1D VELOCITY MODEL BY LOCAL EARTHQUAKE DATA

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Introduction

In this study, one-dimensional (1-D) *P*- and *S*-wave velocity structures of upper crust in the Azerbaijan region and precise hypocentre locations are recorded by the Republican Seismic Survey Centre's stations, during the period 2003 – 2018. We performed an analysis to find the best P-wave one-dimensional velocity model for the crystal structure of the study area, using the **VELEST** algorithm. We used 5423 *P*- and 4478 *S*-arrival times of 2650 events recorded at 30 stations. We found eleven distinct layers within the upper 60 km of the crust. We studied the area from seismological and geological point of view and we analyzed the influence of the velocity model on the earthquake locations. We analyzed the instrumental seismicity of the Middle Kura Depression region recorded by the Republican Seismic Survey Centre's stations, during the period 2003 – 2009[9]. We used standard seismological methods to compute the Vp/Vs ratio, one-dimensional velocity model, and station corrections for earthquake relocations.

Earthquake location can be improved using a reference 1D model close to the true earth model and station corrections that mitigate the effects of the structure close to the receiver and deviations from the simple, homogeneous model. Kissling proposed that the natural solution to this problem is the least square solution. They called this solution the minimum 1D model. Following this approach, we first established the starting 1D models using the available information on the crystal structure. Starting velocity values were selected considering available data and the results of Gasanov A.(1989)[1]. We used four layers each for the crust and the uppermost mantle for a total of eight layers.

COUPLED HYPOCENTER VELOCITY MODEL PROBLEM

The travel time of a seismic wave is a non-linear function of both hypocentral parameters and seismic velocities sampled along the ray path between station and hypocenter. This dependency of hypocentral parameters and seismic velocities is called the coupled hypocenter-velocity model problem (Crosson 1976, Kissling 1988, Thurber 1992)[4, 9]. It can be linearized and in matrix notation is written as (Kissling et al. 1994):

$$\mathbf{t = Hh + Mm + e = Ad + e},$$

t vector of travel time residuals (differences between observed and calculated travel time); **H** matrix of partial derivatives of travel time with respect to hypocentral parameters; **h** vector of hypocentral parameter adjustments; **M** matrix of partial derivatives of travel times with respect to model parameters; **m** vector of velocity parameter adjustments; **e** vector of travel time errors, including contributions from errors in measuring the observed travel times, errors in the calculated travel times due to errors in station coordinates, use of the wrong velocity model and hypocentral parameters, and errors caused by the linear approximation; **A** matrix of all partial derivatives; **d** vector of hypocentral and model parameter adjustments.

In standard earthquake location algorithms the velocity parameters are kept fixed to a priori values - that are assumed to be correct - and the observed travel times are minimized by perturbing hypocentral parameters. Neglecting the coupling between hypocentral and velocity parameters during the location process, however, can introduce systematic errors in the hypocenter location. Furthermore, error estimates strongly depend on the assumed a priori velocity structure. Precise hypocenter locations and error estimates, therefore, demand the simultaneous solution of both velocity and hypocentral parameters. The optimal 1D model will be achieved by simultaneously inverting for hypocenter and velocity parameters [10]. The minimum 1D velocity model obtained by this trial-and-error process represents the velocity model that most closely reflects the priori

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information obtained by other studies, e.g. refraction studies, and that leads to a minimum average of RMS values for all earthquakes.

BUILDING A 1D VELOCITY MODEL: DATA SELECTION AND INITIAL MODEL

We performed an analysis to find the best P-wave one-dimensional velocity model for the crystal structure of the study area, using the **VELEST** algorithm [9]. This approach incorporates iterative simultaneous inversion of hypocenters and 1-D velocity model.

The calculation of a minimum 1D model requires a set of well constrained events. Uncertainties in hypocenter locations will introduce instabilities in the inversion process, because of the hypocenter-velocity coupling. The largest azimuthal gap of observations (GAP) and the minimum number of observations per event are very good criteria to reliable and robust earthquake locations [5-8]. This reduces the data set used for the P-wave inversion to a total number of 2650 events.

After 9 iterations, we obtained a variance improvement of about 86%, and a final RMS of 4.2 s. The computed P and S-wave 1D-velocity model is shown in Fig.1 with red lines.

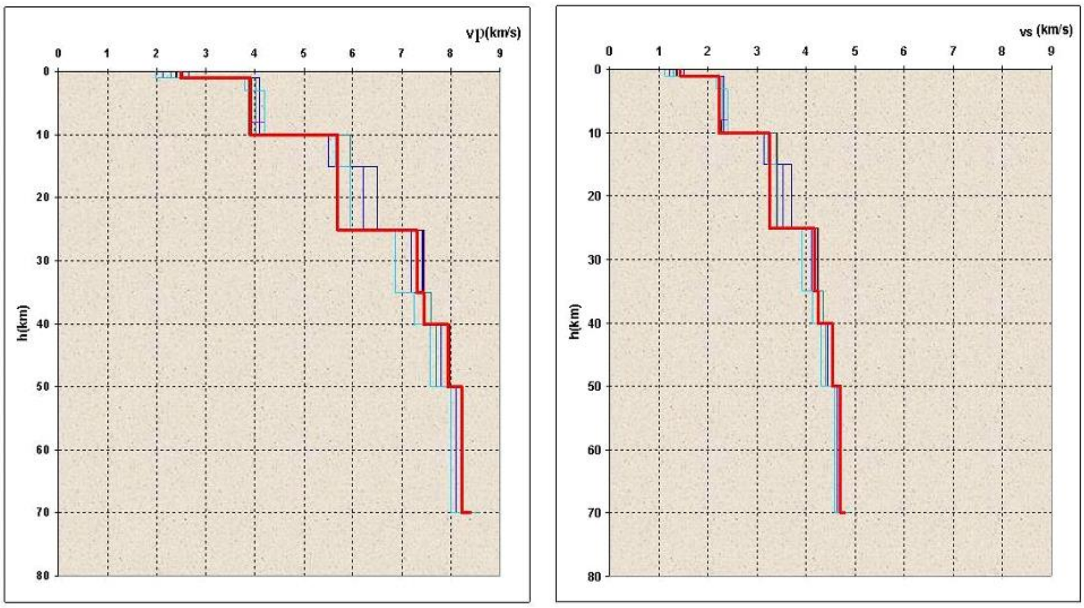

Figure 1. Final 1D velocity models after 9 iterations by Velest program

S-wave phases add important additional constraints on hypocenter locations because partial derivatives of S-wave traveltimes are always larger than those of P waves by a factor equivalent to VP/VS and they act as an important constraint within an epicentral distance of 1.4 focal depths. The use of S waves will in general result in a more accurate hypocentre location, especially regarding focal depth. On the other hand, a large S arrival time errors at a station close to the epicentre can result in a stable solution with a small RMS, but is actually significantly mislocated even for cases with excellent azimuthal station coverage.

A schematic 1D model used to approximate the unknown velocity structure for earthquake location and used as the reference model for 3-D tomographic inversions is shown in Fig.2.

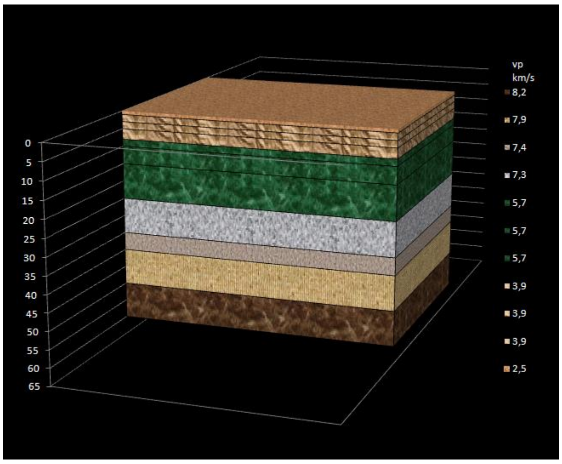

Figure 2. Final schematic 1D velocity model

Discussion

Figures- 3 and- 4 show the final and preliminary locations respectively of 2650 events. Average differences between final and preliminary locations in latitude, longitude, depth and origin time are ±5-10 km, ±5-10 km, 6-11 km and 2 ± 4 s, respectively. The shifting of the hypocentres systematically in one direction, for example focal depth, is a good test for the robustness of a minimum 1-D model. The systematic shift is on the order of ±5-10 km in longitude. This eastward shift is likely due the N–S linear array orientation of the RSSC network. The depth values of final locations indicate that the majority of events occur between 5 and 10 km for the region, while preliminary locations have both more shallow and also deeper events.

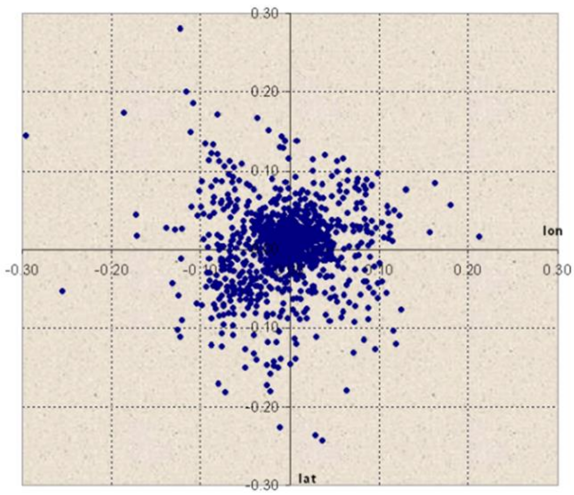

Figure 3. Difference in latitude and longitude between the first location(a) and Velest relocation(b)

After shifting all events to a greater depth by 10 km, two inversions were performed, one with slightly damped and one with strongly overdamped velocities, the results of which are shown in Fig.5, respectively. Since we have solved a coupled hypocentre–velocity problem, the initial bias in the hypocentres may be compensated by adjusting the velocities, or by relocating the events to their original position, or by a combination of these methods.

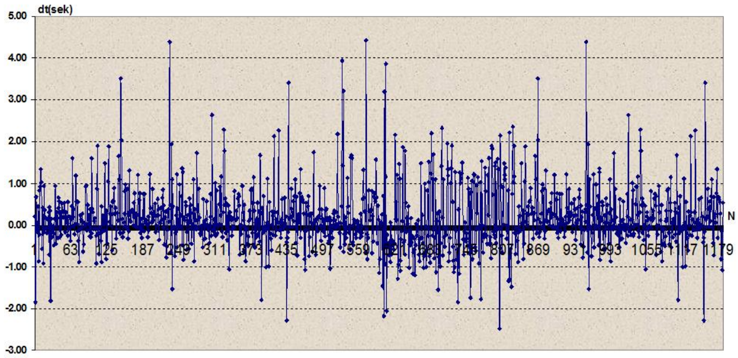

Figure 4. Difference in origin time between the first location(a) and Velest relocation(b)

We note a consistent decrease of RMS values for the relocated earthquakes. Moreover, residuals at the stations within 180 km of the epicenter are greatly reduced. Although hypocentral errors are for some cases larger with the new model, we are satisfied with the relocations, because of the reduction of RMS and the fit of *P*-wave arrivals at close distance from the epicenter.

Conclusions

This paper has focused on the simultaneous determination of the 1-d *P*- and *S*-wave velocity models in the Middle Kura depression, Central Azerbaijan, using the travel time inversion algorithm Velest. We have created a more accurate and stable 1-d *P*- and *S*-wave velocity models which give rise to new locations of aftershocks with minimum errors in RMS values and station corrections for the *P*- and *S*-wave arrival times. It is found that the *P*-wave velocities are quite low (<10 km/s) for the 12 km thick unconsolidated sediments of the Middle Kura depression. The *P*-wave velocity at a depth of 12 km increases to nearly twice that of the upper sedimentary layer. This result is consistent with the *P*-wave velocity model obtained by the results of 3-d seismic tomography given by Gasanov A.G. (1989). The *P*-wave velocity value reaches to 6.3 km/s from 10 to 25 km depth with an increasing gradient a thick layer was defined with a *P*-wave velocity of 7.2 km/s at depth range of 25-45 km [2].

After several tests and trial solutions, 1-D *S*-wave velocitiy model was obtained for the optimum values of *V*P/*V*S ratio. Although, the *V*P/*V*S ratio is very low at shallow depths (<10 km), it gradually decreases in the layers deeper than 10 km. The sudden increase of the *V*P/*V*S ratio at 2 km depth is consistent with a high *P*-wave velocity at that depth.

Several tests on the stability of final velocity model prove that the final 1-D *P*- and *S*-wave velocity models found in this study represent the most acceptable model for future relocation processes in the area. Graphical patterns of RMS residuals, depth, latitude, longitude and depth using the new crustal velocity model confirmed that the event locations have been improved.

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