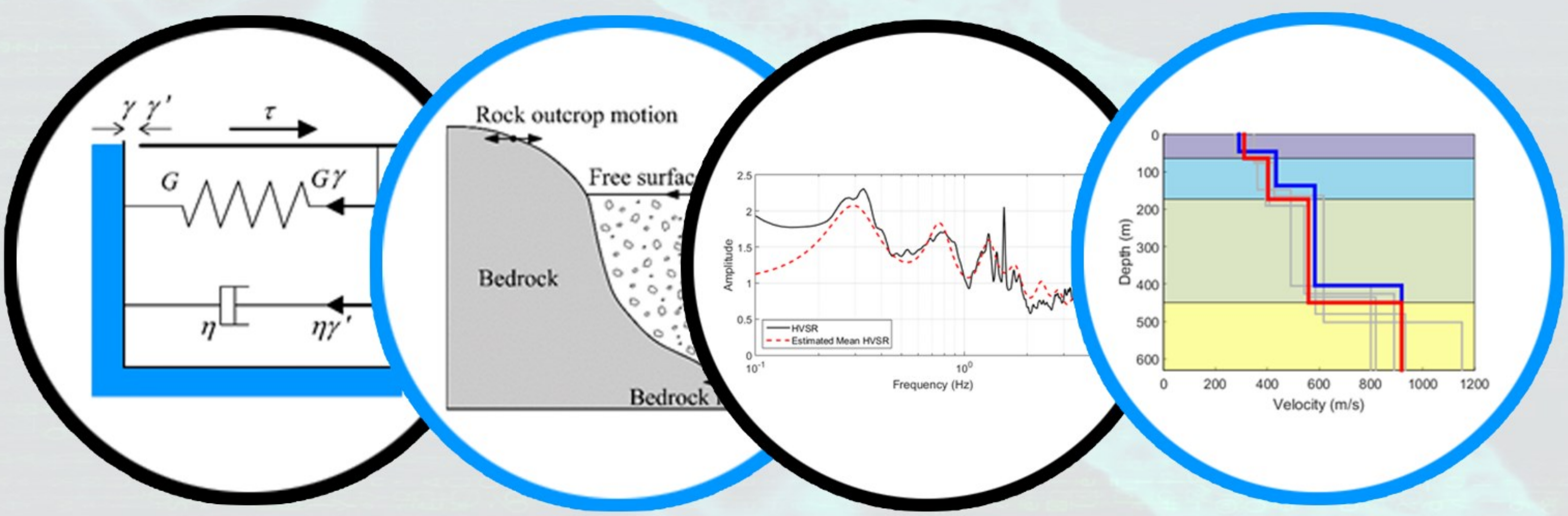
HVSRInv

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

Özkan Kafadar and Çağrı İmamoğlu

USER GUIDE

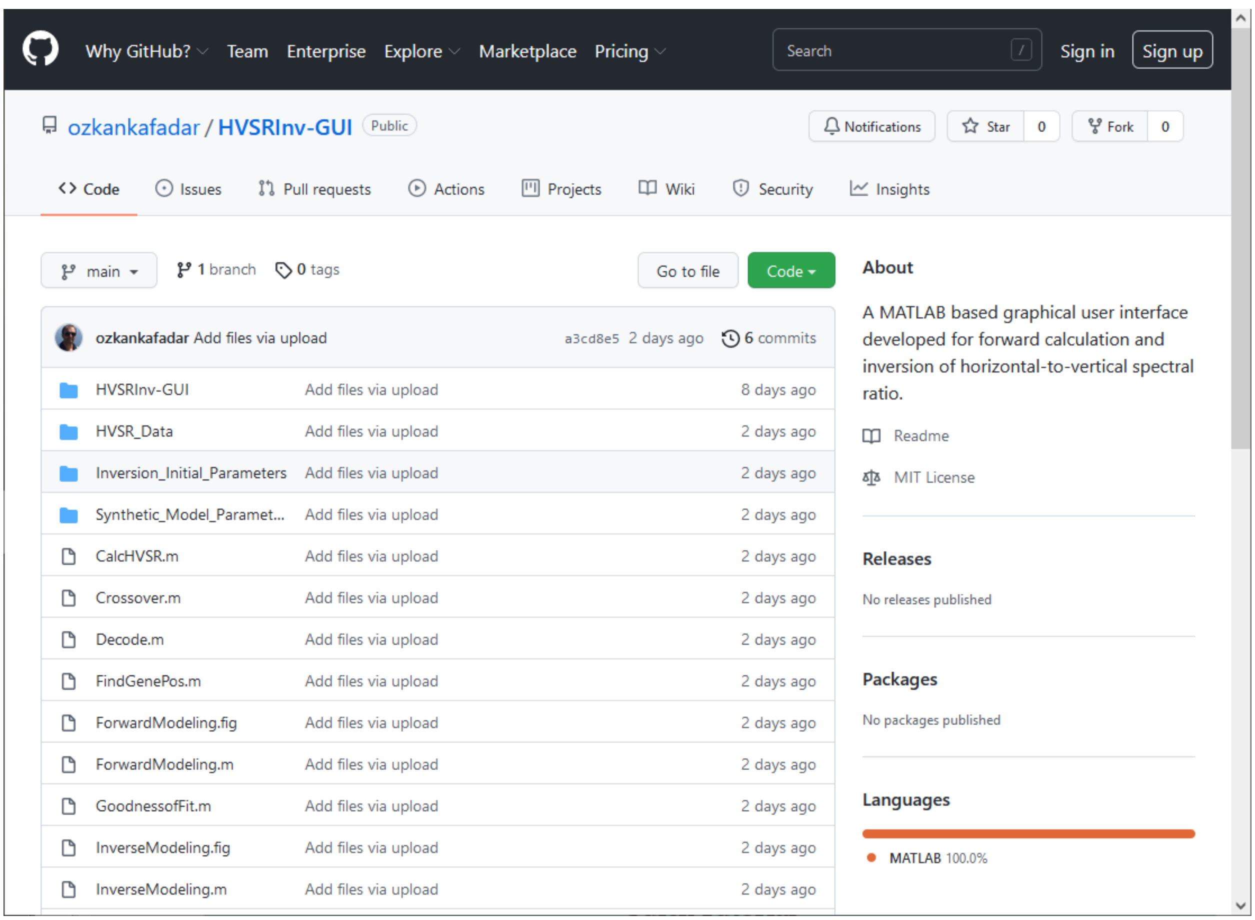


HVSRInv User Manual

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 (2021) for more detailed information.

Authors: Özkan Kafadar and Çağrı İmamoğlu

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



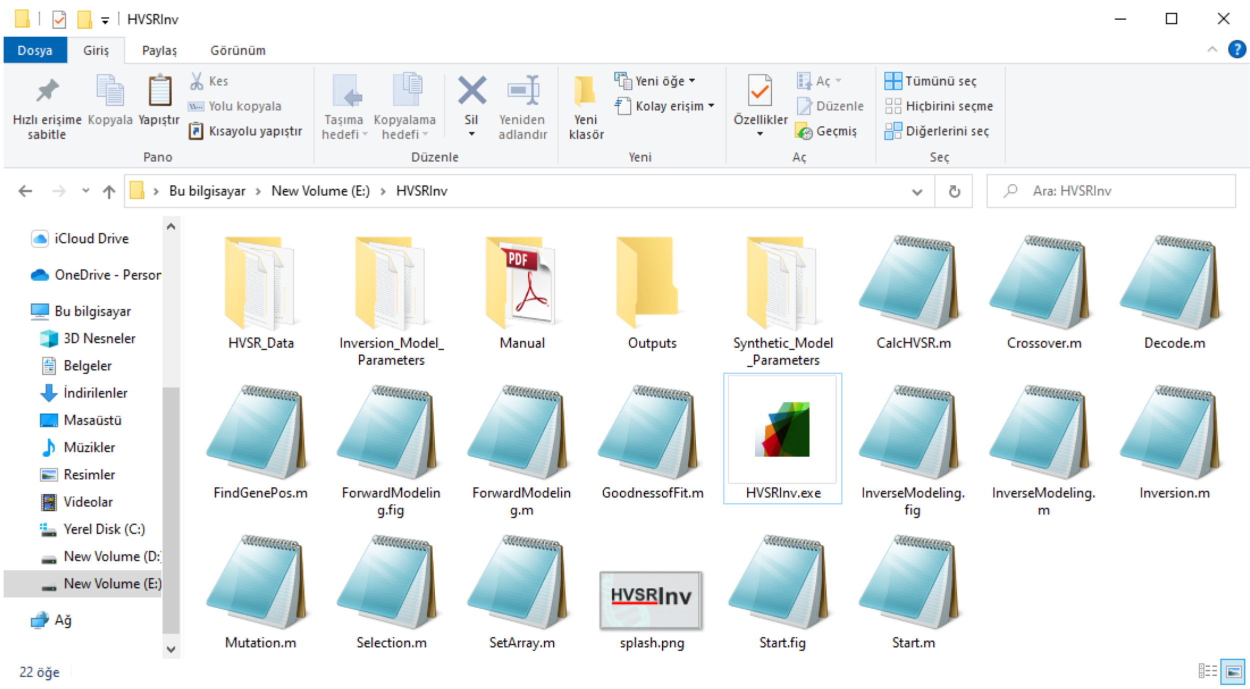
Quick Tutorial

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 in the Exe folder.

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



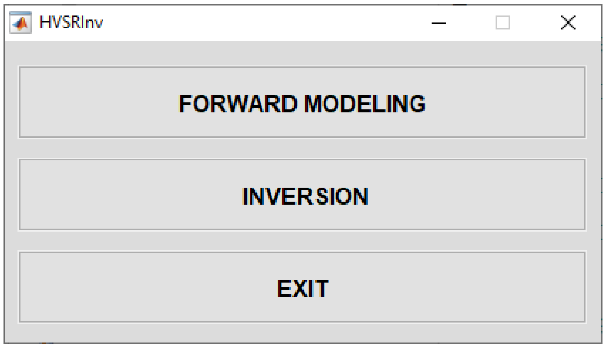
Main Interface

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.



HVSRInv-FORWARD MODELING

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.

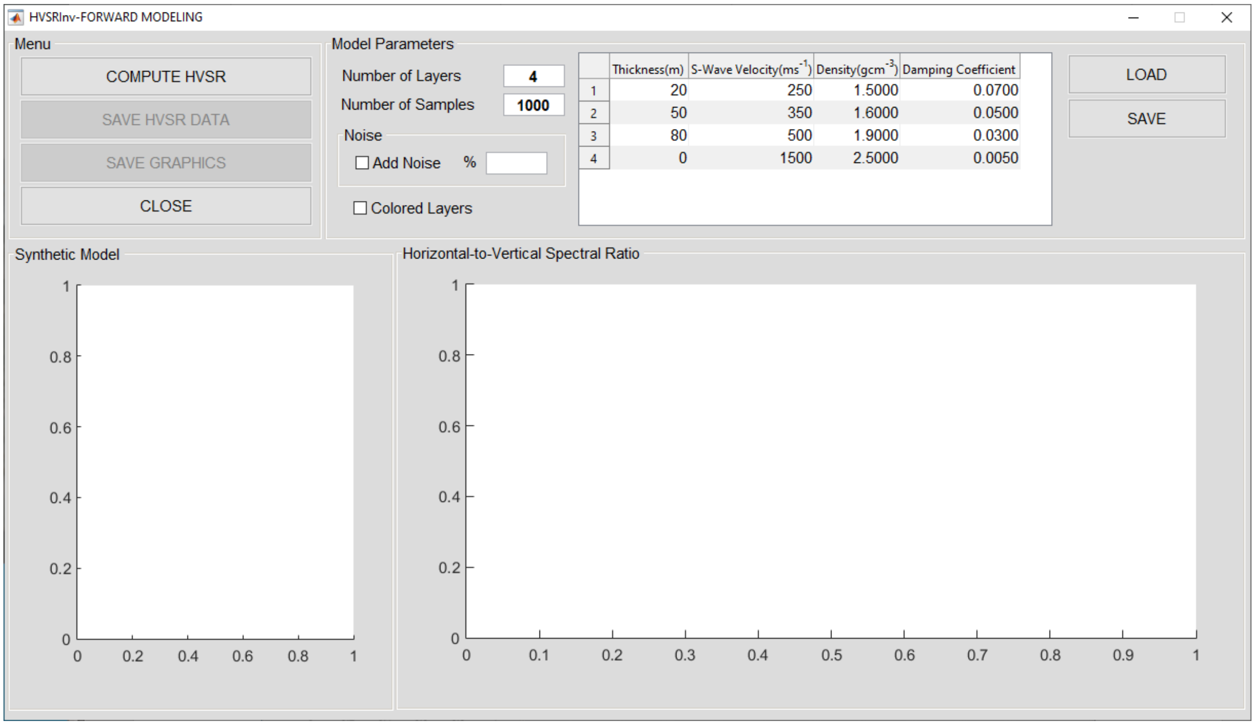
Defining the model parameters manually

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 formulas based on *Vs*-*Qs* correlations defined by Archuleta and Liu (2004) and expressed as follows:

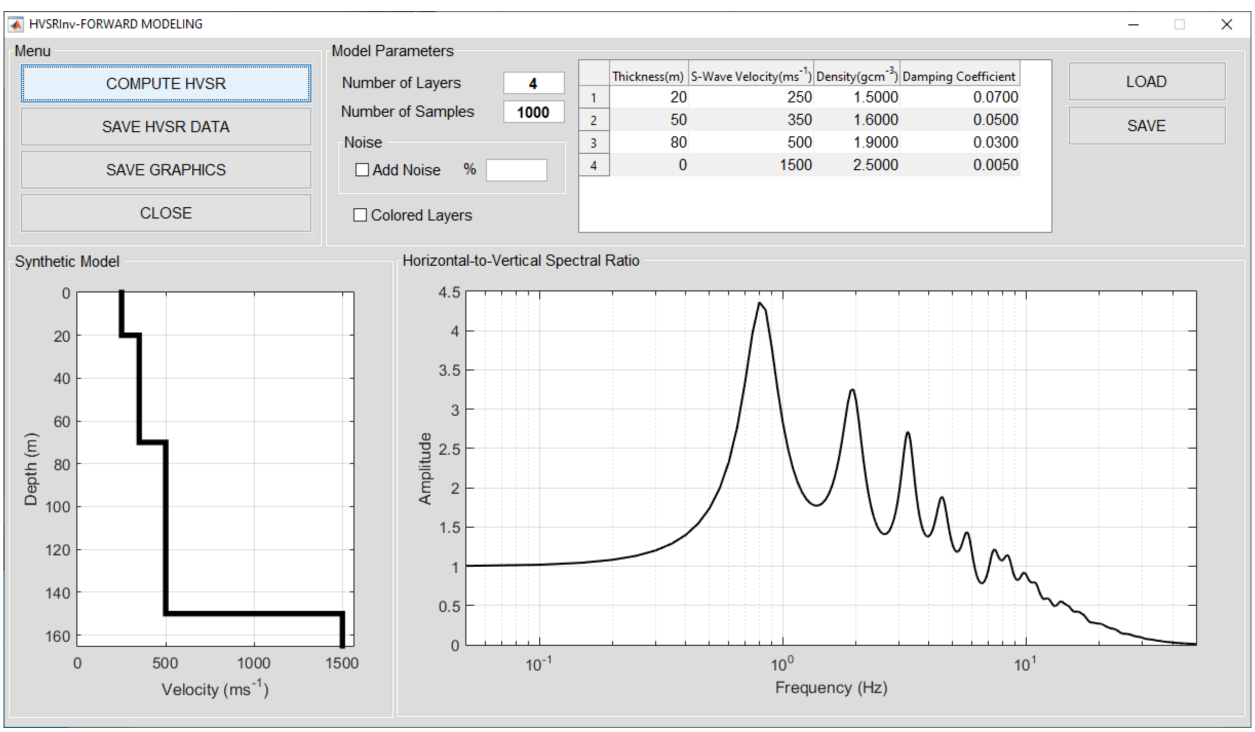
$$\xi = \frac{1}{2Qs}, \mathrm{Qs} = \begin{cases} 0.06Vs & Vs \le 1000\ ms^{-1} \\ 0.04Vs & 1000\ ms^{-1} < Vs < 2000\ ms^{-1} \\ 0.16Vs & Vs \ge 2000\ ms^{-1} \end{cases}.$$

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

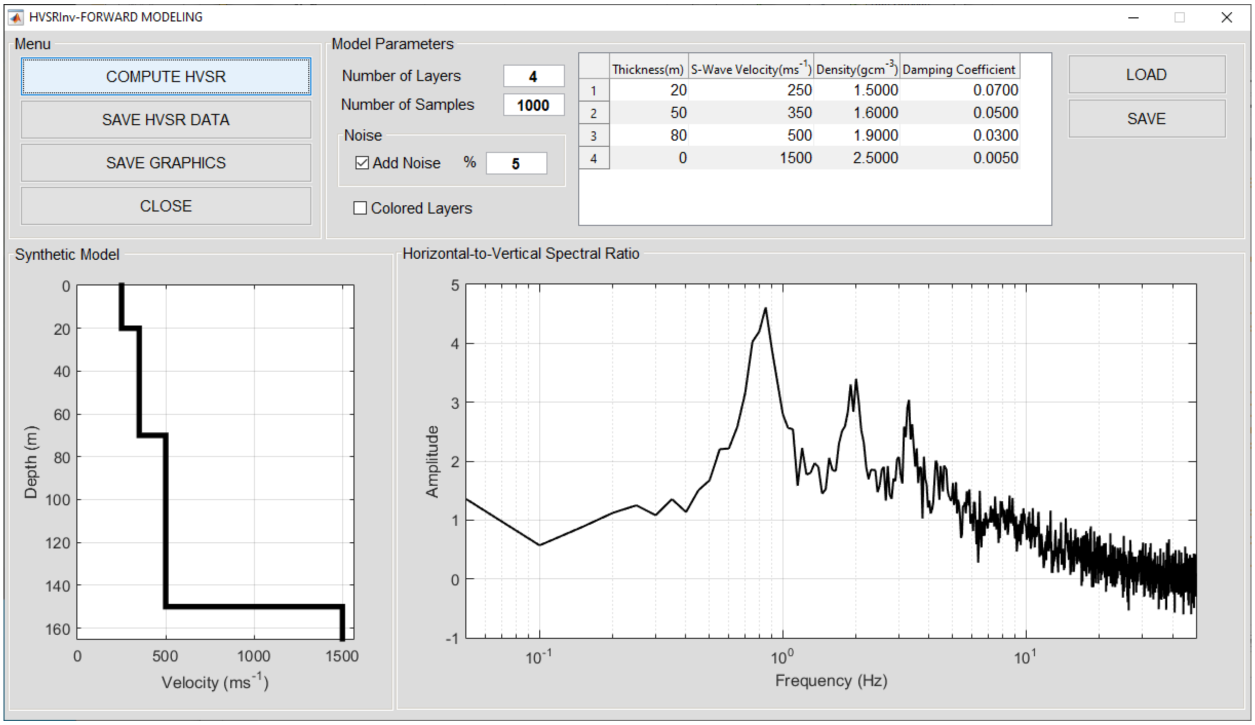
$$\rho = 0.85Vs^{0.14}.$$



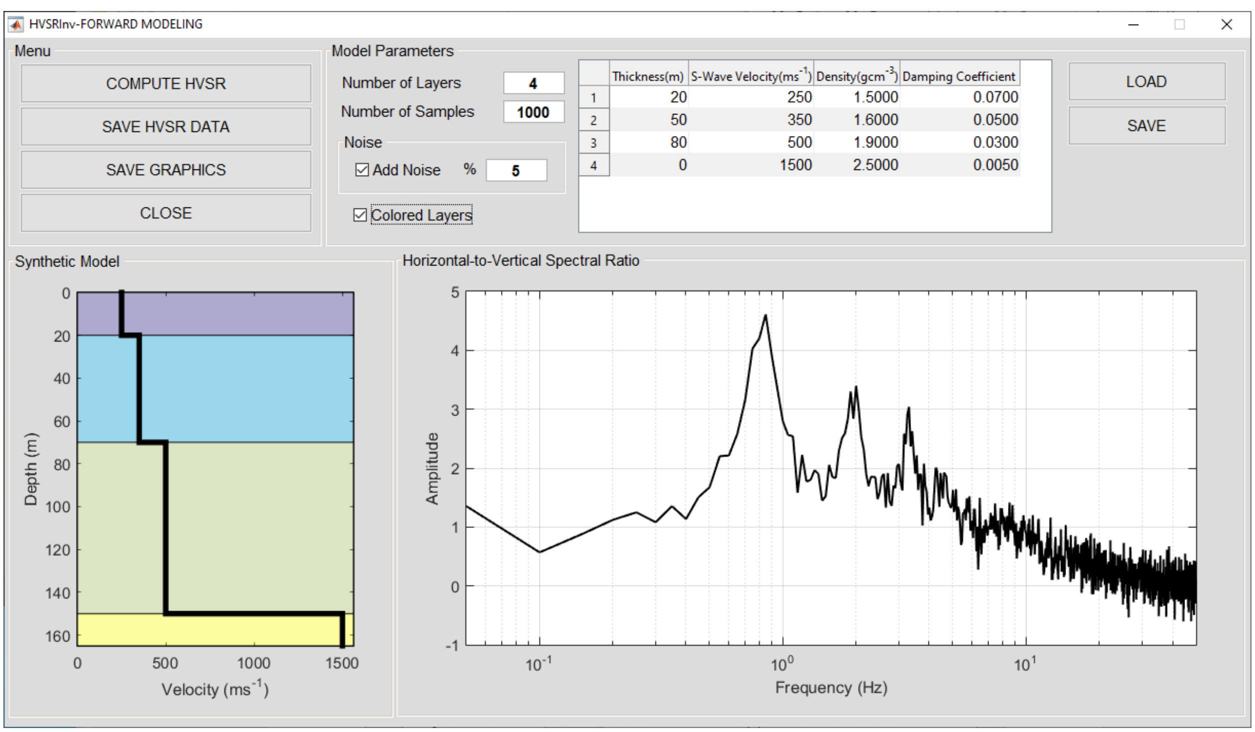
Click the "**COMPUTE HVSR**" button. HVSRInv uses the equivalent linear approach to compute the synthetic site response (Please, see Kafadar and İmamoğlu (2021) for theory of the equivalent linear approach).



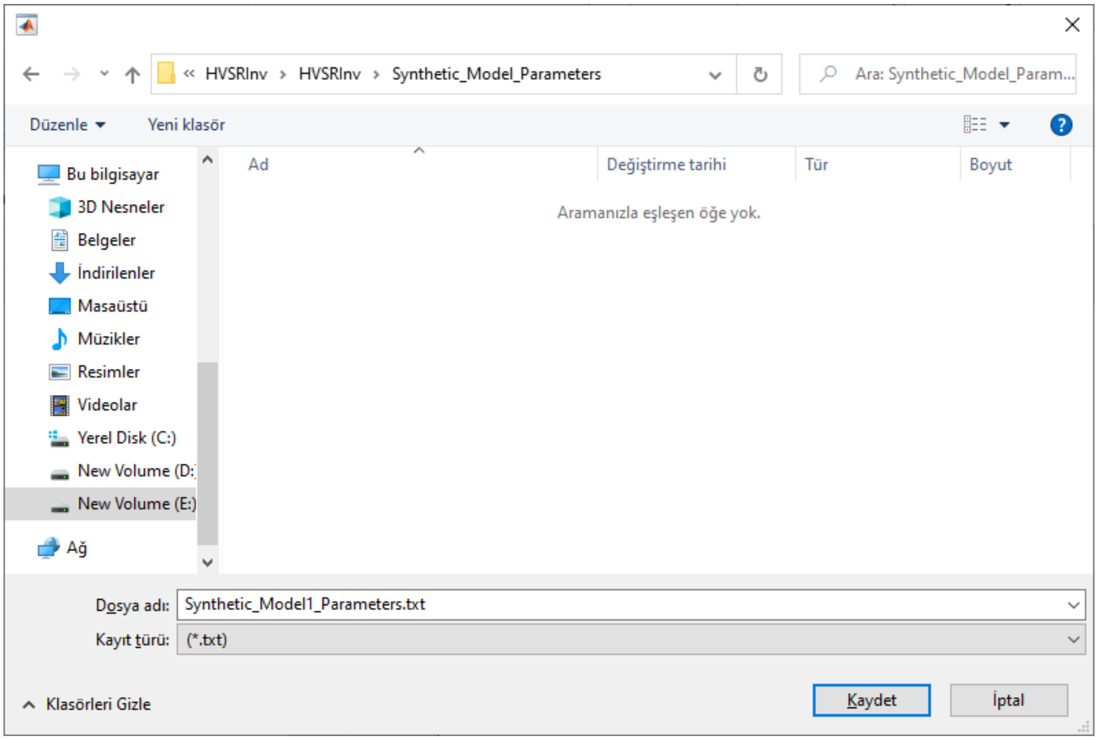
HVSRInv also allows computing the noisy synthetic horizontal-to-vertical spectral ratio. For this process, the user should click the "**Add Noise**" checkbox and enter the noise ratio, and then click the "**COMPUTE HVSR**" button.



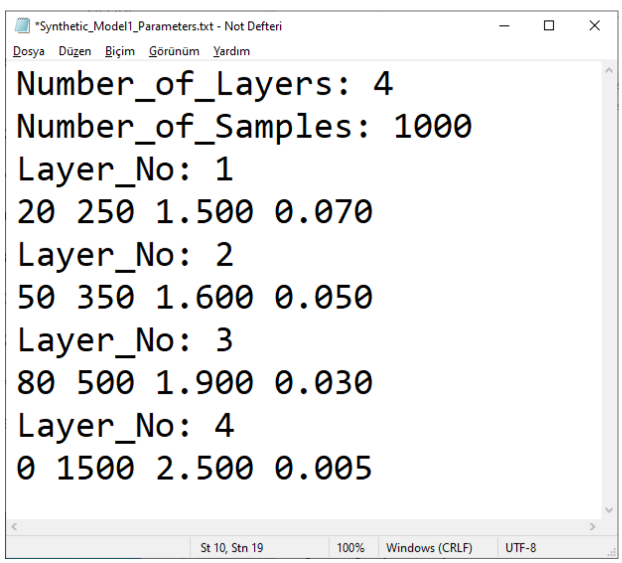
For colored illustration of the shear wave velocity profile, the "**Colored Layers**" checkbox can be utilized.



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.

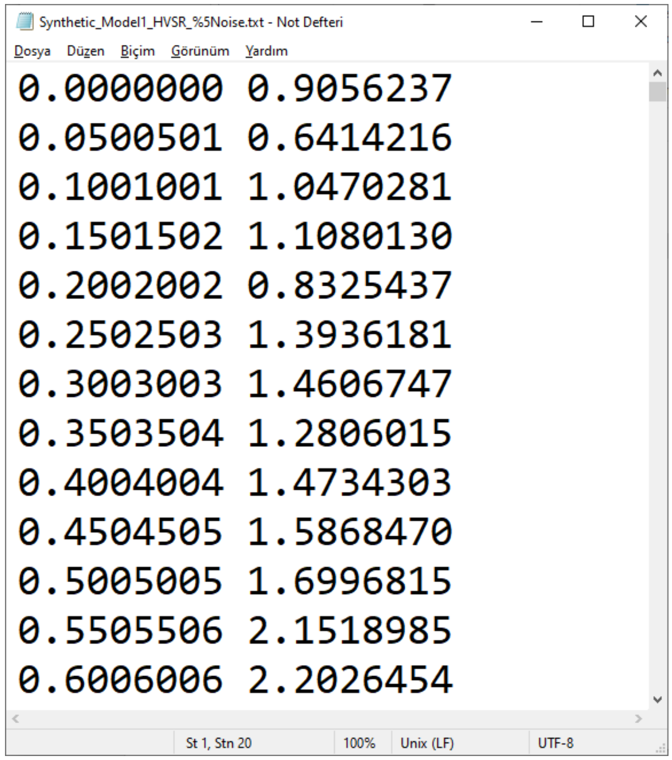


The input file, including the model parameters, is shown in following figure.


*Synthetic_Model1_Parameters.txt - Not Defteri

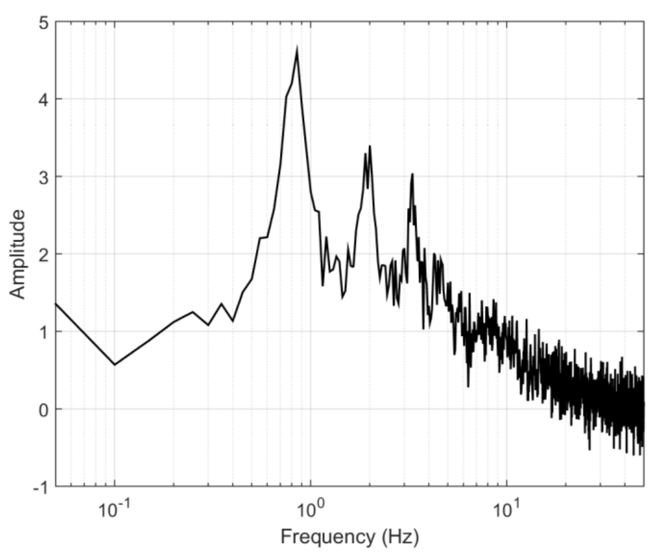
```
Number_of_Layers: 4
Number_of_Samples: 1000
Layer_No: 1
20 250 1.500 0.070
Layer_No: 2
50 350 1.600 0.050
Layer_No: 3
80 500 1.900 0.030
Layer_No: 4
0 1500 2.500 0.005
```

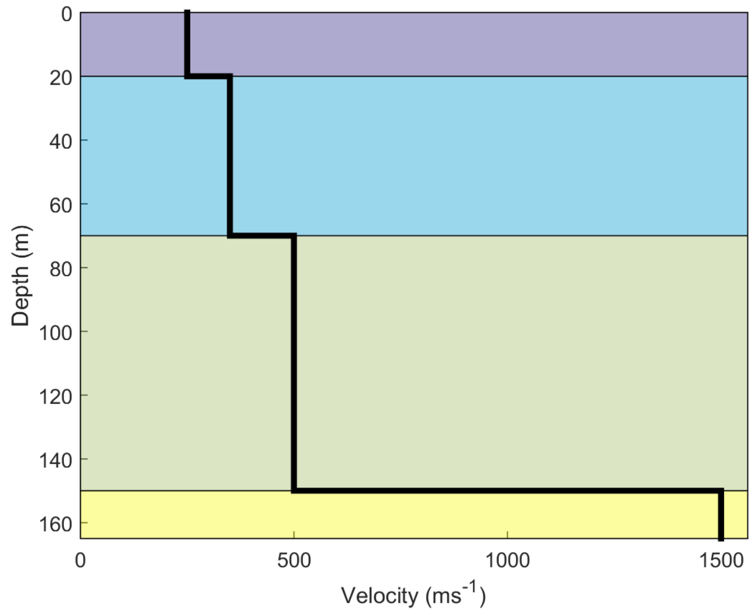
The calculated synthetic horizontal-to-vertical spectral ratio can be saved into a text file clicking the "**SAVE HVSR DATA**" button. The first and second columns in the HVSR input file are frequency values and HVSR data, respectively.




```
0.0000000 0.9056237
0.0500501 0.6414216
0.1001001 1.0470281
0.1501502 1.1080130
0.2002002 0.8325437
0.2502503 1.3936181
0.3003003 1.4606747
0.3503504 1.2806015
0.4004004 1.4734303
0.4504505 1.5868470
0.5005005 1.6996815
0.5505506 2.1518985
0.6006006 2.2026454
```

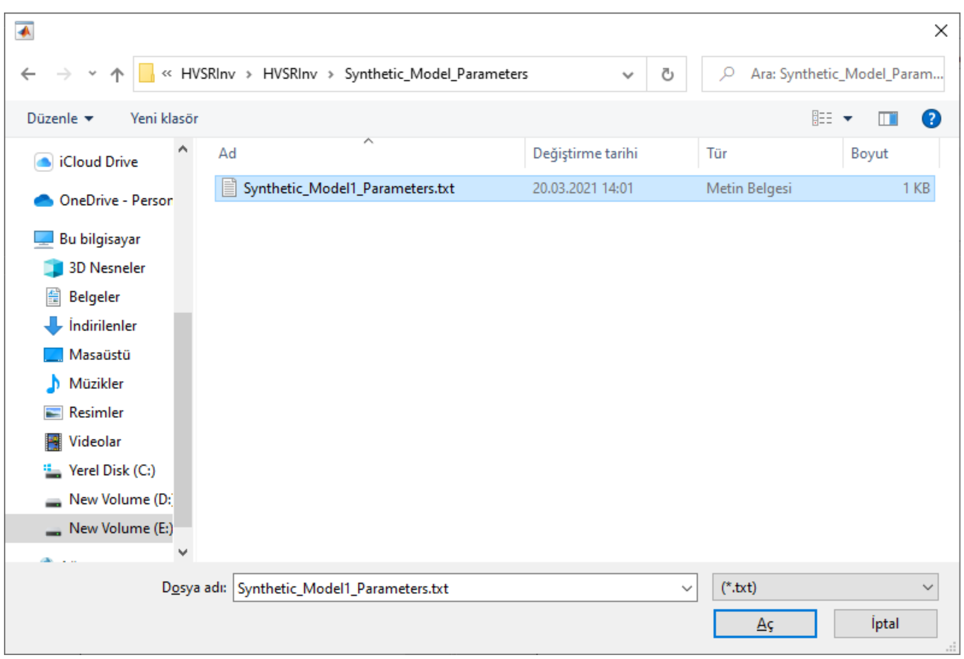
The graphics can be saved by means of the "**SAVE GRAPHICS**" button. The opened first save dialog box is for HVSR graphics, second one is for shear wave velocity model graphics. The output graphics are shown in following figures.





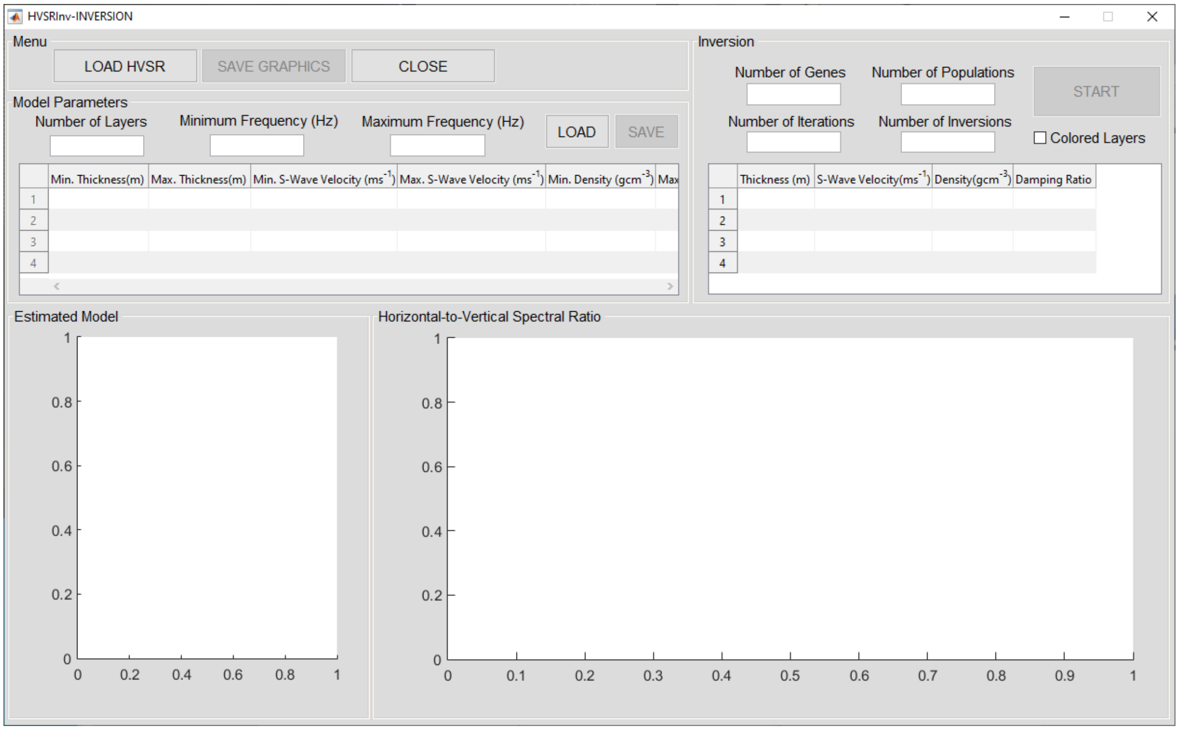
Defining the model parameters by "LOAD" button

Click the "**LOAD**" button and select the input file including the model parameters.

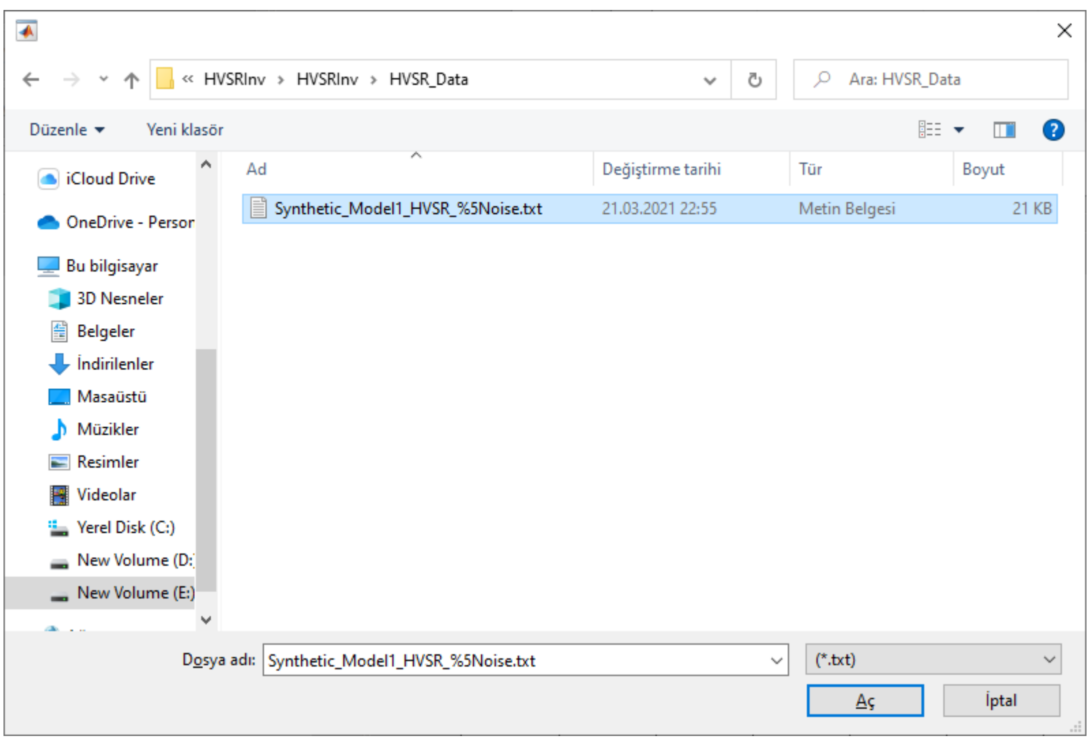


HVSRInv-INVERSION

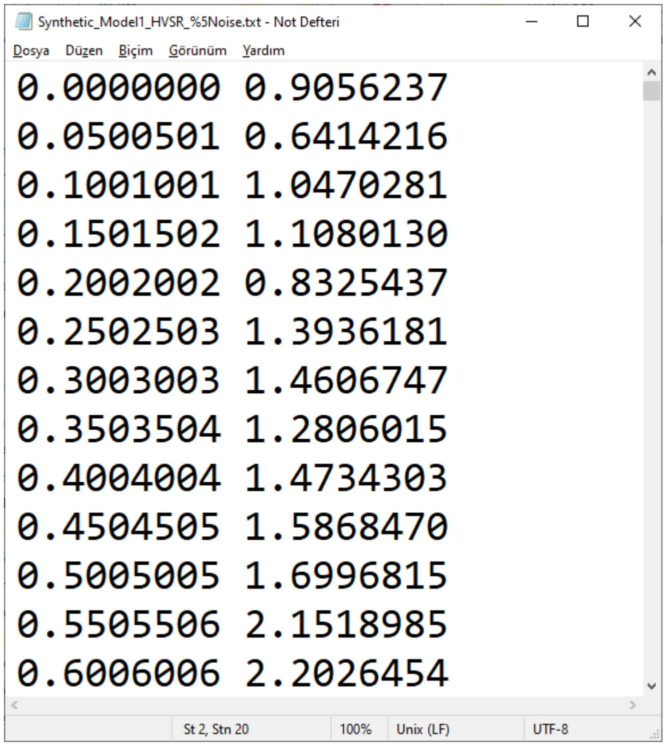
The “**INVERSION**” graphical interface consists of several graphical objects.



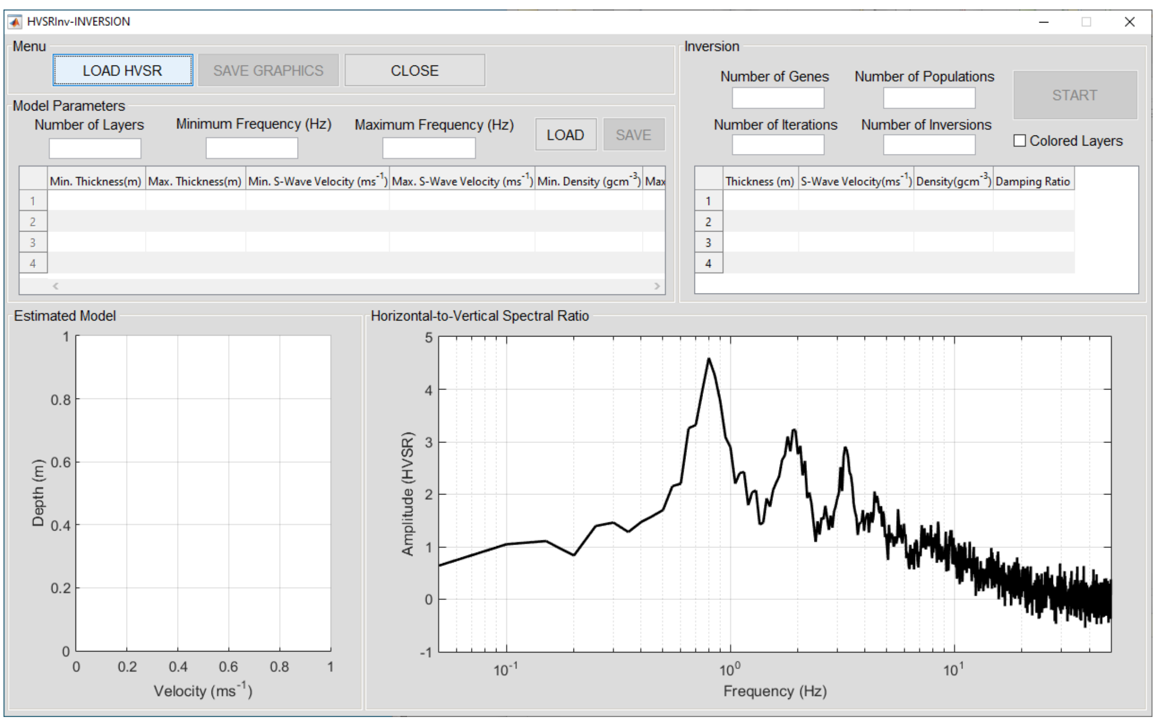
The first step for HVSR inversion is loading the HVSR data. To do this, the “**LOAD HVSR**” button is clicked and selected the input file.



The input file consists of two columns: frequency values and HVSR data. The input file is as follows:



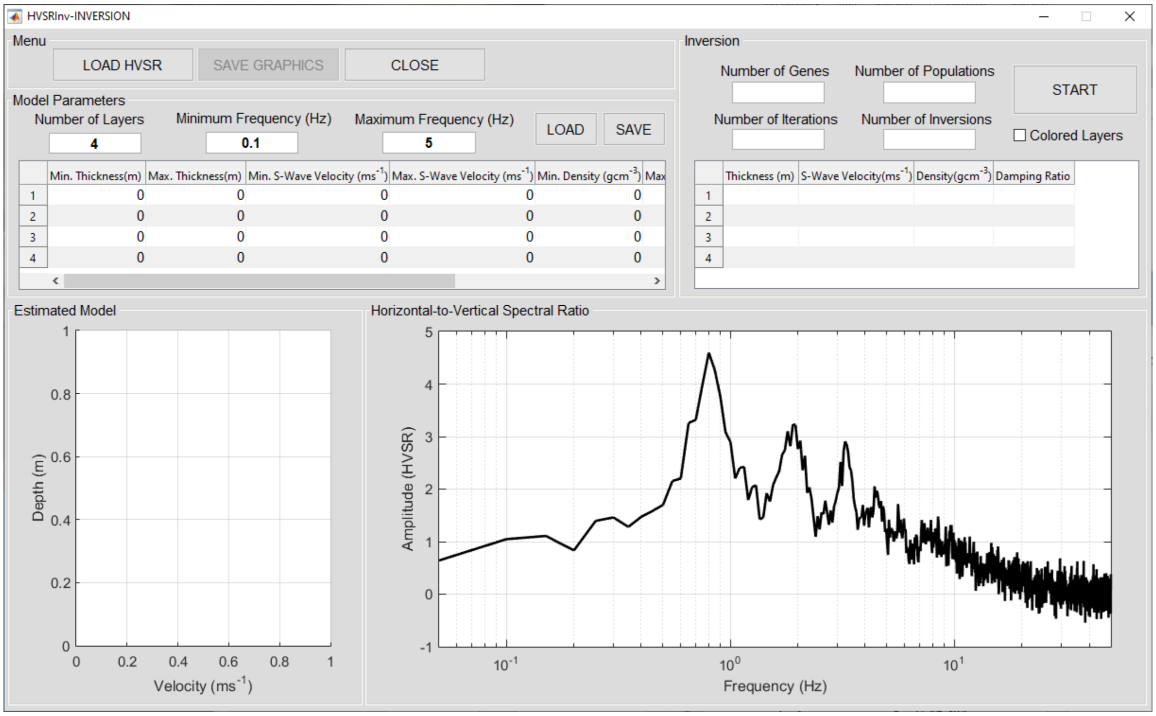

```
0.0000000 0.9056237
0.0500501 0.6414216
0.1001001 1.0470281
0.1501502 1.1080130
0.2002002 0.8325437
0.2502503 1.3936181
0.3003003 1.4606747
0.3503504 1.2806015
0.4004004 1.4734303
0.4504505 1.5868470
0.5005005 1.6996815
0.5505506 2.1518985
0.6006006 2.2026454
```



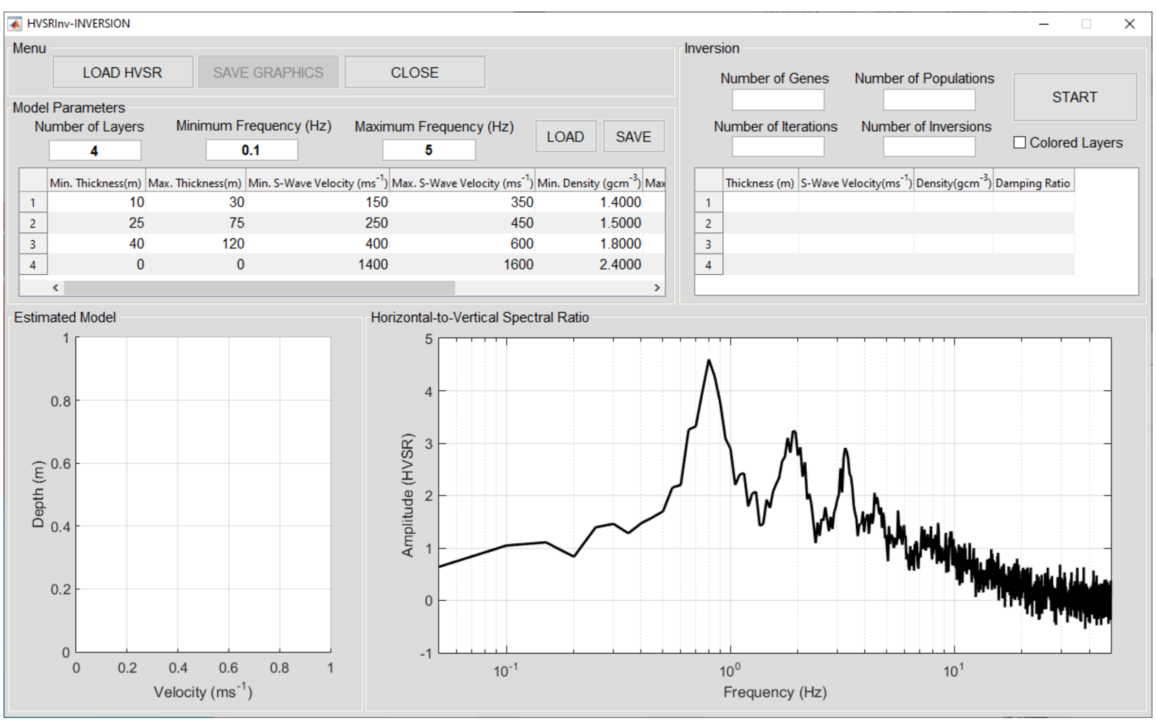
In the second step, the model parameters should be defined. The model parameters can be defined manually or loaded by means of an input file.

Defining the model parameters manually

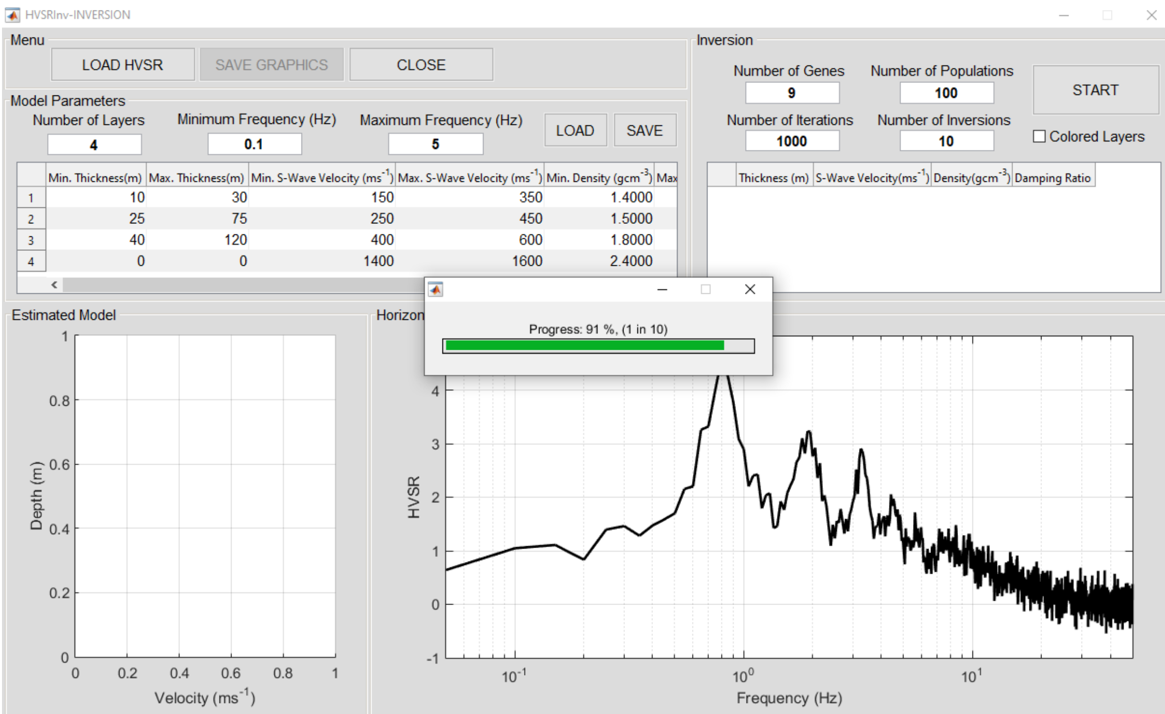
Enter the number of layers, minimum frequency and maximum frequency values for inversion.

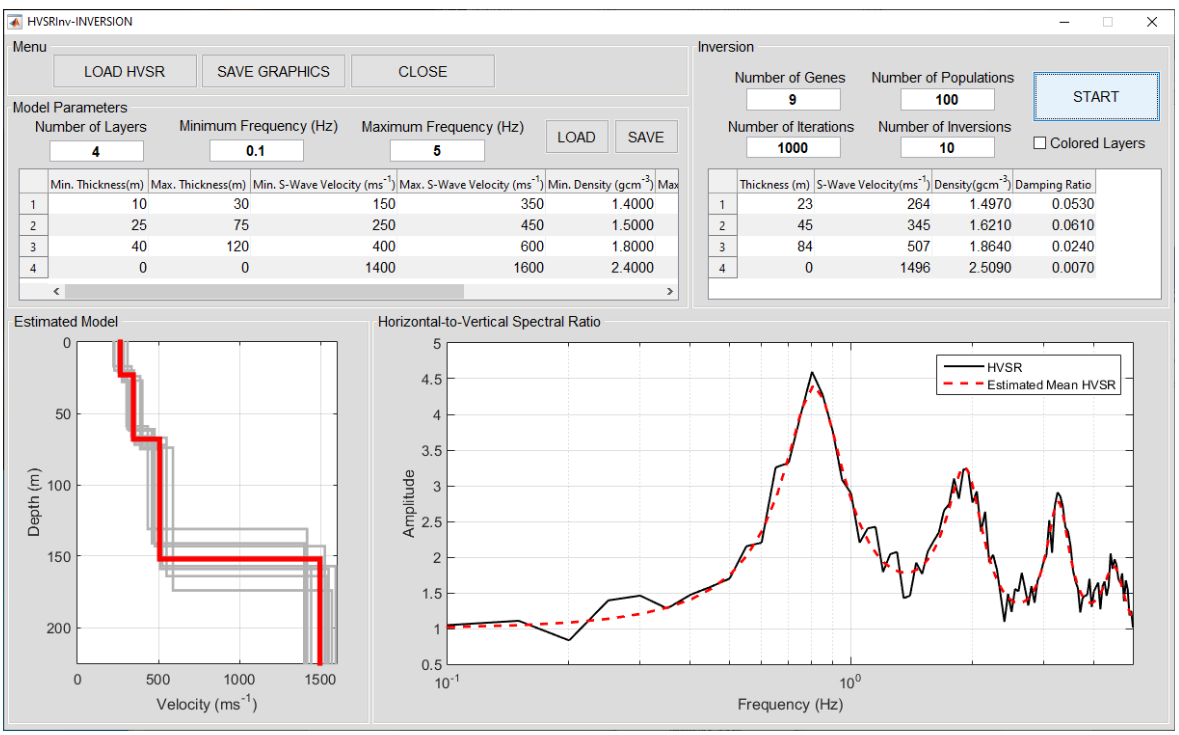


Then, enter the model parameters for each layers; min-max thicknesses, min-max S-wave velocities, min-max densities and min-max damping ratios.

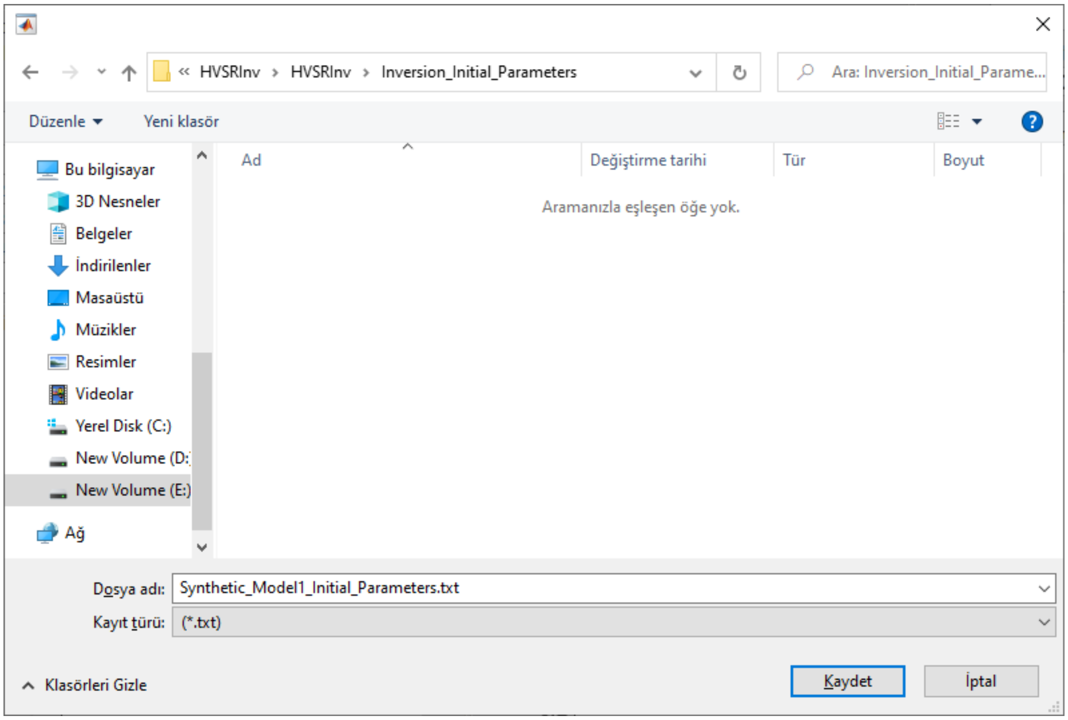


In the last step for inversion, the number of genes, populations, iterations and inversions should be entered and clicked the “**START**” button. It is not worthy that as the number of gene, population, iteration and inversion increases, the running time of the algorithm also increases. Please, see Kafadar and İmamoğlu (2021) for flowchart diagram and details of the used elitist genetic algorithm.

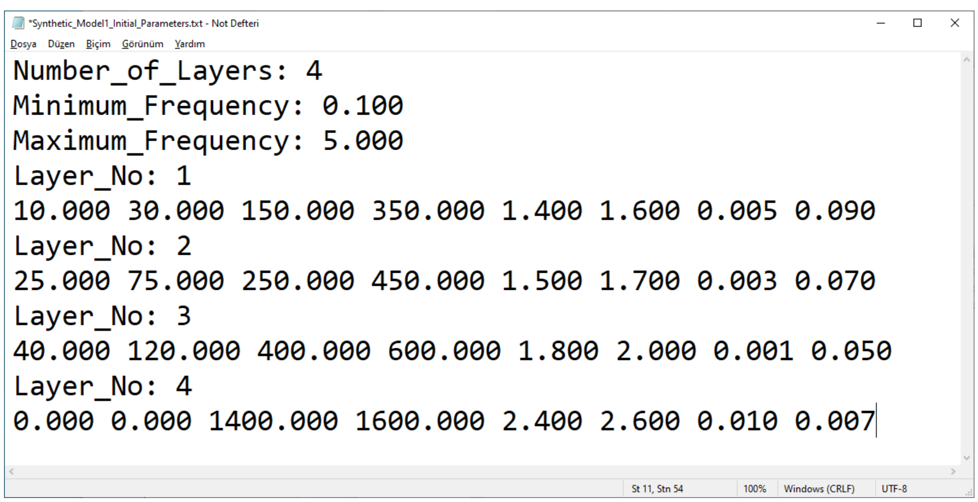




The “**SAVE**” button should be clicked to save the model parameters into a text file. Then enter a filename and click the Save button in the save dialog box.

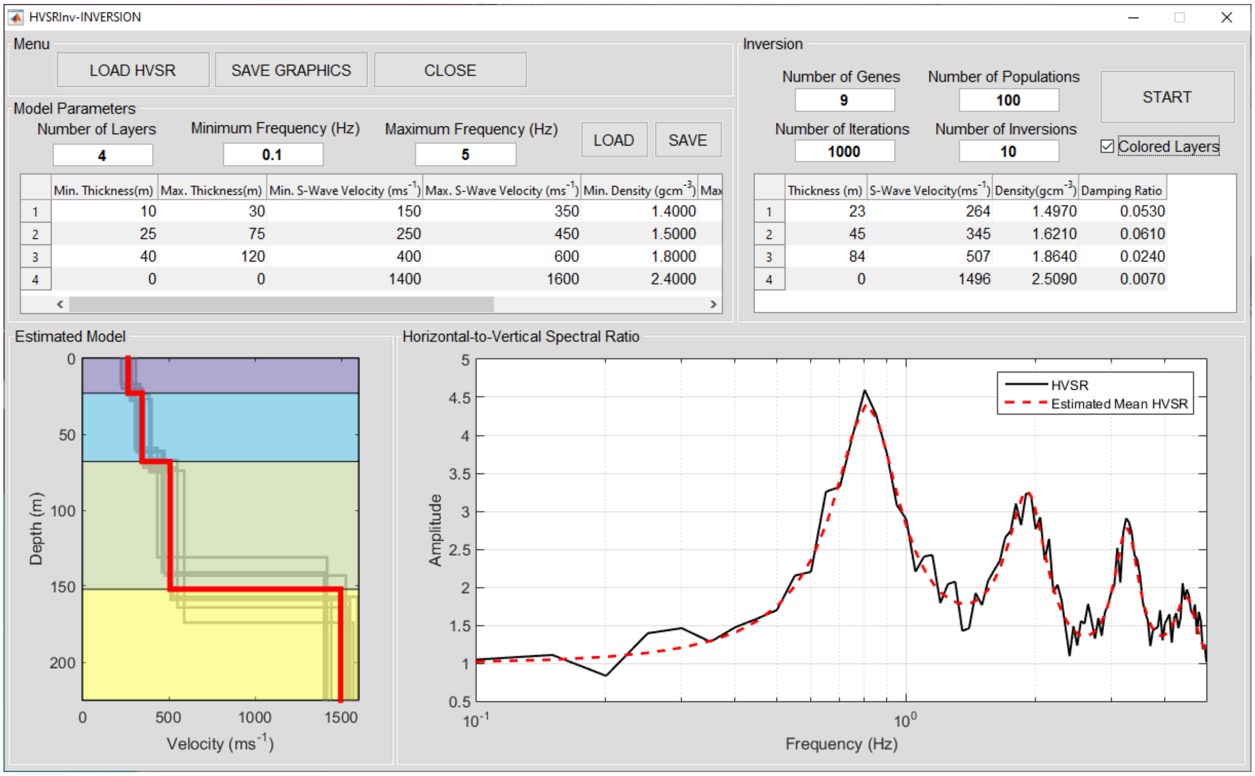


The format of the input file including the model parameters used for inversion is as follows:



```
Number_of_Layers: 4
Minimum_Frequency: 0.100
Maximum_Frequency: 5.000
Layer_No: 1
10.000 30.000 150.000 350.000 1.400 1.600 0.005 0.090
Layer_No: 2
25.000 75.000 250.000 450.000 1.500 1.700 0.003 0.070
Layer_No: 3
40.000 120.000 400.000 600.000 1.800 2.000 0.001 0.050
Layer_No: 4
0.000 0.000 1400.000 1600.000 2.400 2.600 0.010 0.007
```

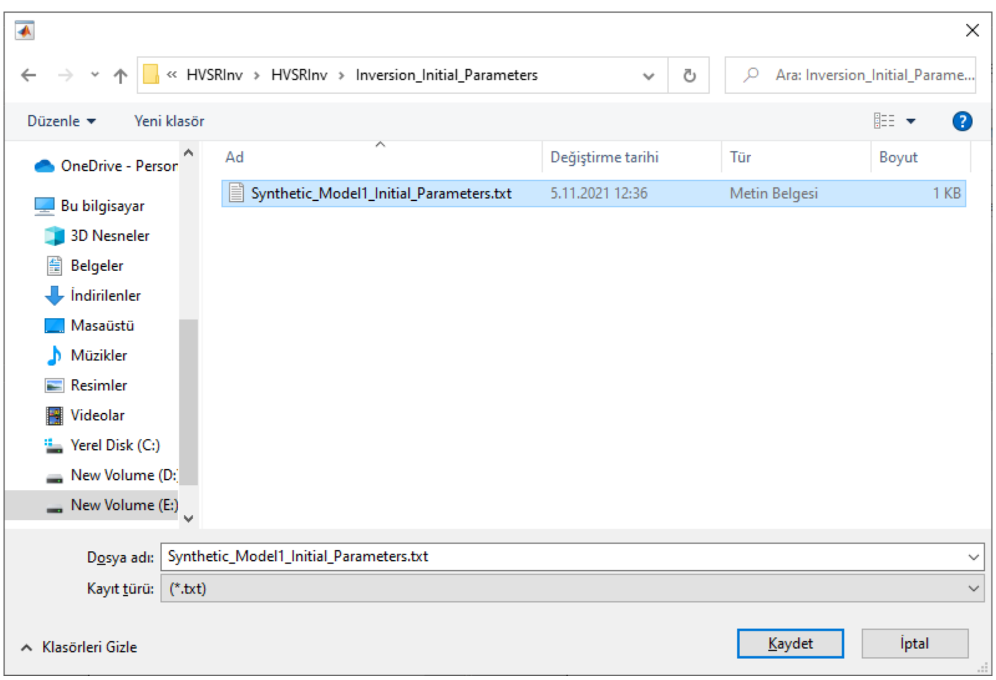
For colored illustration of the shear wave velocity profile, the “**Colored Layers**” checkbox should be clicked.

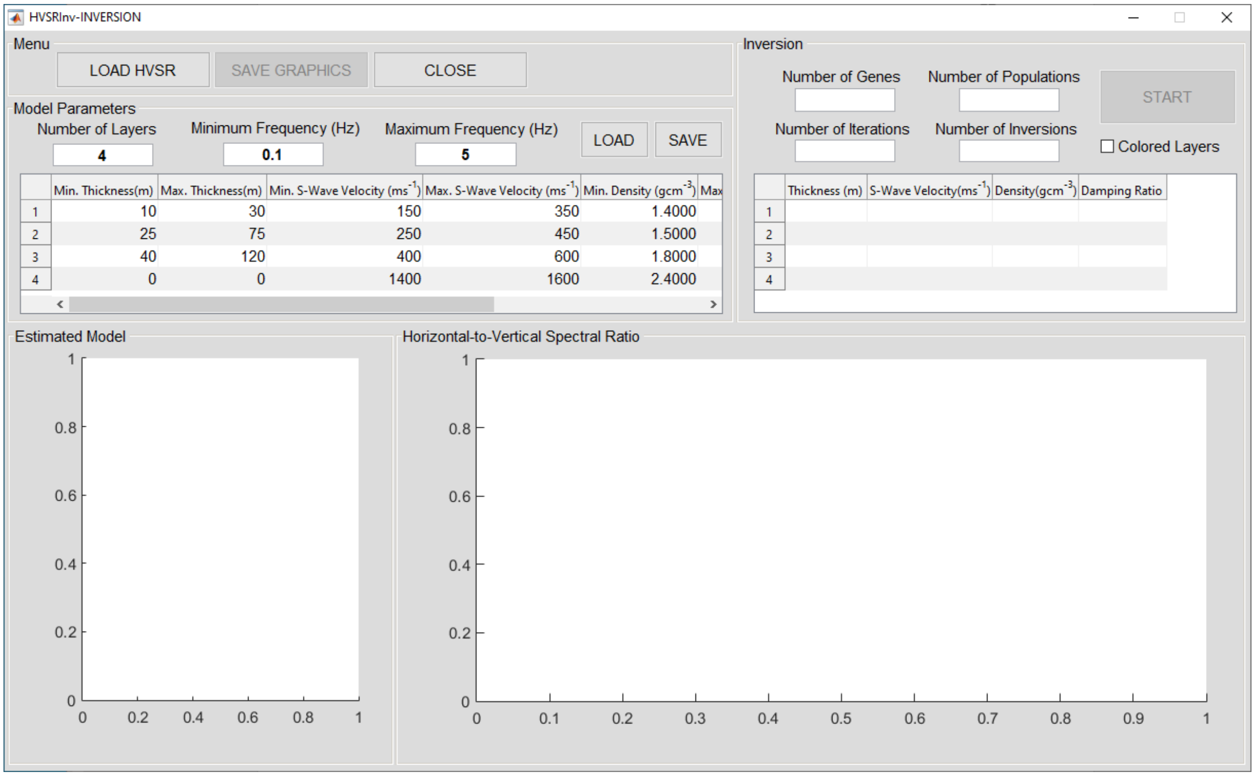


Besides, the graphics can be saved by means of the "**SAVE GRAPHICS**" button. The opened first save dialog box is for HVSR graphics, second one is for shear wave velocity model graphics.

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:

*Synthetic_Model1_HVSR_%5Noise_output.txt - Not Defteri

Dosya Düzen Biçim Görünüm Yardım

```
HVSR data file: Synthetic_Model1_HVSR_%5Noise_output.txt
Inversion parameters
Number_of_Genes: 9
Number_of_Populations: 50
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
15.000 219.000 1.600 0.090
60.000 372.000 1.500 0.041
80.000 500.000 1.970 0.050
0.000 1600.000 2.600 0.010
Inversion_No:2
H V Den Damp
20.000 300.000 1.400 0.090
66.000 400.000 1.520 0.035
90.000 577.000 1.900 0.038
0.000 1600.000 2.600 0.010
Inversion_No:3
H V Den Damp
15.000 197.000 1.600 0.055
45.000 306.000 1.640 0.066
80.000 490.000 1.800 0.047
0.000 1574.000 2.520 0.007
Inversion_No:4
H V Den Damp
19.000 250.000 1.500 0.047
54.000 364.000 1.500 0.053
75.000 468.000 2.000 0.047
0.000 1600.000 2.600 0.010
Inversion_No:5
H V Den Damp
26.000 307.000 1.480 0.069
50.000 379.000 1.700 0.045
100.000 600.000 1.810 0.023
0.000 1594.000 2.580 0.007
Average Model
H V Den Damp
19.000 255.000 1.516 0.070
55.000 364.000 1.572 0.048
85.000 527.000 1.896 0.041
0.000 1594.000 2.580 0.009
```

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HVSRInv-Subroutines

Subroutine	Description
CalcHVSR	This function calculates the synthetic HVSR using the equivalent linear approximation. Input arguments are the shear wave velocities *V* (array of *layerNum* elements), thicknesses *T* (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).
CrossOver	This function performs the crossover operation in genetic algorithm. The input argument *A* indicates the 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 *B* is the population matrix.
FindGenePos	This function finds the positions of genes using the position vector *C*.
GoodnessofFit	This function calculates the fit between the observed and synthetic data. The parameters *Syn* and *Obs* are the synthetic and observed data.
Inversion	This function applies the inversion operation using an elitist genetic algorithm. 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 *Freqs*, HVSR data *HVSR*, 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 thickness, maximum thickness, number of gene for thickness, minimum shear wave velocity, maximum shear wave velocity, number of gene for shear wave velocity, minimum density, maximum density, number of gene for density, minimum damping ratio, maximum damping ratio and number of gene for damping ratio) and plot axes *Handle*.
Mutation	This function changes a gene of the old generation with desired probability. The input parameters *Old* and *P* are the old generation and probability value.
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.

References

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.

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.

Kafadar, O., İmamoğlu, Ç., 2021. HVSRInv: Estimation of the amplification properties of soil through HVSR inversion based on an elitist genetic algorithm, Computers & Geosciences.

Kramer, S.L., 1996. Geotechnical Earthquake Engineering. Prentice Hall, Upper Saddle River, New Jersey, 254–280.

Uyanık, O., Çatlıoğlu, B., 2015. Determination of density from seismic velocities, Jeofizik, 17, 3-15.

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.