figure 2 shows the task flow of the analysis. From Model-A0, two velocity models having thinner layers are made: one have 28 layers and another 12 layers in order to check the influence of layer division, and then the simultaneous inversion for velocity structure and hypocenter parameters is performed using VELEST from these two models and Model-A0 itself. Among three inverted velocity models one inverted from Model-A0 itself has the minimum average residual and then selected (Model-A1). From Beloussov et al. (1980) and Roecker (1982) we constructed a Model-B0. From Model-B0 two models having thinner layers are made as shown in Figure 6 and the simultaneous inversion is performed from them and Model-B0 itself. Among the inverted structures, one inverted from Model-B0 shows the minimum average residual and then selected (Model-B1). While fixing the other structural model parameters of Model-A1 and Model-B1, we performed the search of the optimal Moho depth. Namely, two series of inversion are performed by changing only Moho depth from 57 Km to 70Km while the depths of other boundaries are fixed. For both models, Moho depth is determined 60 Km.

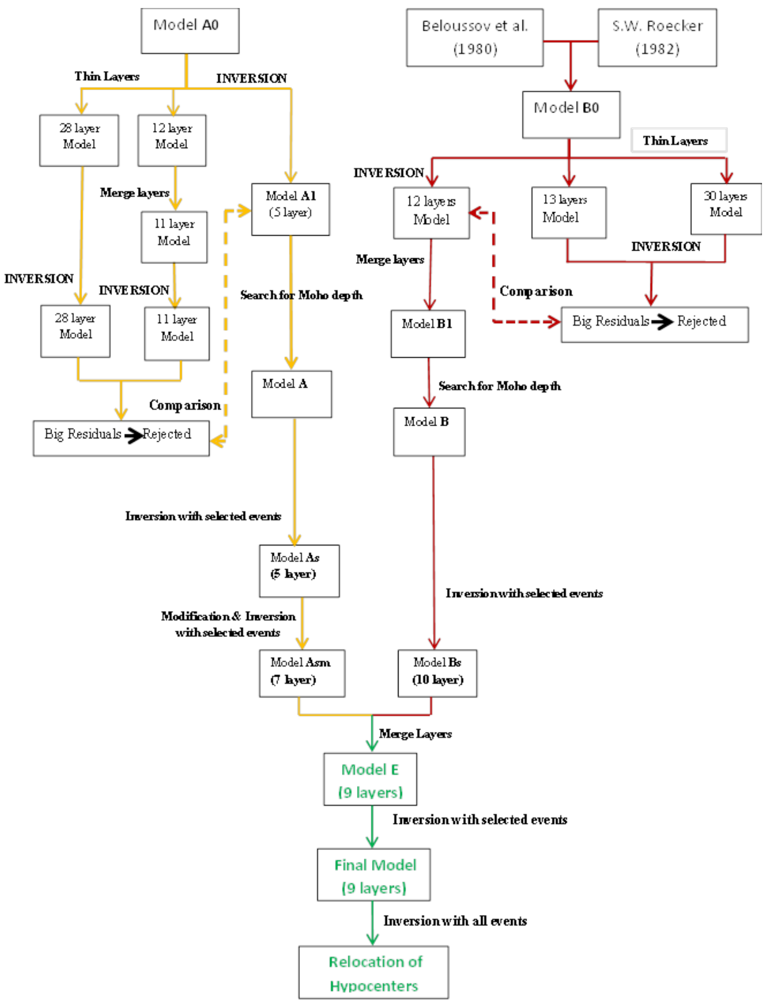


Figure 2. Task Flow to obtain the optimum1-D Velocity Model.

The inverted structures from Model-A1 and Model-B1 are named Model-A (5 layers) and Model-B (10 layers, consecutive layers having similar velocities are merged), respectively. Considering their different ways of layer division, Model-A and Model-B are not very different each other and it seems that the optimal model may be found in between them. For better accuracy of analysis, 267 events recorded at 6 or more stations are selected and the simultaneous inversion is performed again with these selected events. The structure inverted from Model-A and Model-B are named Model-As and Model-Bs, respectively. Model-Bs differs from Model-As by the boundaries at depth of 23 Km and 110 Km. then, we modify Model-As (5 layers) to 7 layer model and perform the inversion again to obtain Model-Asm. We found these are similar to each other. Model-Asm is merged with Model-Bs into Model-E (9 layers) and the inversion gives the final 1-D structure Model-F (9 layers). Finally, we perform the inversion for hypocenter parameters fixing the velocity structure to Model-F in order to relocate all the events. The number of events becomes 387, because the events that are recorded at less than 3 stations are rejected from the analysis.

Table 1. The AAUR values of the velocity models used in this study

Model	Number of layers	Events	AAUR
Model-A0	5	All	0.867
Model-B0	12	All	1.242
Model-A1	5	All	0.183
Model-B1	10	All	0.188
Model-A	5	All	0.183
Model-B	10	All	0.188
Model-As	5	Selected	0.244
Model-Bs	10	Selected	0.439
Model-Asm	7	Selected	0.374
Model-E	9	Selected	0.195
Model-F	9	Selected	0.249
Model-F	9	All	0.174

5. RESULTS AND DISCUSSION

In Figure 3, Model-A0: the current velocity model being used for hypocenter determination by WAPDA also shown for comparison. Figure 3 shows that P-wave velocity of Model-F in the layers shallower than Moho 60 Km is faster than those of Model-A0. The main newly added boundaries are at the depth of 23 km and 110 km. They are roughly consistent with the depth of Moho and the bottom of the lithosphere explored by Kumar et al. (2005). Figure 4(a) shows the hypocenters relocated using Model-A0 whereas those relocated using Model-F are shown in Figure 4(b). The epicenter distribution shows not a large difference between these two velocity models, but there is a detectable difference between their depth distributions. Figure 4(c) shows that the number of earthquakes slightly increased in the range between 0 to 100km. Figure 5 shows the comparison of the RMS of the arrival time residuals: blue bars show the hypocenters relocated using Model-F and red

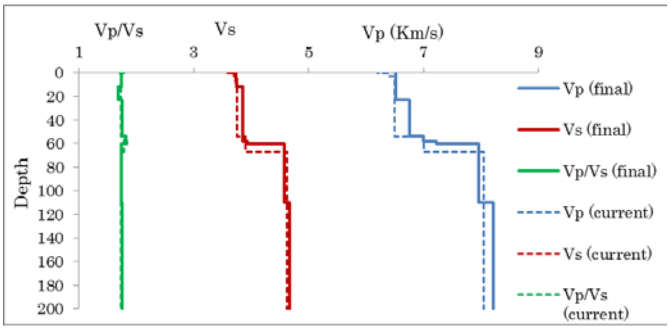
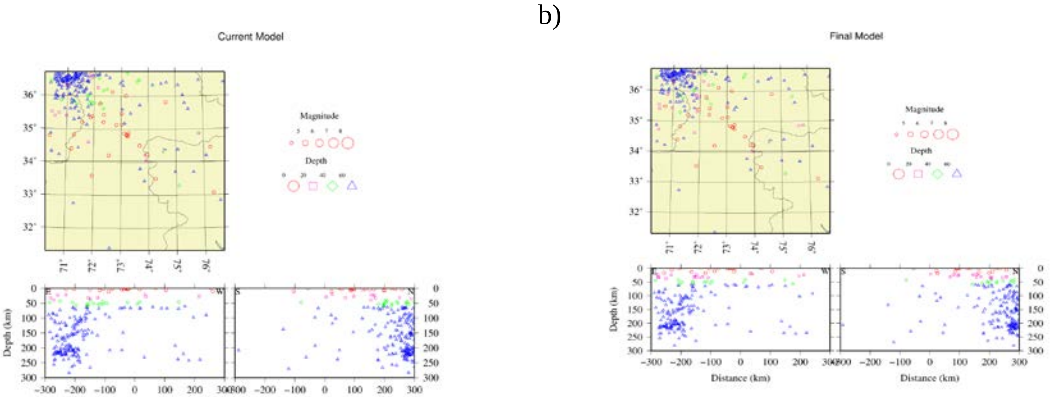


Figure 3. Model-F (the final model) and Model-A0 (currently used one) and their Vp/Vs ratio.

a)

b)



c)

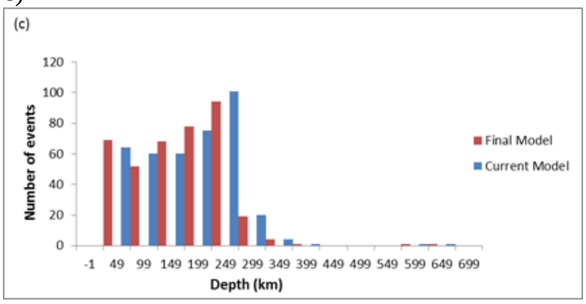


Figure 4. The hypocenters and frequency distributions of the focal depths of 387 earthquakes used in this study for the inversion of 1-D velocity model. a) The hypocenters relocated using Model-A0, and b) The hypocenters relocated using Model-F. c) the frequency distribution of focal depths of the hypocenters relocated using Model-F (red bars) and Model-A0 (blue bars).

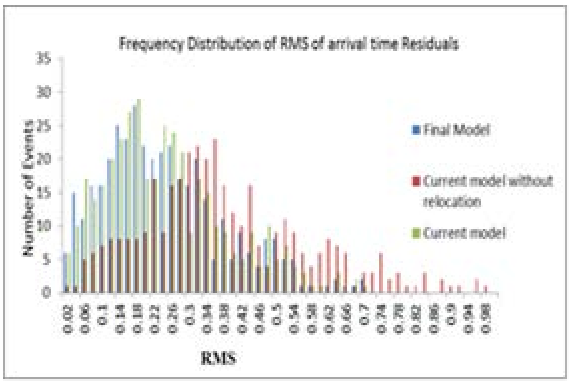
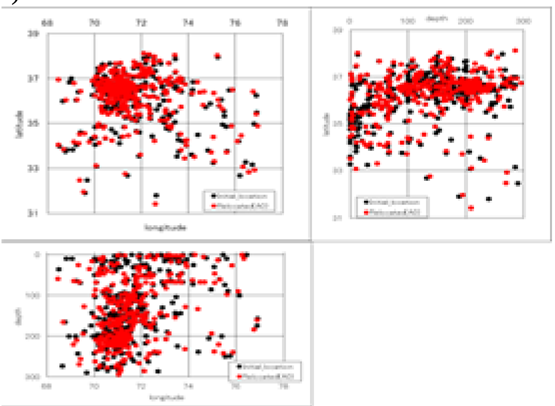


Figure 5. Comparison of the frequency distribution of RMS of the arrival time residuals: red bars denotes those given in the original catalog of Tarbela network without relocation, green bars those correspond to those in Figure 4 a) (relocated hypocenters using Model-A0) and blue bars those correspond to Figure 4 b) (relocated hypocenters using Model-F).

a)



b)

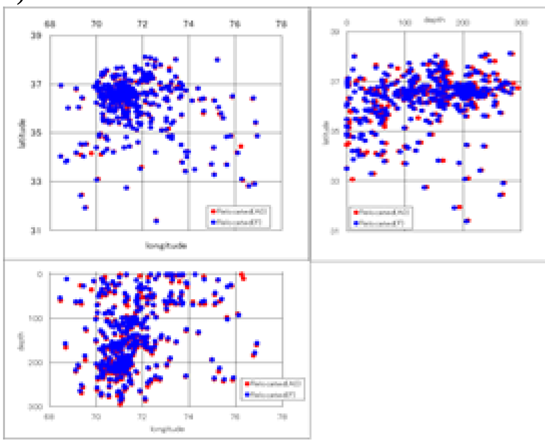


Figure 6. Comparison of hypocenters: a) those given in the original catalog of Tarbela network calculated using Model-A0 without relocation (black dots) vs. those relocated using Model-A0 (red dots), b) those relocated using Model-A0 (red dots) vs. those relocated using Model-F (blue dots).

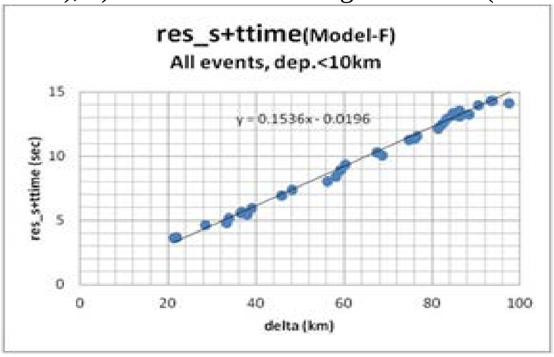
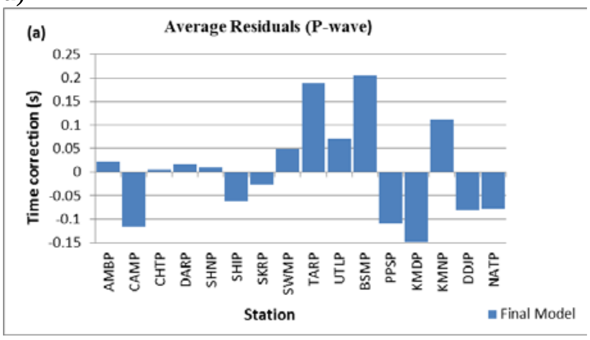


Figure 7. Tobs (= res_s + ttime) over epicentral distance for the events of which depth is less than 10 km, where res_s denotes residuals of each phases and ttime the theoretical travel times calculated using Model-F. Namely, Tobs is equal to observed arrival time minus determined origin time.

a)



b)

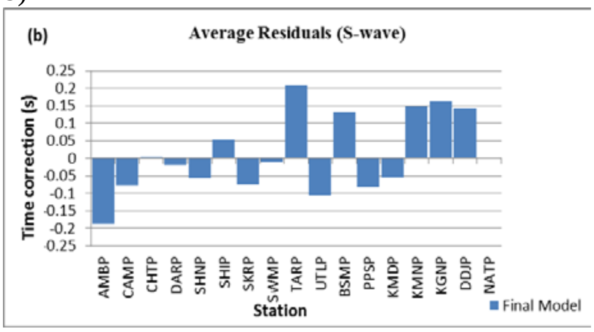


Figure 8. Average residuals of each station that can be used as the station corrections: a) for P-wave and b) for S-wave, respectively.

bars those relocated using Model-A0, whereas green bars those correspond to the hypocenters given in the original catalog of Tarbela network calculated using Model-A0, however, without relocation. It is clearly shown that the first two are smaller than the last one, namely, 0.234 s, 0.236 s and 0.428 s for blue, red and green bars, respectively. This result shows that Model-F is the best fit model for the observed arrival times among these three; however, the difference between the first two is slight. Figure 6(a) shows the comparison of the hypocenters relocated using Model-A0 and those of the initial location given in the original catalog of Tarbela network and a significant change by the relocation using VELEST. In contrast, Figure 6(b) the comparison of the former model-A_0 with those relocated using Model-F. The epicenters are almost unchanged; however, the depth becomes shallower slightly and systematically.

6. CONCLUSION

We perform a series of simultaneous inversion of P and S waves' velocity structure and hypocenter location using VELEST and the arrival time data obtained by Microseismic Monitoring System (MSMS), WAPDA, Tarbela, in order to determine P and S wave 1-D velocity structures of the crust and upper mantel beneath the Northern Areas of Pakistan with a set of station corrections. The search started from two velocity models: one is the currently used model by MSMS, WAPDA Tarbela (Model-A0) and another the structure of Beloussov et al. (1980) combined with Roecker (1982), and finally converged to a structure (Model-F) through a systematic search for the optimum Moho depth.

The Moho depth is estimated to be 60 km. This is consistent with existing studies. The finally determined structure model (Model-F) with 9 layers shows P-wave velocity in the upper crust is faster than that of the model currently used for routine hypocenter determination with 5 layers (Model-A0). The main boundaries that are newly added are at the depth of 23 km and 110 km. Model-F has higher velocities in comparison with Model-A0 at the lower crust that lies at the depth from 23 km to 60 km.

The relocation of hypocenters using this Model-F gives the values of the station corrections. The quantitative correlation with the local condition of each station is remained for future study as well as its stability or dependency on dataset.

The comparison of the residuals of the relocation using Model-F with that using Model-A0 shows that these are equivalent in terms of the residuals: its RMS and its distribution over the epicentral distance range from 0km to 450km. Model-F, however, shows a better consistency with existing studies (e.g., Roecker, 1982; Kumar et al., 2005). Therefore, it seems worth to test more about this newly proposed structure model using newly obtained data, especially the phases converted at Moho and the boundaries at the depth of 23 km and 110 km, and those excited by far events and refracted at these boundaries. It is possible that a shallow layer is hidden at the surface due to the limitation of dataset that does not contain any event shallower than 10 km that occurred within the epicentral distance shorter than 20 km from any station. Records due to shallow events within the network are indispensable in order to verify whether a hidden layer exists or not.

The existing Tarbela velocity model (Model-A0), as mentioned in the first data analysis report (National Engineer, 2010), of the MSMS Tarbela Dam project was verified and a new model (Model-F) is proposed. This new model is expected to improve the accuracy of the routine hypocenter determination and to make it possible to perform 3-D seismic tomography for the Northern Areas of Pakistan in the future.

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