HVSR**Inv**
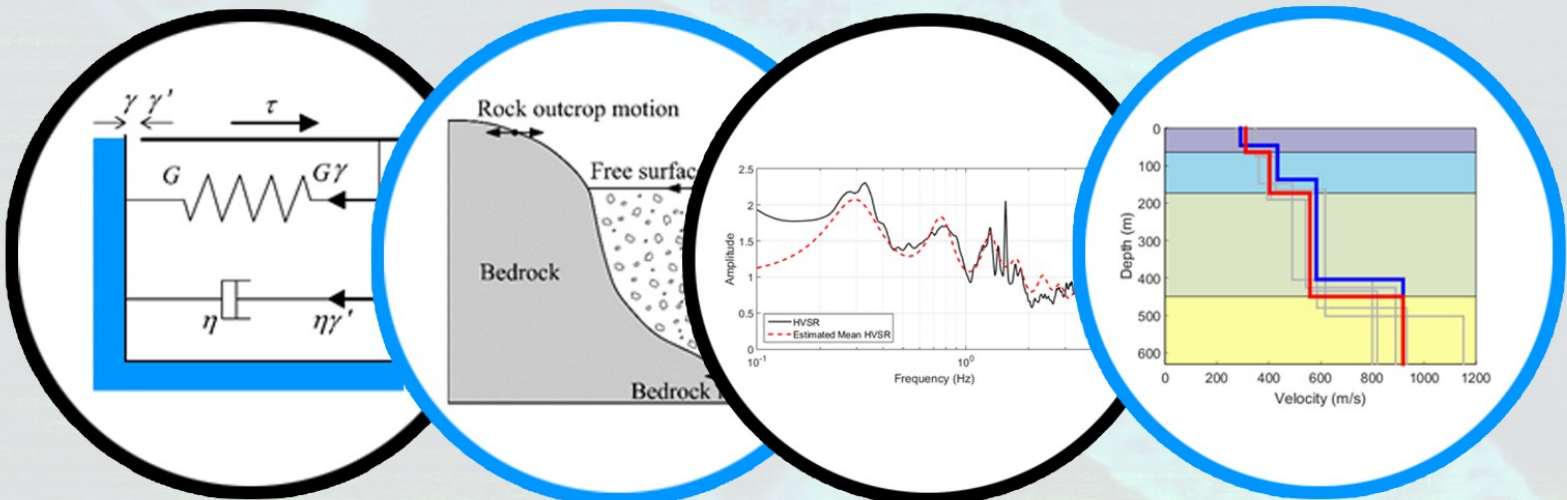
Estimation of the amplification properties of soil through HVSR inversion based on an elitist genetic algorithm

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USER GUIDE

HVSRInv is a MATLAB-based graphical user interface developed for forward calculation and inversion of the horizontal-to-vertical spectral ratio. It uses the equivalent linear approach (Schnabel et al., 1972; Kramer, 1996; Bardet et al., 2000) based on the viscoelastic Kelvin-Voigt model to compute the theoretical site response of the horizontally stratified soil layers. The code can easily estimate the dynamic parameters such as thickness, shear wave velocity, density and damping ratio of the soil layers through an elitist genetic algorithm, and thereby obtain the shear wave velocity profiles. Please, see Kafadar and İmamoğlu (2022) for more detailed information.

- Kafadar, O., İmamoğlu, Ç., 2022. HVSRInv: Estimation of the amplification properties of soil through HVSR inversion based on an elitist genetic algorithm, Mathematical Geosciences.
- Bardet, J.P., Ichii, K., Lin, C.H., 2000. EERA: A Computer Program for Equivalent-linear Earthquake Site Response Analyses of Layered Soil Deposits. Department of Civil Engineering, University of Southern California.
- Kramer, S.L., 1996. Geotechnical Earthquake Engineering. Prentice Hall, Upper Saddle River, New Jersey, 254–280.
- Schnabel, P.B., Lysmer, J., Seed, H.B., 1972. SHAKE: a computer program for earthquake response analysis of horizontally layered sites: Report No. EERC72-12, University of California, Berkeley.

Quick Tutorial

Installation

HVSRInv requires Matlab 2015a and later versions.

- If your computer has not a full MATLAB R2015a (64-bit) installation, please, install MATLAB Compiler Runtime (MCR), which can be downloaded from MathWorks website (http://www.mathworks.com/products/compiler/mcr).
- Open HVSRInv.exe.

GitHub repository: https://github.com/ozkankafadar/HVSRInv

HVSRInv includes several subroutines and user interfaces. The program files and sub folders are shown below.
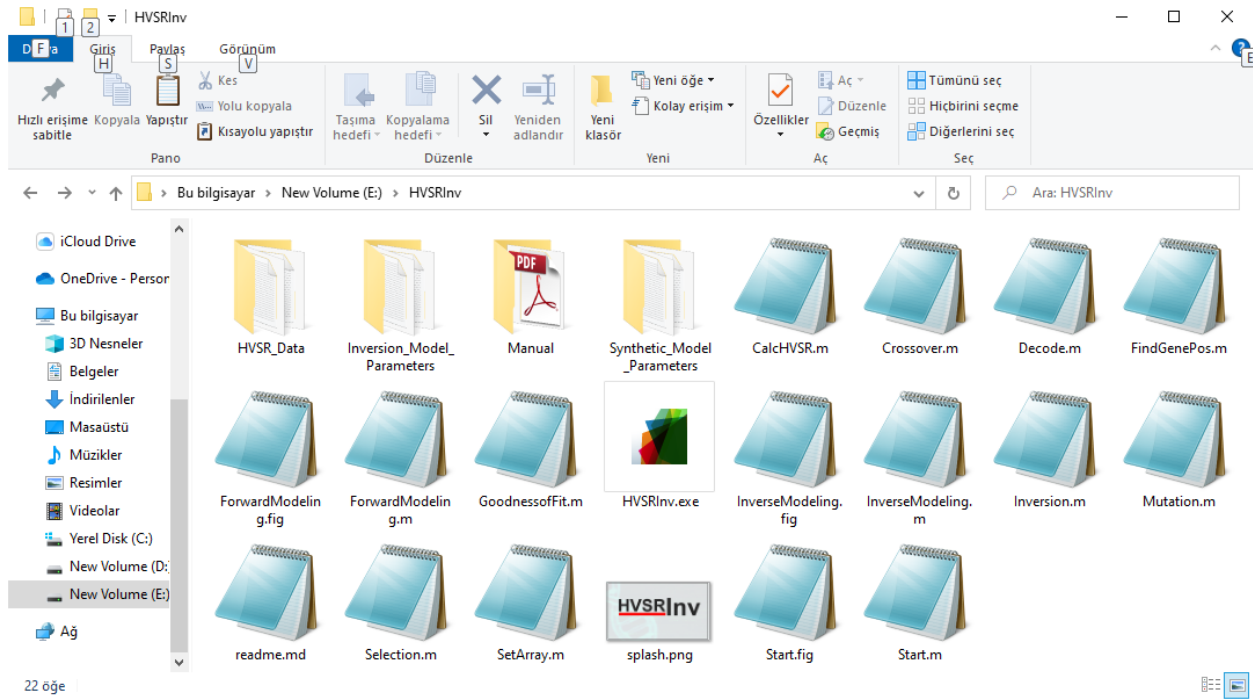
Main Interface

The main form consists of three buttons: "**FORWARD MODELING**", "**INVERSION**" and "**EXIT**".

- "**FORWARD MODELING**" is the user interface designed for forward calculation of horizontal-to-vertical spectral ratio.
- "**INVERSION**" is the user interface designed for inversion of horizontal-to-vertical spectral ratio.
- "**EXIT**" terminates the program.
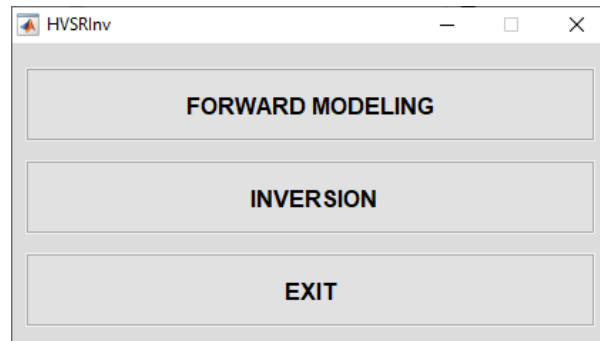
The "**FORWARD MODELING**" graphical interface consists of several graphical objects. The first step for forward calculation is to define the model parameters. The model parameters can be defined manually or loaded by means of an input file.

🞣 Defining the model parameters manually

Enter the number of layers, number of samples, and model parameters for each layers. When the shear wave velocity is entered into model parameters table, the density and damping ratio are calculated automatically. But they can also be changed manually if the user is desired. The damping ratio ξ is calculated using the formula based on *Vs-Qs* correlations defined by Archuleta and Liu (2004) and expressed as follows:

$$\xi = \frac{1}{2Qs}, Qs = \begin{cases} 0.06Vs & Vs \leq 1000 \ ms^{-1} \\ 0.04Vs & 1000 \ ms^{-1} < Vs < 2000 \ ms^{-1} \\ 0.16Vs & Vs \geq 2000 \ ms^{-1} \end{cases}.$$

Besides the density ρ is calculated using following formula defined by Uyanık and Çatlıoğlu (2015):

$$\rho = 0.85Vs^{0.14}.$$

- Archuleta, R.J., Liu, P., 2004. Improved predication method for time histories of near-field ground motions with application to southern California. Tech. rep., United States Geological Survey.

- Uyanık, O., Çatlıoğlu, B., 2015. Determination of density from seismic velocities, Jeofizik, 17, 3-15.
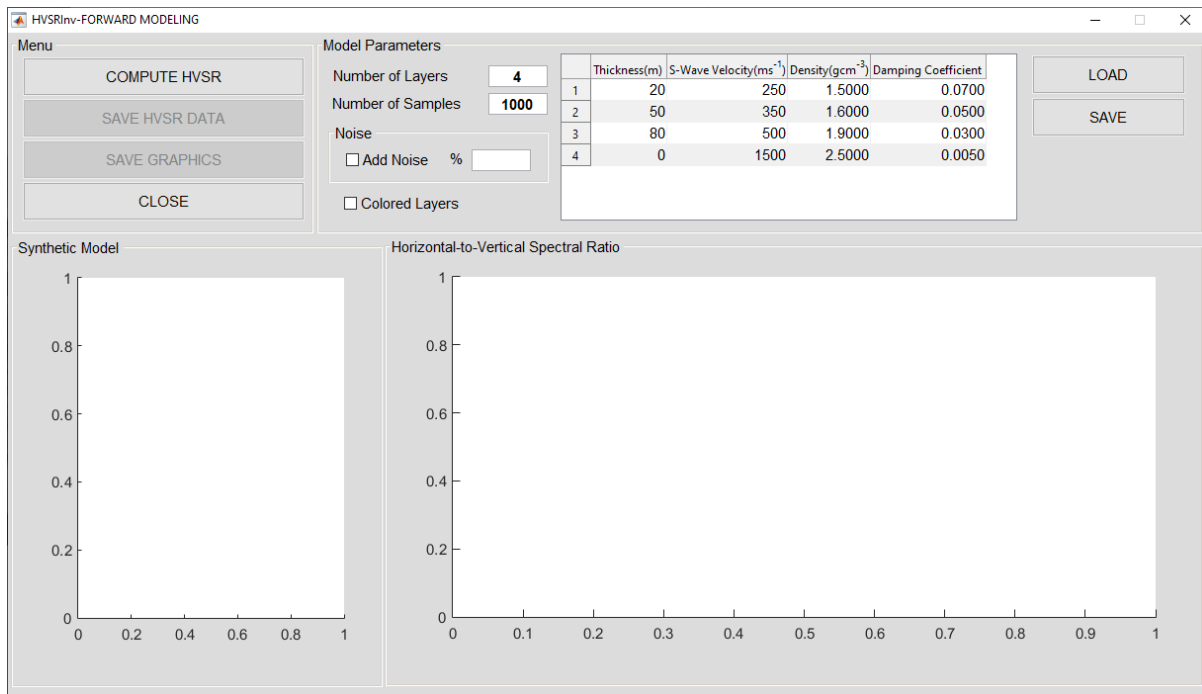
Click the "**COMPUTE HVSR**" button. HVSRInv uses the equivalent linear approach to compute the synthetic site response (Please, see Kafadar and İmamoğlu (2021) for theory of the equivalent linear approach).
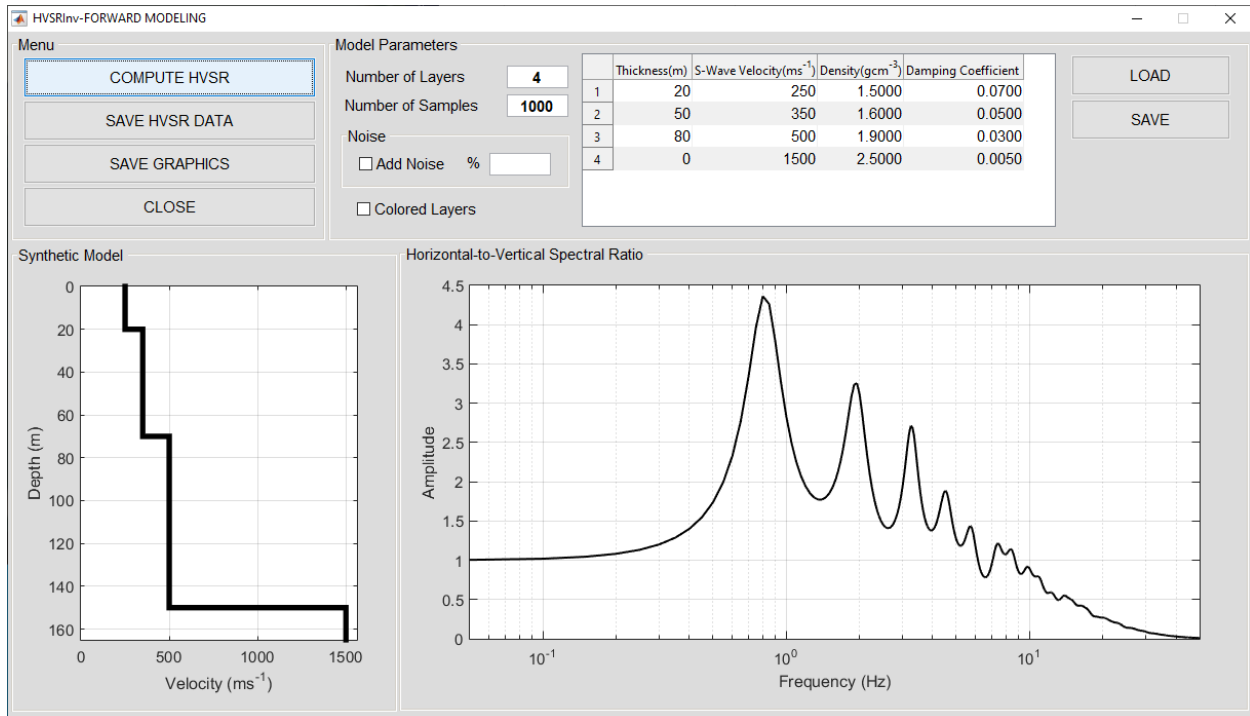
HVSRInv also allows computing the noisy synthetic horizontal-to-vertical spectral ratio. For this process, the user should click the "**Add Noise**" checkbox and enter the noise ratio, and then click the "**COMPUTE HVSR**" button.
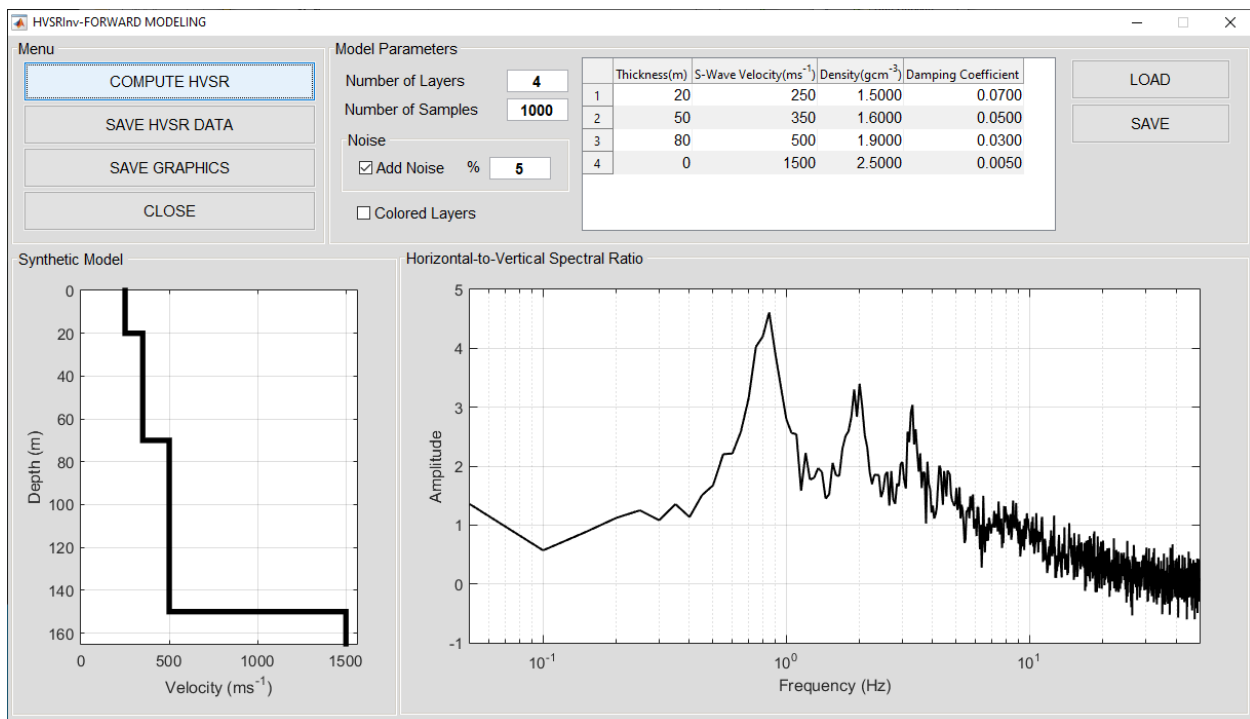
For colored illustration of the shear wave velocity profile, the "**Colored Layers**" checkbox can be utilized.
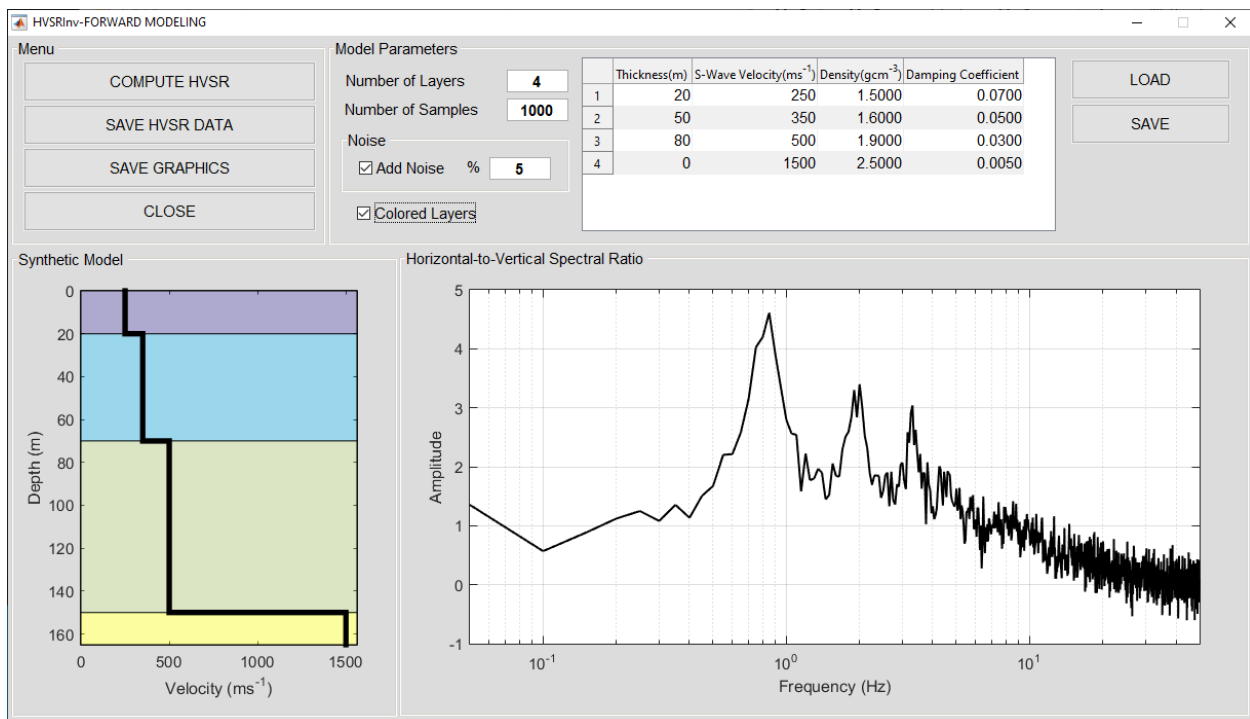
The "**SAVE**" button should be clicked to save the model parameters into a text file. Then, it should be entered a filename and clicked the Save button in the save dialog box.
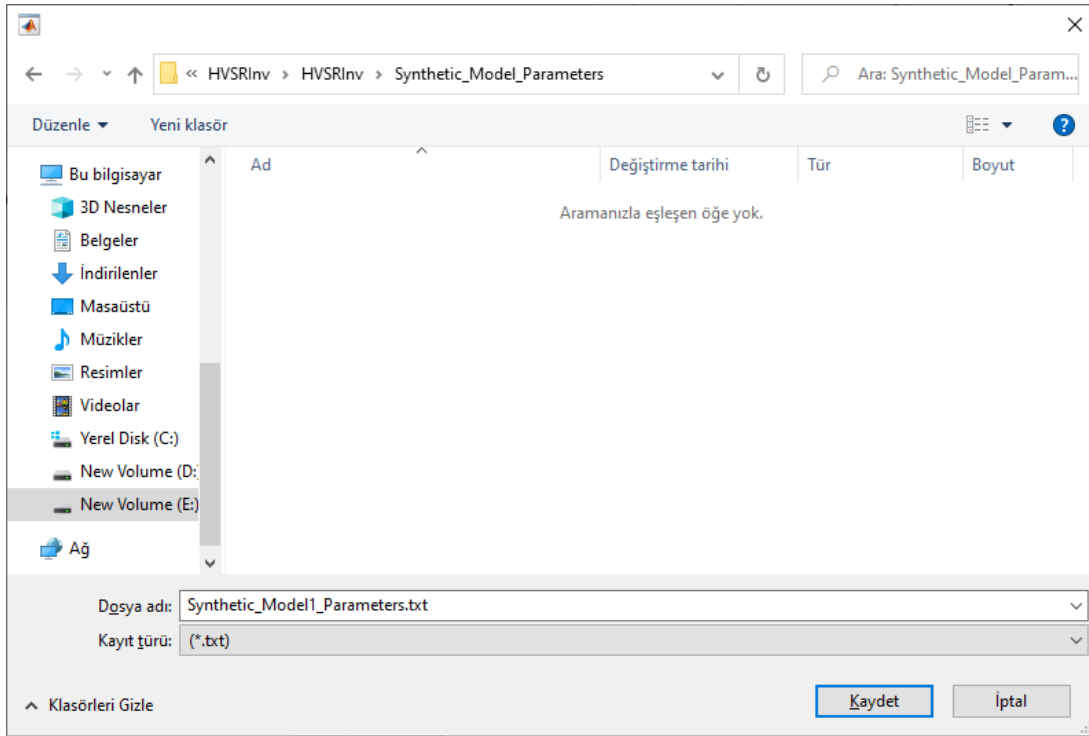
The input file, including the model parameters, is shown in following figure.

The calculated synthetic horizontal-to-vertical spectral ratio can be saved into a text file clicking the "**SAVE HVSR DATA**" button. The first and second columns in the HVSR input file are frequency values and HVSR data, respectively.

The graphics can be saved by means of the "**SAVE GRAPHICS**" button. The opened first save dialog box is for HVSR graphics, second one is for shear wave velocity model graphics. The output graphics are shown in following figures.
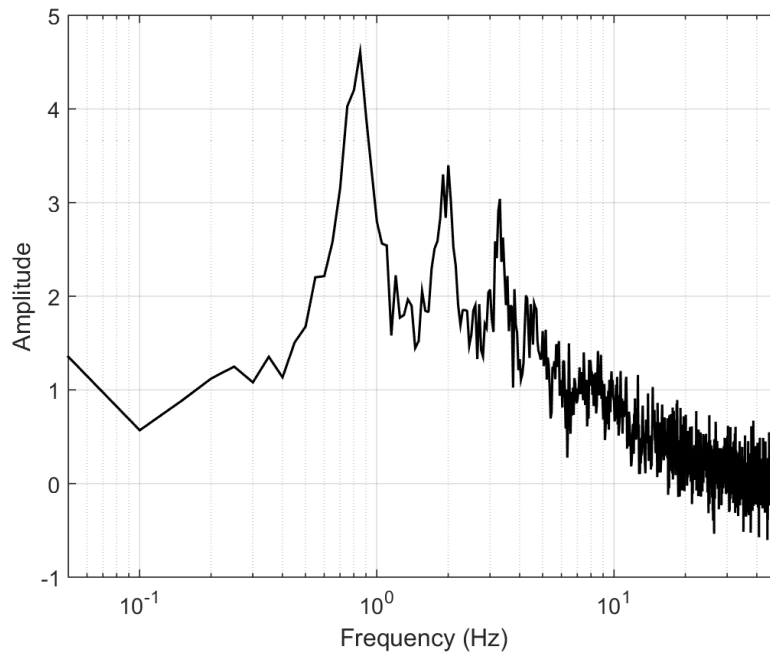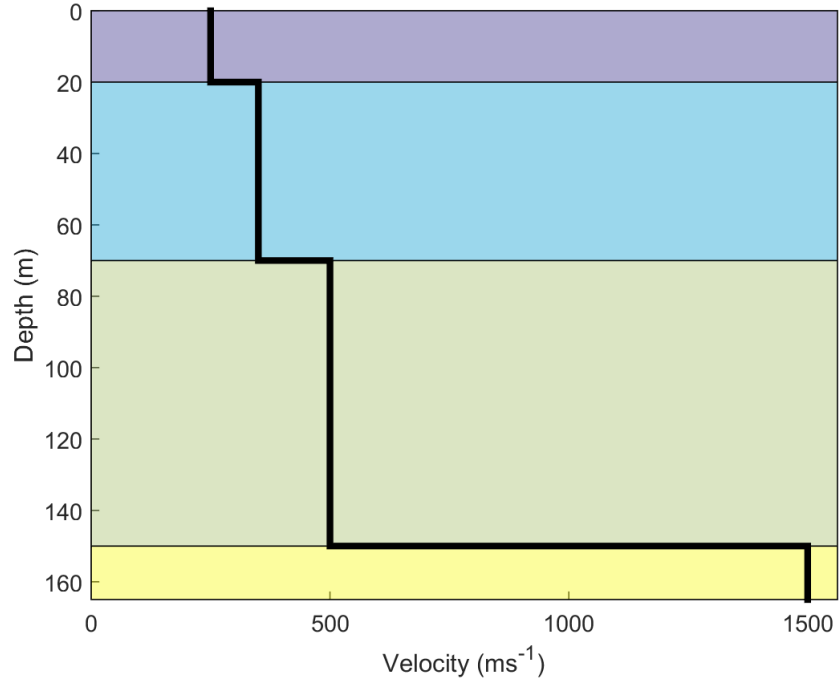
➕ Defining the model parameters by "LOAD" button

Click the "**LOAD**" button and select the input file including the model parameters.
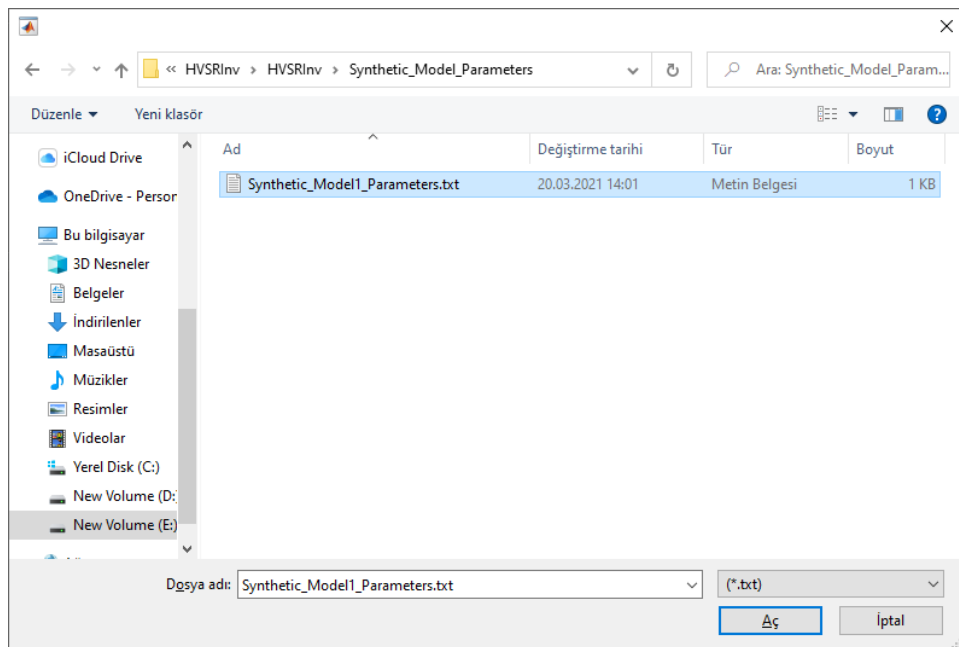
The "**INVERSION**" graphical interface consists of several graphical objects.
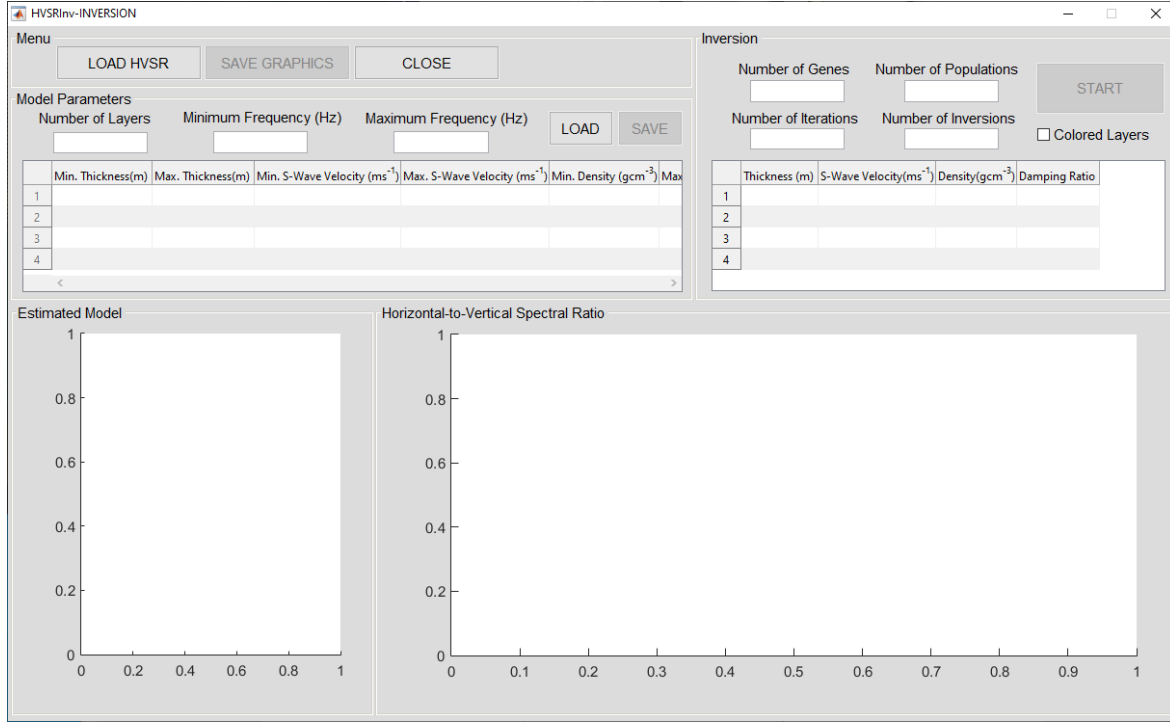
The first step for HVSR inversion is loading the HVSR data. To do this, the "**LOAD HVSR**" button is clicked and selected the input file.
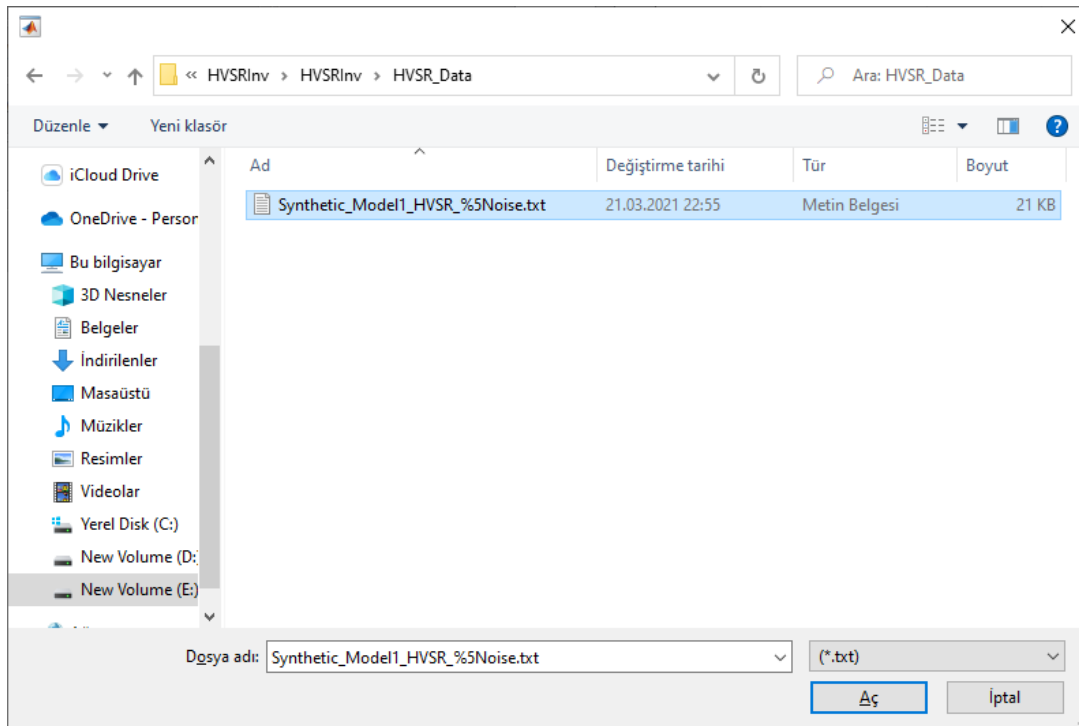
The input file consists of two columns: frequency values and HVSR data. The input file is as follows:
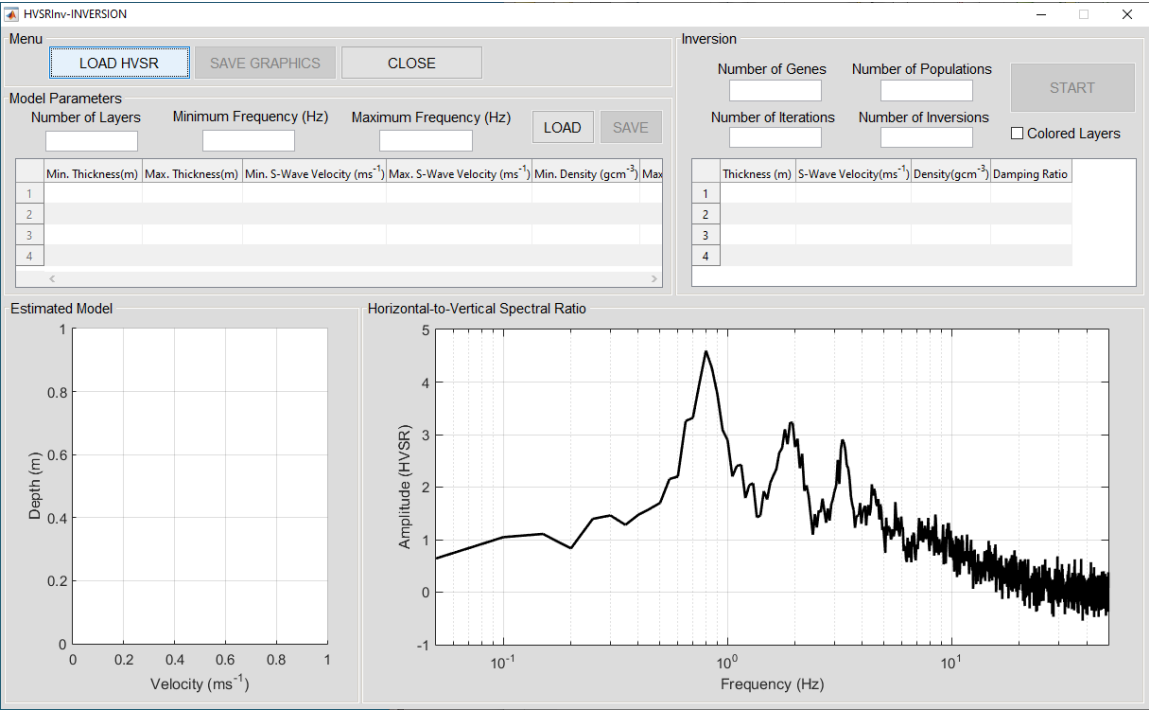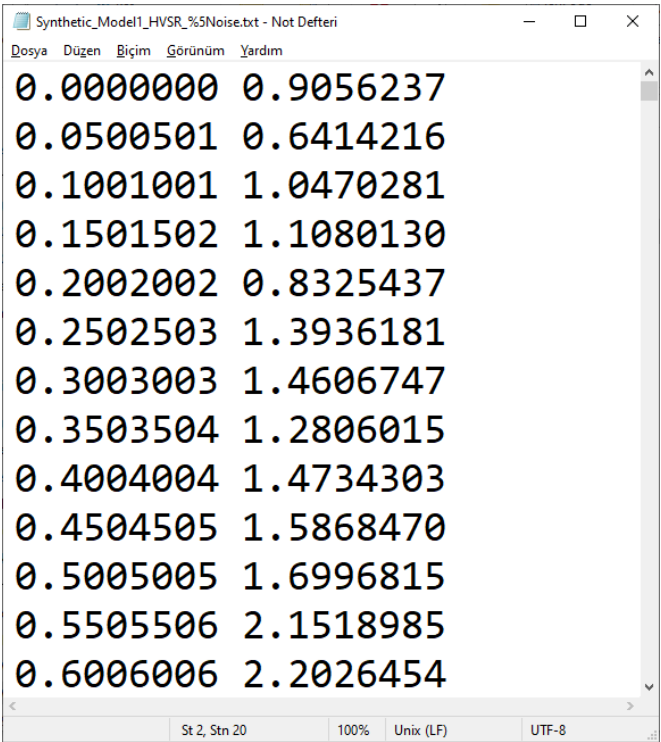
In the second step, the model parameters should be defined. The model parameters can be defined manually or loaded by means of an input file.

🔸 Defining the model parameters manually

Enter the number of layers, minimum frequency and maximum frequency values for inversion.
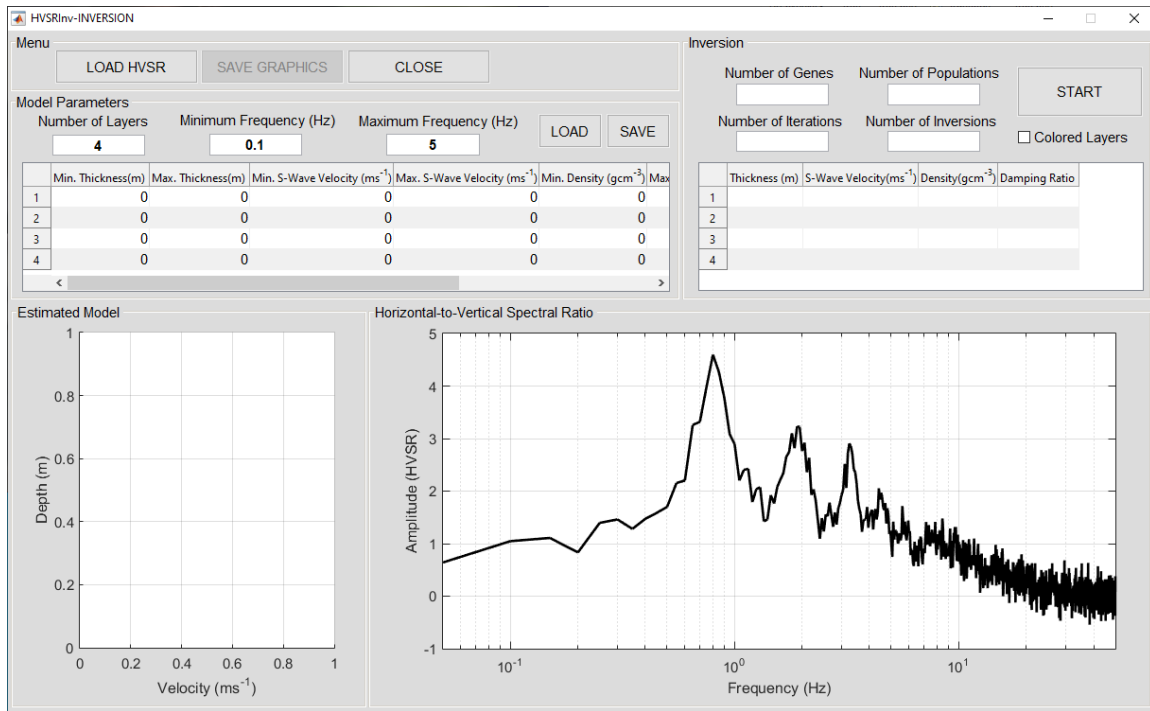
Then, enter the model parameters for each layers; min-max thicknesses, min-max S-wave velocities, min-max densities and min-max damping ratios.
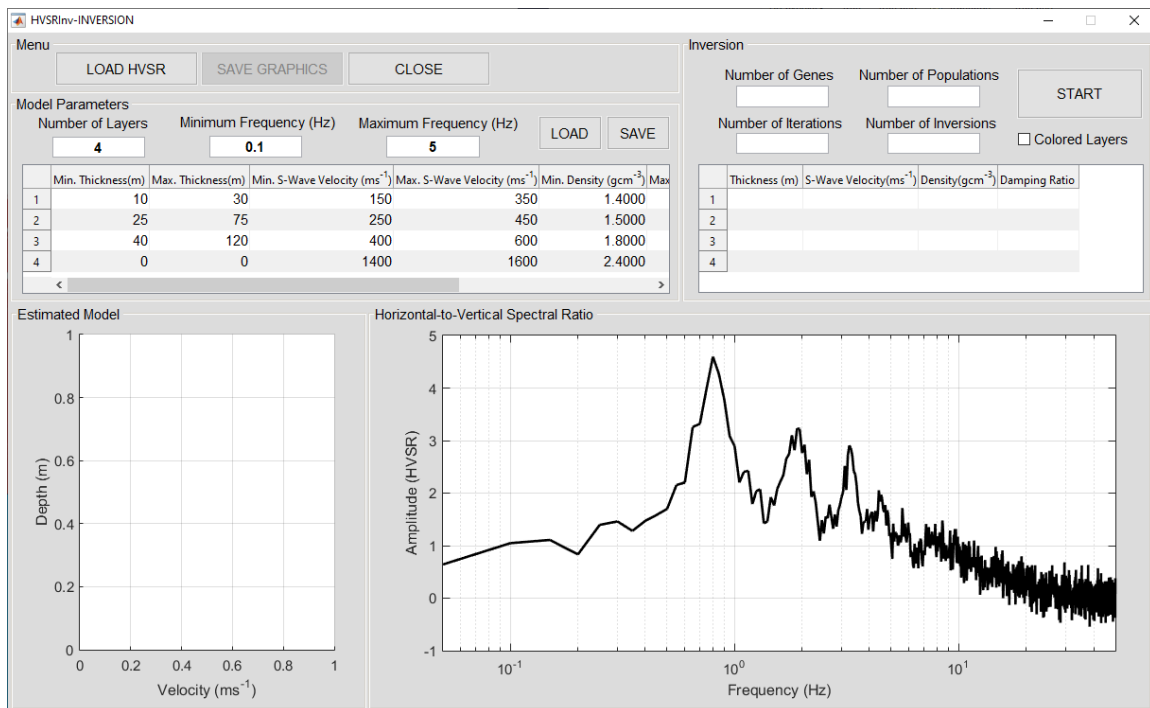
In the last step for inversion, the number of genes, populations, iterations and inversions should be entered and clicked the "**START**" button. It is not worthy that as the number of gene, population, iteration and inversion increases, the running time of the algorithm also increases. Please, see Kafadar and İmamoğlu (2021) for flowchart diagram and details of the used elitist genetic algorithm.
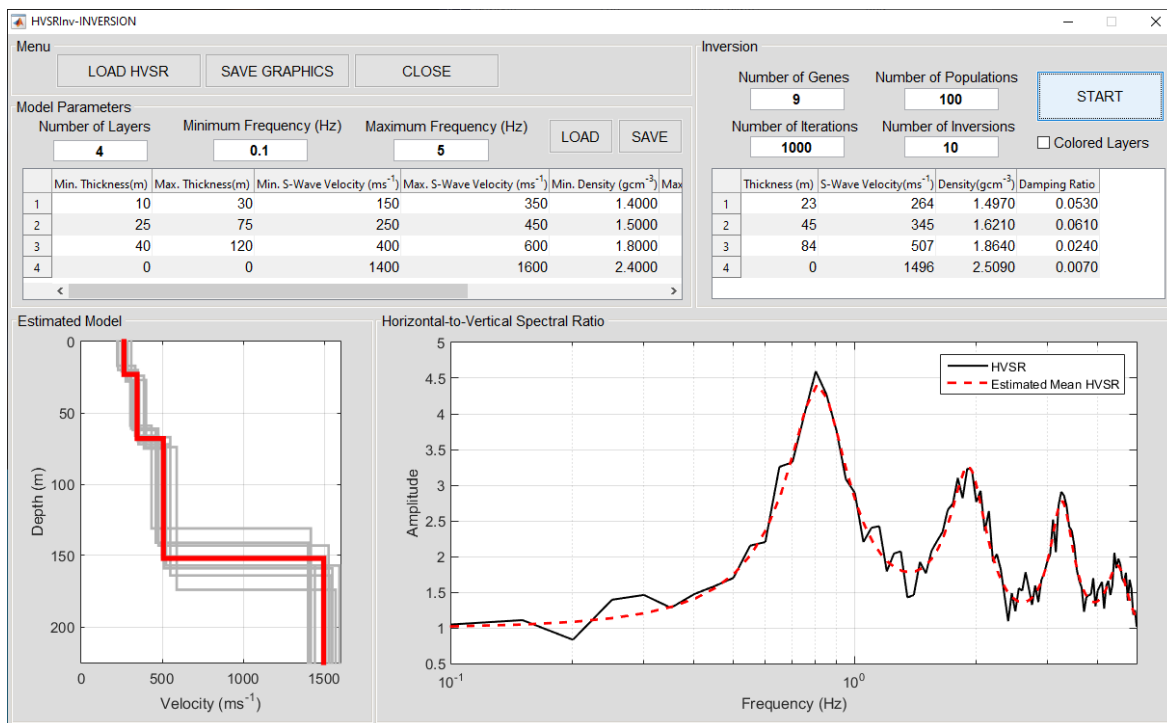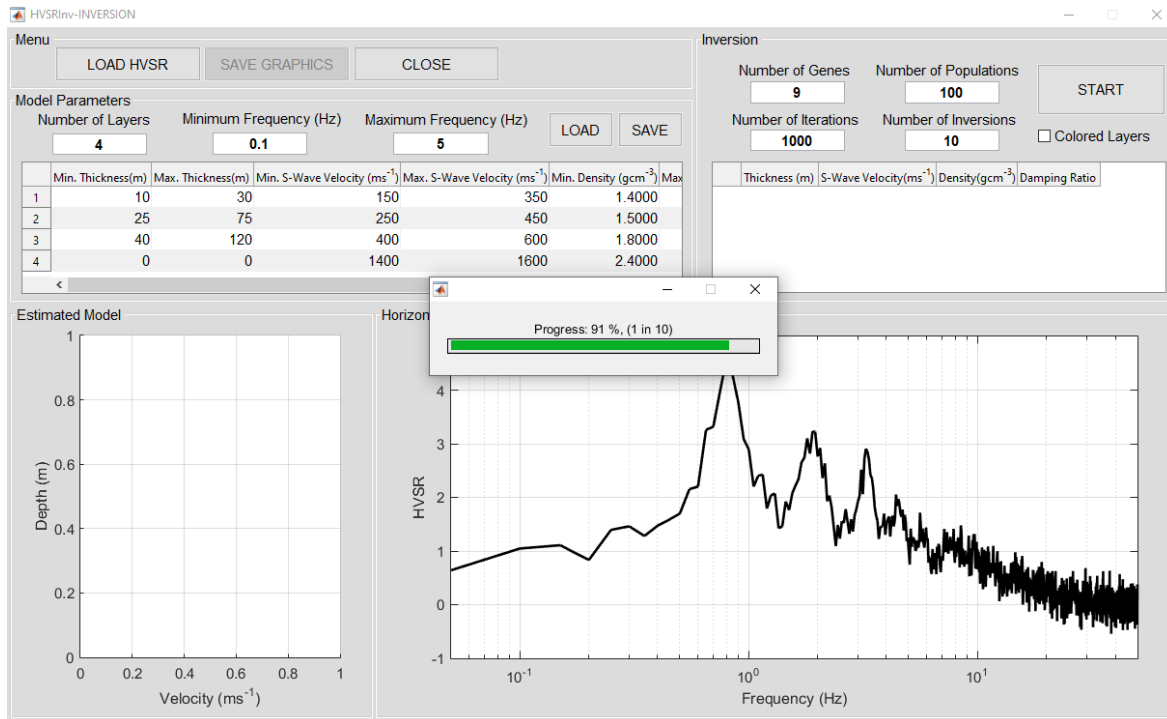
The "**SAVE**" button should be clicked to save the model parameters into a text file. Then enter a filename and click the Save button in the save dialog box.
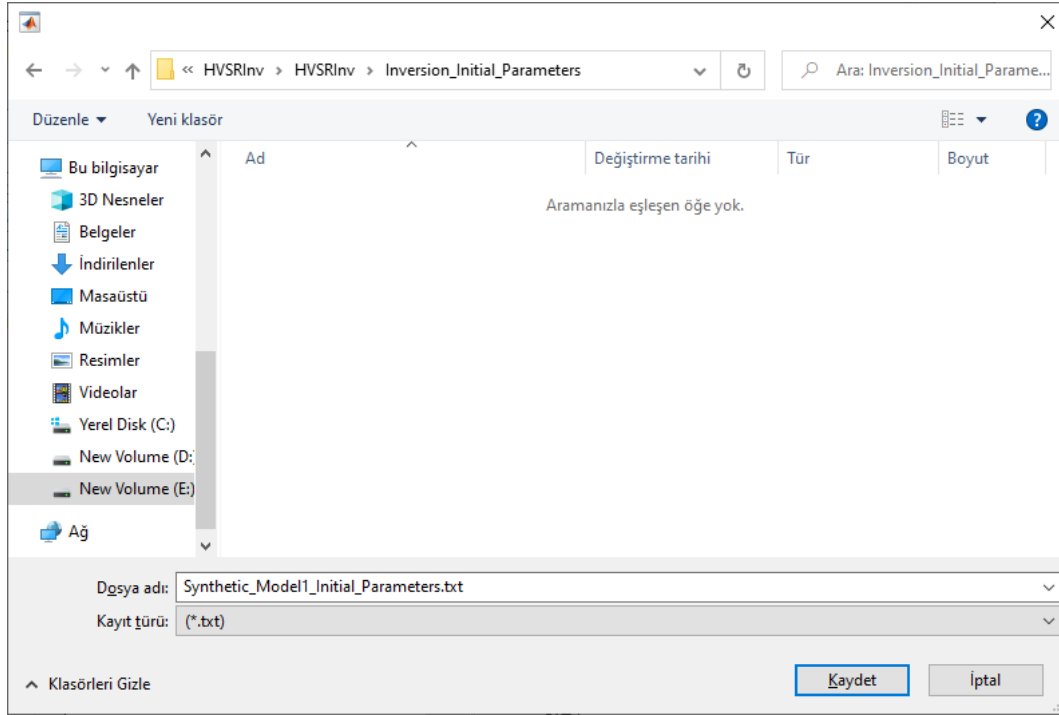
The format of the input file including the model parameters used for inversion is as follows:

For colored illustration of the shear wave velocity profile, the "**Colored Layers**" checkbox should be clicked.
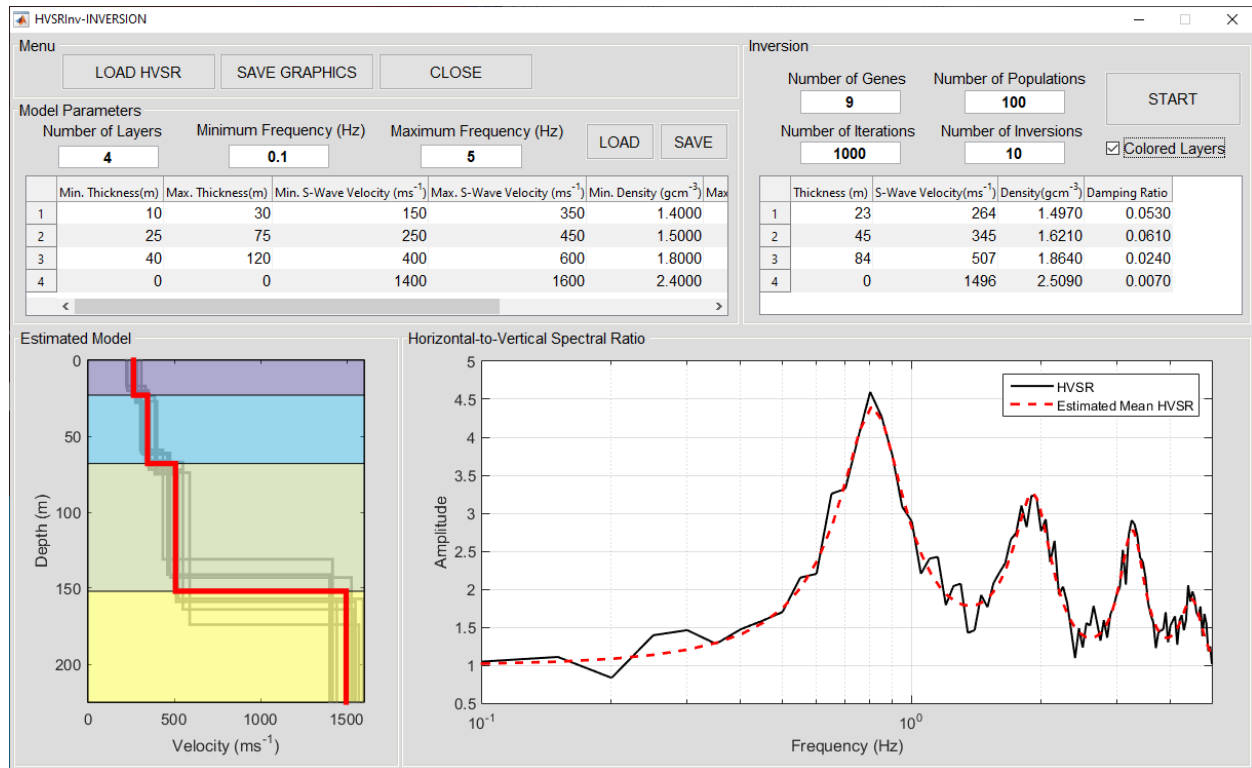
Besides, the graphics can be saved by means of the "**SAVE GRAPHICS**" button. The opened first save dialog box is for HVSR graphics, second one is for shear wave velocity model graphics.

⬦ Defining the model parameters by "LOAD" button

Click the "**LOAD**" button and select the input file including the model parameters.
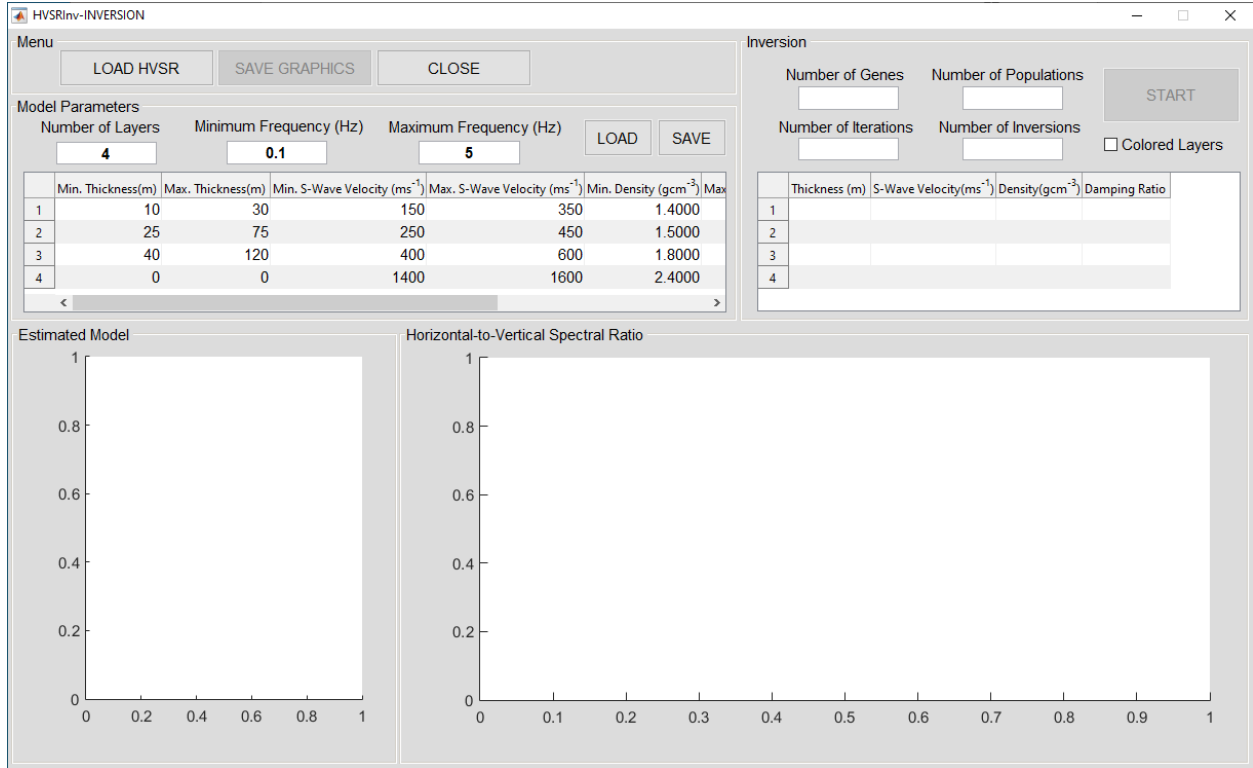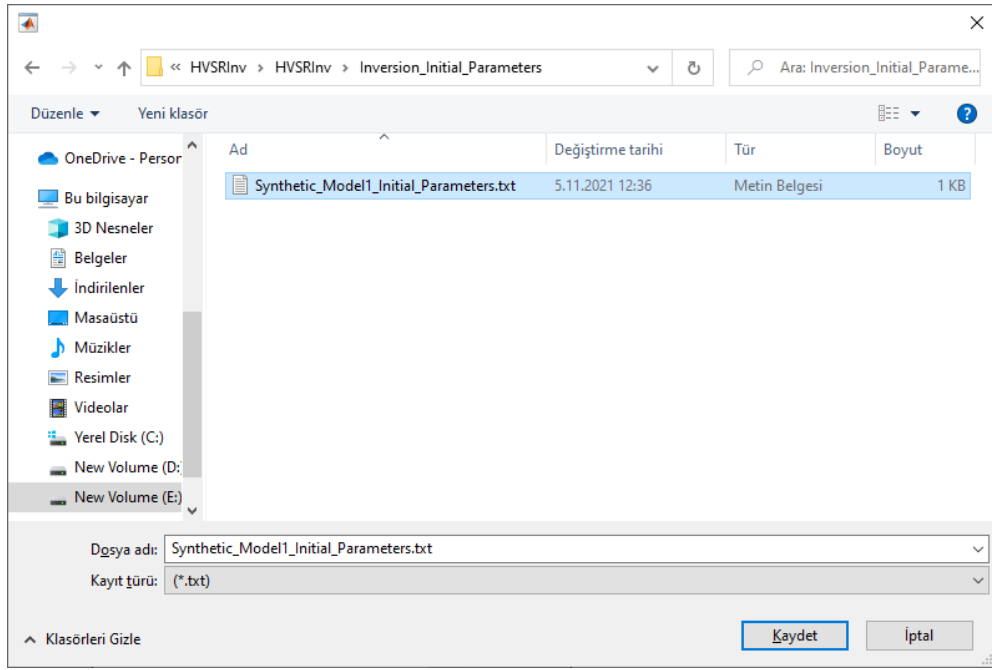
Then, as mentioned above, the number of gene, population, iteration and inversion should be entered and clicked the "**START**" button. When the inversions finish, an output file, including the model parameters and inversion results, is created. The format of the output file is as follows:

```
HVSR data file: Synthetic_Model1_HVSR_%5Noise_output.txt
Inversion parameters
Number_of_Genes: 9
Number_of_Populations: 100
Number_of_Iterations: 300
Number_of_Inversions: 5
Model parameters
Number_of_Layers: 4
Minimum_Frequency: 0.100
Maximum_Frequency: 5.000
Layer_No: 1
HMin HMax VMin VMax DenMin DenMax DampMin DampMax
10.000 30.000 150.000 350.000 1.400 1.600 0.005 0.090
Layer_No: 2
HMin HMax VMin VMax DenMin DenMax DampMin DampMax
25.000 75.000 250.000 450.000 1.500 1.700 0.003 0.070
Layer_No: 3
HMin HMax VMin VMax DenMin DenMax DampMin DampMax
40.000 120.000 400.000 600.000 1.800 2.000 0.001 0.050
Layer_No: 4
HMin HMax VMin VMax DenMin DenMax DampMin DampMax
0.000 0.000 1400.000 1600.000 2.400 2.600 0.010 0.007
Outputs
Inversion_No:1
H V Den Damp
27.0000 312.0000 1.4008 0.0471
50.0000 378.0000 1.6119 0.0658
89.0000 544.0000 1.9174 0.0192
0.0000 1573.0000 2.5926 0.0074
Inversion_No:2
H V Den Damp
27.0000 300.0000 1.4031 0.0636
47.0000 375.0000 1.5528 0.0490
81.0000 486.0000 2.0000 0.0146
0.0000 1434.0000 2.4982 0.0072
Inversion_No:3
H V Den Damp
22.0000 269.0000 1.5006 0.0607
48.0000 344.0000 1.6499 0.0448
84.0000 519.0000 1.8877 0.0318
0.0000 1474.0000 2.6000 0.0072
Inversion_No:4
H V Den Damp
26.0000 244.0000 1.5945 0.0592
30.0000 350.0000 1.6198 0.0700
87.0000 462.0000 1.8481 0.0133
0.0000 1404.0000 2.4067 0.0073
Inversion_No:5
H V Den Damp
22.0000 247.0000 1.5523 0.0426
44.0000 350.0000 1.5368 0.0680
82.0000 492.0000 1.8403 0.0255
0.0000 1534.0000 2.4274 0.0070
Average Model
H V Den Damp
25.0000 274.0000 1.4903 0.0546
44.0000 359.0000 1.5942 0.0595
85.0000 501.0000 1.8987 0.0209
0.0000 1484.0000 2.5050 0.0072
```

HVSRInv-Subroutines

Subroutine	Description
CalcHVSR	This function calculates the synthetic HVSR using the equivalent linear approximation explained in Section 2 in detail. Input arguments are the shear wave velocities *Vel* (array of *LayerNum* elements), thicknesses *Thi* (array of *LayerNum* – 1 elements), densities *Den* (array of *LayerNum* elements), damping ratios *Damp* (array of *LayerNum* elements) of layers and frequencies *Freq* (array of *SampleNum* elements), respectively.
CrossOver	This function performs the crossover operation in GA. The crossover is an operation that is used to obtain a new combination from two or more solutions. The input argument *Pop* indicates the population matrix to be crossed over.
Decode	This function decodes the model parameters used for inversion. The input arguments are lower *Lim1* and upper *Lim2* limits of the model parameters. The parameter *Pop* is the population matrix.
FindGenePos	This function finds the positions of genes using the position vector *Pos*.
GoodnessofFit	This function calculates the fit between the synthetic and observed data. The parameters *SynData* and *ObsData* are the synthetic and observed data, respectively.
Inversion	This function applies the inversion operation using an elitist GA. The input parameters are number of layers *LayerNum*, number of inversions *InvNum*, number of iterations *IterNum*, number of populations *PopNum*, number of genes *GeneNum*, frequencies *Freq*, HVSR data *HVSRData*, minimum *FreqMin* and maximum *FreqMax* frequency values for inversion, number of samples *SampleNum*, model parameters *InitModData* for inversion (array of *LayerNum* rows and eight columns, each rows includes the parameters minimum and maximum thicknesses, minimum and maximum shear wave velocities, minimum and maximum densities, minimum and maximum damping ratios) and plot axes *Handle*, respectively.
Mutation	This function changes a gene of the old generation with desired probability. The mutation operator is used to maintain genetic diversity similar to biological mutation. The input parameters *OldGen* and *Prob* are the old generation and probability value, respectively.
Selection	This function performs a selection using the fitness values of the individuals. The parameters *Fit* and *Pop* are fitness values of the individuals and population matrix, respectively.