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Dynamic simulation models for seismic behavior of soil systems – Part II: Solution algorithm and numerical applications

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Abstract. This paper is the second part of the study for determining the seismic behavior of soil systems. The aim of this part is to present solution approaches for determining seismic site amplification. For this purpose, two solution techniques are used. The first technique is equivalent linear analysis which is mostly used in literature. The other technique is real time parameter updating approach and this approach uses the possibilities of Simulink effectively. A graphical user interfaced (GUI) program called DTASSA standing for Discrete-Time Analysis of Seismic Site Amplification is developed. In DTASSA, automatic block diagram producing system is developed and seismic site amplification for multiple soil layers may easily be investigated in real time. Numerical applications have been carried out to check the reliability of developed algorithm. The results of DTASSA are compared with SUA, EERA and NERA programs for the particular example problems.

Keywords: seismic site amplification; soil dynamics; digital simulation; Simulink; Matlab

1. Introduction

Site amplification can be determined with a large variety of methods. One dimensional ground response analyses are the most commonly used techniques for determining site amplification. (Choudhury and Savoikar 2009, Philips and Hashash 2009, Hashash *et al*. 2010, Roullé and Bernardie 2010, Rota *et al*. 2011, Boaga *et al*. 2012, Phillips *et al*. 2012). These methods are generally preferred in the literature not only because of their simplicity but also because horizontal layering of soil deposits. Linear and equivalent-linear models are frequently used for site response analysis (Idriss and Seed 1968, Schnabel *et al*. 1972, Idriss and Sun 1992, Bardet *et al*. 2000, Yang and Yan 2006, 2009, Robinson *et al*. 2006). These models mainly are used for their computational convenience. However, equivalent-linear analyses in the frequency domain have some disadvantages. The equivalent linear approach is unreliable in wave propagation in soft soil columns. The researchers have proposed some approaches to improve the accuracy of the approximate solution. A constant linear shear modulus and damping at a representative level of strain is used throughout the analysis and it is the main limitation of the approach (Kwak *et al*. 2008). The disadvantages of equivalent-linear analyses are deeply evaluated in many studies (Seed and Idriss 1970, Sun *et al*. 1988, Vucetic and Dobry 1991, Kramer 1996, Bardet and Tobita 2001,

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Ching and Glaser 2001).

In this study, time domain equations are used to determine site amplification. In the first part of this study, block diagrams for dynamic simulation of seismic soil behavior has been generated (Sahin 2015). The aim of this part is to present solution approaches for determining seismic site amplification.

The discrete-time approach is more accurate than frequency-domain techniques and it provides better physical insight into the problem (Şafak 1995). The block diagrams are developed by using SIMULINK (2009) which is a simulation tool in MATLAB (2009) and they are presented in the first part of this study. The proposed solution techniques for seismic amplification and developed computer program are presented in this part. The first technique is equivalent linear analysis which mostly used in literature. The new property of this approach presented here is that the equations used for site response are in time domain (Şafak 1995) and the Simulink block diagrams developed for site amplification are used for analysis. The second solution technique is real time parameter updating approach. This method is used in this study for the first time and the capabilities of Simulink are used here effectively. The main advantage of this approach is updating material properties at each time step during simulation. The developed Simulink models are connected to graphical user interfaced software named as DTASSA (Discrete-Time Analysis of Seismic Site Amplification). The dynamic system blocks are automatically generated and linked depending on the soil media by using DTASSA program.

2. Equivalent linear analysis for site response

The equivalent linear approach has been introduced originally by Schnabel *et al.* (1972) in the program *SHAKE* for out-of-plane vertically incident shear waves. In this study, the seismic behavior is simulated using an equivalent linear model in time domain. Damping ratio and modulus reduction curves are used to approximate the nonlinear soil response, and an equivalent-linear approach is utilized over these models.

In the analysis process, firstly the maximum linear shear modulus is calculated by using the following equation

$$G_{\max}(\text{linear}) = \rho_s v_s^2 \tag{1}$$

Where ρ_s is the mass density in the soil and v_s is the shear-wave velocity in the soil. The linear secant modulus is calculated depending on the modulus reduction as follows

$$G_{\sec}(\text{linear}) = G_{\text{red}} \times G_{\max}(\text{linear}) \tag{2}$$

Then the time history of shear strains for each layer is obtained. The maximum strain level is scaled by using strain ratio to give an effective strain level, which is then used for the determination of the corresponding damping ratios (ξ) and modulus reductions (G_{red}) for the next iteration. Then the altered damping ratios are converted to quality factor (Q) which represents damping of each layer in discrete time formulations as follows

$$Q = \frac{1}{2\xi} \tag{3}$$

The shear wave velocities of each layer are also calculated depending on the change in modulus reduction (G_{red}) as follows

$$v_s = \sqrt{\frac{G_{\text{sec}}(\text{linear})/G_{\text{red}}}{\rho_s}} \tag{4}$$

By using the calculated quality factors and velocities, the one way travel time (τ), sampling time interval in the series (T), reflection coefficient (r) and filter parameter (α) are determined and analysis process is repeated until the difference between the damping ratios and modulus reductions computed in two adjacent iterations are within a tolerance value defined by users.

The representation of iteration process on material curves is given in Figs. 1-2. Red arrow indicates iterative convergence towards values of G_{red} and ξ that are consistent with effective strain for an example layer. As shown in this figure, the damping ratio and modulus reduction are initialized firstly, and the maximum shear strain and effective shear strain are calculated. Then the compatible modulus reduction and damping value corresponding to effective shear strain is found for the next iteration. The quality factors and shear wave velocities of each layer are calculated by using the calculated damping value and modulus reduction for *i*'th iteration as follows

$$Q = \frac{1}{2\xi(i)} \tag{5}$$

$$v_s = \sqrt{\frac{G_{\text{sec}}/G_{\text{red}}(i)}{\rho}} \tag{6}$$

The analysis parameters are also calculated by using quality factors and shear wave velocities. Then the system is reanalyzed again depending on the updated parameters. This process is repeated until the tolerance value is under 5% or any user defined value. The strain ratio is usually taken into account as 0.65. It depends on the earthquake magnitude and may be changed by users. It is same for all layers.

3. Real time parameter updating approach for site response

Equivalent linear analysis is an iterative solution method and the system is reanalyzed in each iteration process. The maximum shear strain is taken into account to update model parameters. However, it may be better to update the system parameters in each time step for a more realistic soil model. Simulink gives users the opportunity to update system parameters at each time step during simulation. The shear strain of the layer is calculated at each time step and then the modulus reduction and damping value corresponding to this shear strain is found. The quality factors and shear wave velocities are calculated by using the obtained damping value and modulus reduction for *i*'th time step as follows

$$Q = \frac{1}{2\xi(i)} \tag{7}$$

$$v_s = \sqrt{\frac{G_{\text{sec}}/G_{\text{red}}(i)}{\rho}} \tag{8}$$

The other analysis parameters are calculated by using updated quality factors and shear wave velocities. Thereby, it may be possible to observe seismic soil behavior at each time step. The Simulink model developed for single soil layer with damping has been produced in the first part of this paper. The proposed block diagram is upgraded for real time parameter updating technique and is presented in Fig. 3. As it can be seen from this figure, some new blocks have been added. A strain calculation block and a user defined block including embedded MATLAB function is added into the block diagram. This function is added to update system parameters at each time steps. The details of this function are presented in Appendix I.

In analysis process of real time parameter updating approach, the system parameters may be changed in real time and system response depending on this change may be observed while simulation is running. For such operation, a slider control is used as shown in Fig. 4.

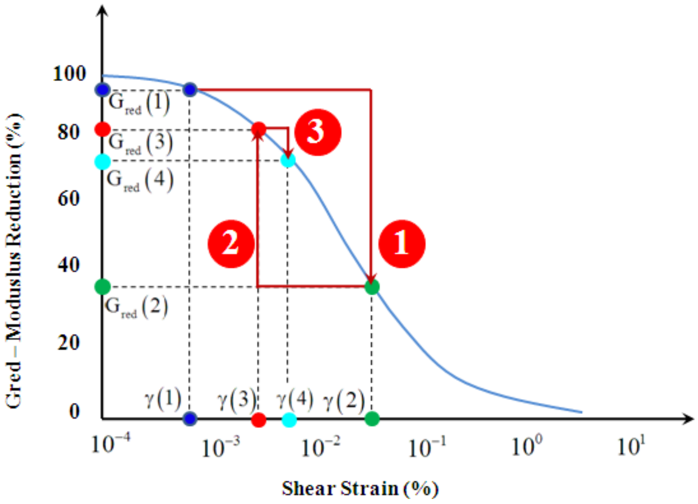


Fig. 1 Iteration representation on modulus reduction (G_{red}) curve for a selected material model

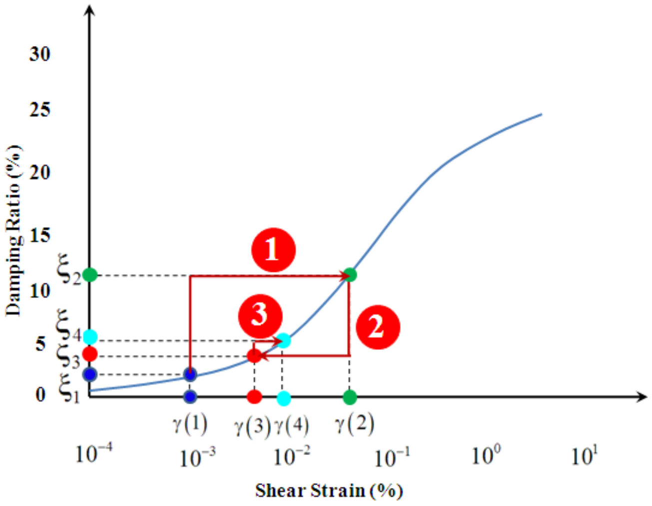


Fig. 2 Iteration representation on damping ratio (ξ) curve for a selected material model

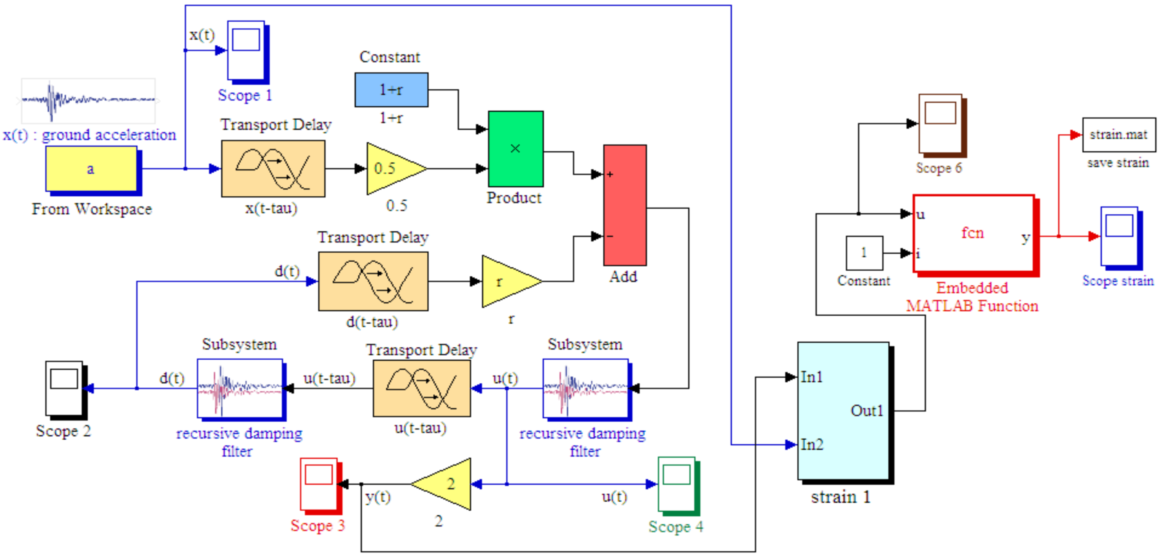
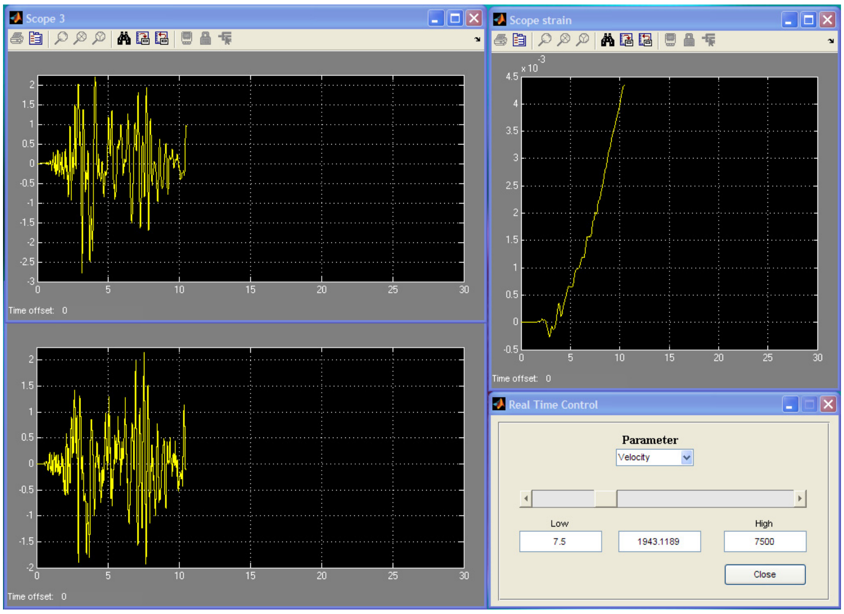


Fig. 3 Block diagram developed for observing real time soil behavior of single layer with damping



Parameter: Velocity

Low: 7.5

1943.1189

High: 7500

Fig. 4 Real time parameter controlling tool developed for observing system response while simulation is running

4. DTASSA software

An administration program with graphical user interface (GUI) is developed in MATLAB to produce Simulink block diagrams proposed for site amplification and to monitor seismic soil behavior by using proposed solution techniques. The program is named as DTASSA (Discrete-Time Analysis of Seismic Site Amplification). The main window of DTASSA is presented in Fig. 5.

As it can be seen from Fig. 5, any earthquake data may be applied to the system as a bedrock motion or rock outcrop motion. The earthquake data loading system is developed suitable to PEER earthquake database system (Peer Strong Motion Database 2011). The time interval, time limit and the data are extracted from the PEER file which has AT2 extension. The soil layers may be introduced to the system with no restriction. The soil media may be divided into *n* layers and the Simulink models automatically constructed by using DTASSA program. The produced Simulink model may be opened, rearranged, and executed interactively in Simulink window or may be executed from DTASSA menus.

There is a material model library in the program and new models may be added to the system as shown in Fig. 6. The models available here may be selected as soil material type in main menu. The analysis for equivalent linear analysis and real time parameter updating approach is executed depending on these damping and modulus reduction graphics. After the analysis is completed, the upgoing and downgoing waves, strain time history of each layer and the surface motion may be monitored by using DTASSA program. Any nonlinear material models may be added into this library and these models may be considered in analysis process.

4.1 Equivalent linear analysis algorithm used in DTASSA program

As previously explained, the damping ratio and modulus reduction are assumed as a function of shear strain amplitude in the equivalent linear model. The damping ratio (i.e., quality factor (Q)) and modulus reduction (i.e., G_{red}) are determined by iterations so that it becomes consistent with the level of strain induced in each layer. The flowchart developed for implementing equivalent linear analysis in time domain is presented in Fig. 7.

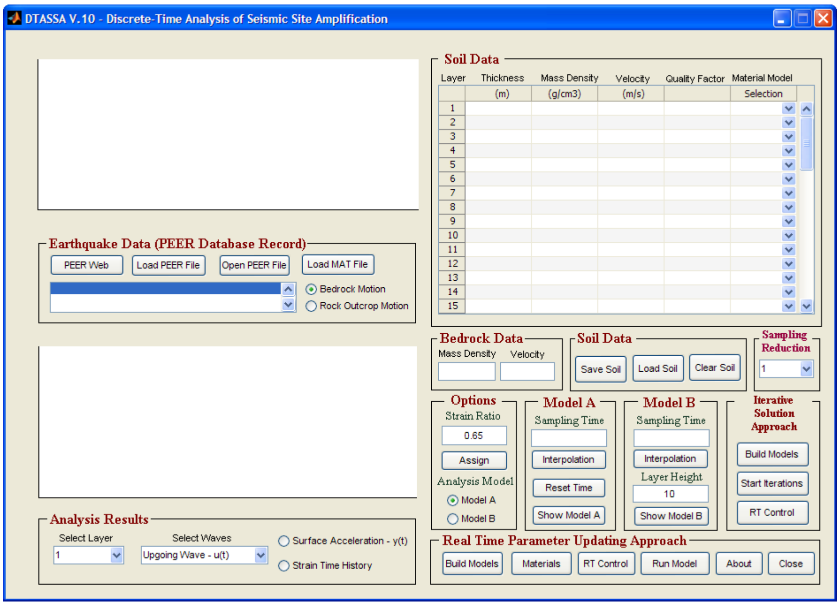
As shown in Fig. 7, the damping ratio and modulus reduction are initialized firstly, and the maximum shear strain and effective shear strain are calculated. Then the compatible damping value corresponding to effective shear strain is found for the next iteration. The quality factors and shear wave velocities are calculated by using the assigned damping value and modulus reduction. The analysis parameters are also calculated depending on these variables. This process is repeated with the new values of updated analysis parameters until the tolerance value is under 5% or any user defined value.

The strain ratio in flowchart is taken into account as 0.65. It depends on the earthquake magnitude and may be changed by users. It is same for all layers.

4.2 Real time parameter updating algorithm used in DTASSA

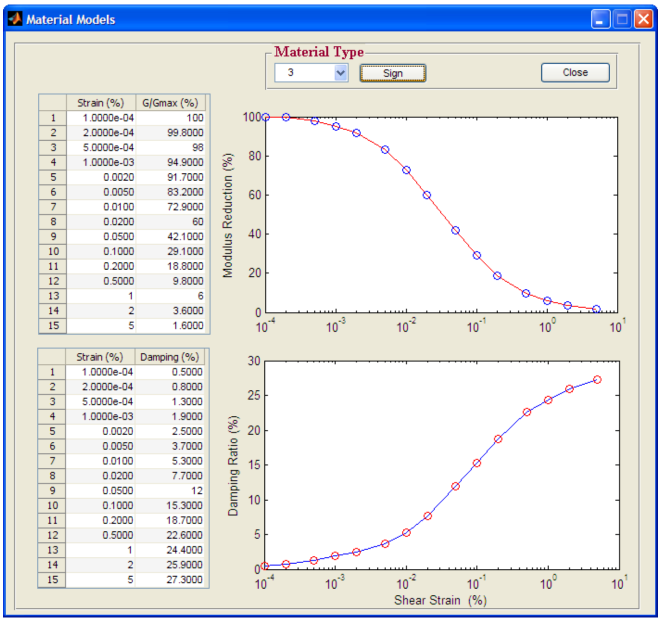
As indicated before, in real time parameter updating approach, the shear strains of all layers are calculated at each time step and then the modulus reductions and damping values corresponding to these shear strains for each layer are found from material curves. The quality factors and shear wave velocities are calculated for each layer by using the obtained damping values and modulus reductions at each time step. The analysis parameters are also calculated by using the updated quality factors and shear wave velocities. The Simulink model developed for site amplification of a sample soil media with three layers has been presented in the first part of this paper. The proposed block diagram is upgraded for real time parameter updating technique and is presented in

Fig. 8. As it can be seen from this figure, strain calculation blocks and real time parameter updating blocks including embedded MATLAB function are added in the proposed block diagram. The embedded MATLAB function is added to update system parameters at each time step. The details of this function are given in Appendix I.



● Bedrock Motion
○ Rock Outcrop Motion
Sampling Reduction: 1
Strain Ratio: 0.65
Analysis Model: ● Model A ○ Model B
Layer Height: 10
Select Layer: 1
Select Waves: Upgoing Wave - u(t)
○ Surface Acceleration - y(t)
○ Strain Time History

Fig. 5 DTASSA program main window

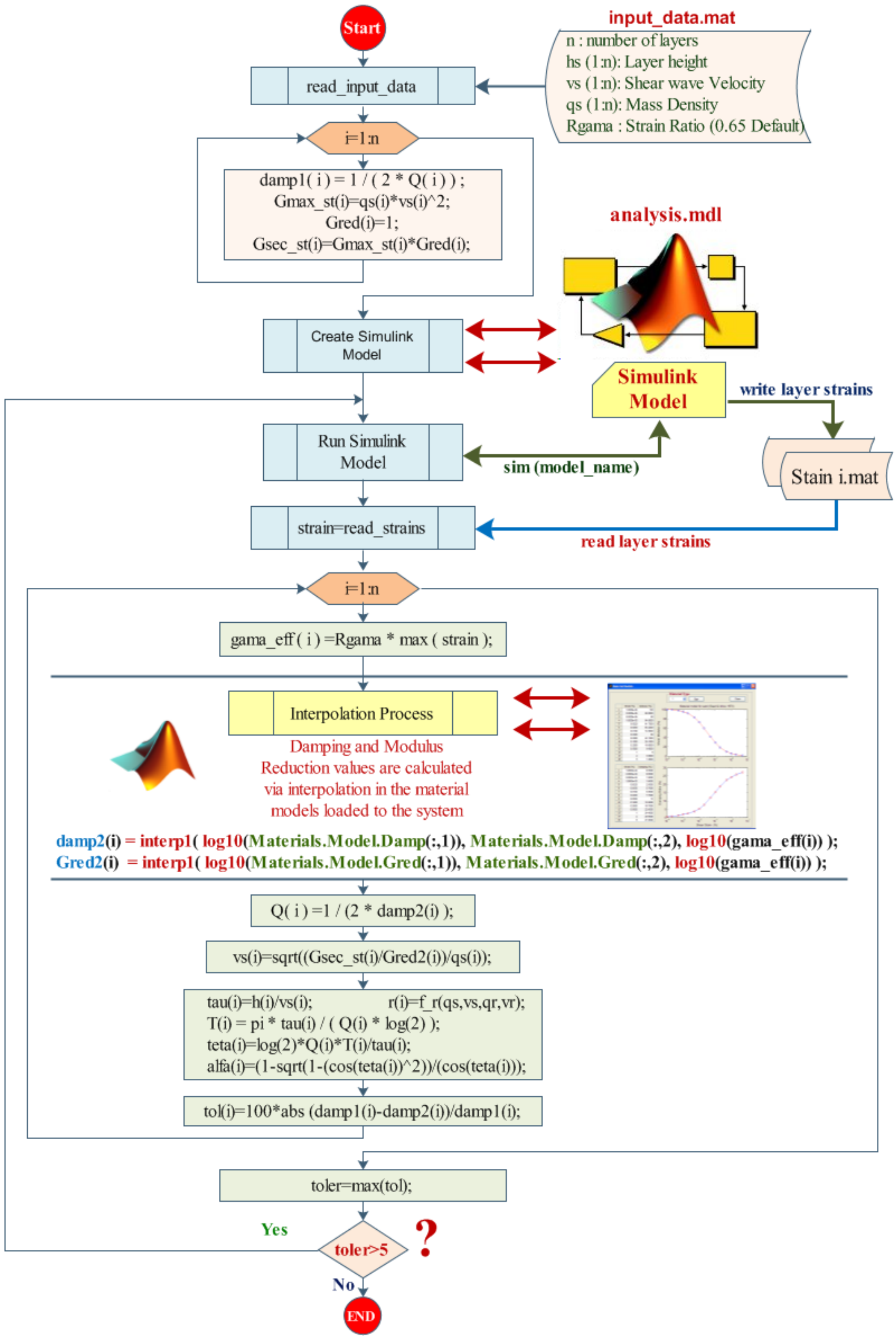


Material Type: 3

	Strain (%)	G/Gmax (%)
1	1.0000e-04	100
2	2.0000e-04	99.8000
3	5.0000e-04	98
4	1.0000e-03	94.9000
5	0.0020	91.7000
6	0.0050	83.2000
7	0.0100	72.9000
8	0.0200	60
9	0.0500	42.1000
10	0.1000	29.1000
11	0.2000	18.8000
12	0.5000	9.8000
13	1	6
14	2	3.6000
15	5	1.6000

	Strain (%)	Damping (%)
1	1.0000e-04	0.5000
2	2.0000e-04	0.8000
3	5.0000e-04	1.3000
4	1.0000e-03	1.9000
5	0.0020	2.5000
6	0.0050	3.7000
7	0.0100	5.3000
8	0.0200	7.7000
9	0.0500	12
10	0.1000	15.3000
11	0.2000	18.7000
12	0.5000	22.6000
13	1	24.4000
14	2	25.9000
15	5	27.3000

Fig. 6 Material models window used in DTASSA



```
damp1( i ) = 1 / ( 2 * Q( i ) ) ;
Gmax_st(i)=qs(i)*vs(i)^2;
Gred(i)=1;
Gsec_st(i)=Gmax_st(i)*Gred(i);
```

```
gama_eff( i ) =Rgama * max ( strain );
```

```
damp2(i) = interp1( log10(Materials.Model.Damp(:,1)), Materials.Model.Damp(:,2), log10(gama_eff(i)) );
Gred2(i)  = interp1( log10(Materials.Model.Gred(:,1)), Materials.Model.Gred(:,2), log10(gama_eff(i)) );
```

```
Q( i ) =1 / (2 * damp2(i) );
```

```
vs(i)=sqrt((Gsec_st(i)/Gred2(i))/qs(i));
```

```
tau(i)=h(i)/vs(i);                r(i)=f_r(qs,vs,qr,vr);
T(i) = pi * tau(i) / ( Q(i) * log(2) );
teta(i)=log(2)*Q(i)*T(i)/tau(i);
alfa(i)=(1-sqrt(1-(cos(teta(i))^2))/(cos(teta(i)));
```

```
tol(i)=100*abs (damp1(i)-damp2(i))/damp1(i);
```

```
toler=max(tol);
```

Fig. 7 Flowchart used for equivalent linear analysis including iteration of damping ratio and modulus reduction with shear strain

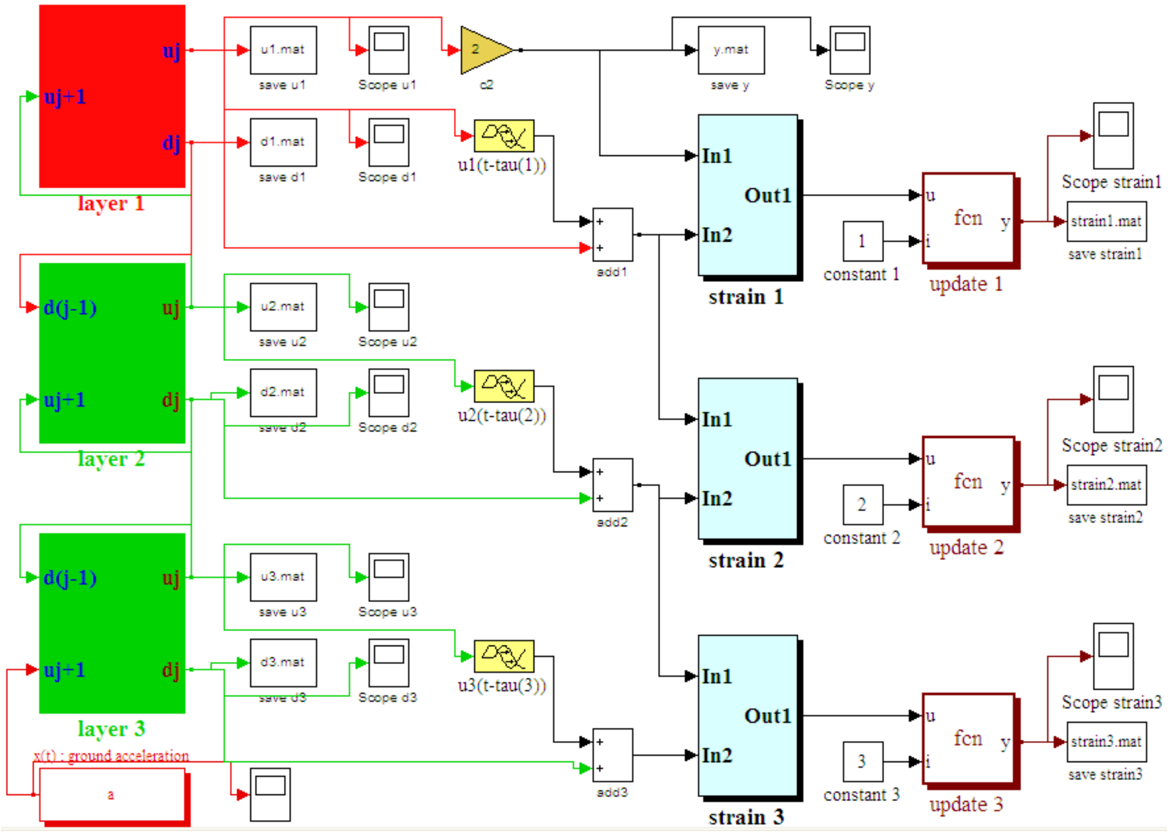


Fig. 8 Block diagram for real time parameter updating approach developed for seismic soil behavior of three layered soil media

5. Numerical applications

5.1 First numerical application

As an application, a three-layered site subjected to the acceleration–time histories, recorded during 1999 Kocaeli Earthquake is considered. IZT090 component of 17 August 1999 Kocaeli earthquake is chosen for the analysis. The seismic record is presented in Fig. 9. The data source is Disaster and Emergency Management Presidency in Turkey (URL 1) and data was recorded at Izmit Station. The source record used here is processed by Pacific Engineering and processed data is downloaded from Peer Strong Motion Database (URL 2). The raw measured seismic data is processed to make the data useful for engineering analysis. The response of the strong motion instrument has been corrected and random noise in the recorded signals has been reduced. The high- and low-frequency ranges of the useable signal in the records are extended. The processing of the strong motion data has been performed by Dr. Walter Silva of Pacific Engineering, El Cerrito, California (URL 3).

The details of the source data and observation station are given in Fig. 10. The latitude and longitude of the hypocenter are 40.7270 deg and 29.9900 deg. The depth is 15 km. The latitude

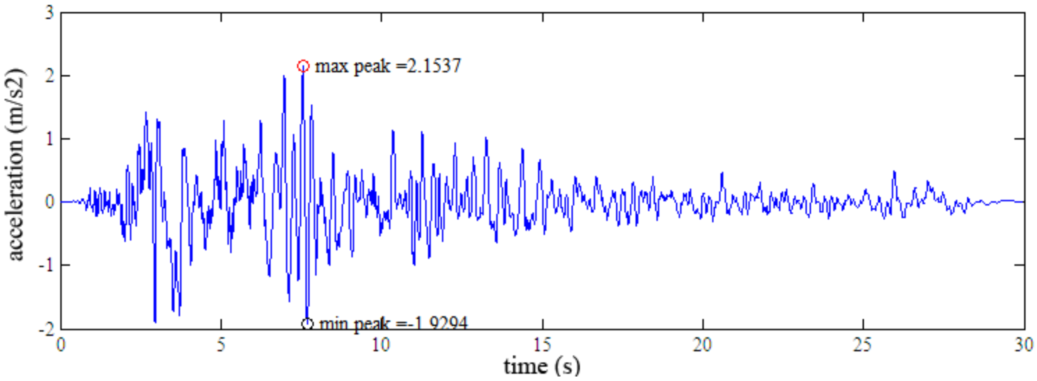


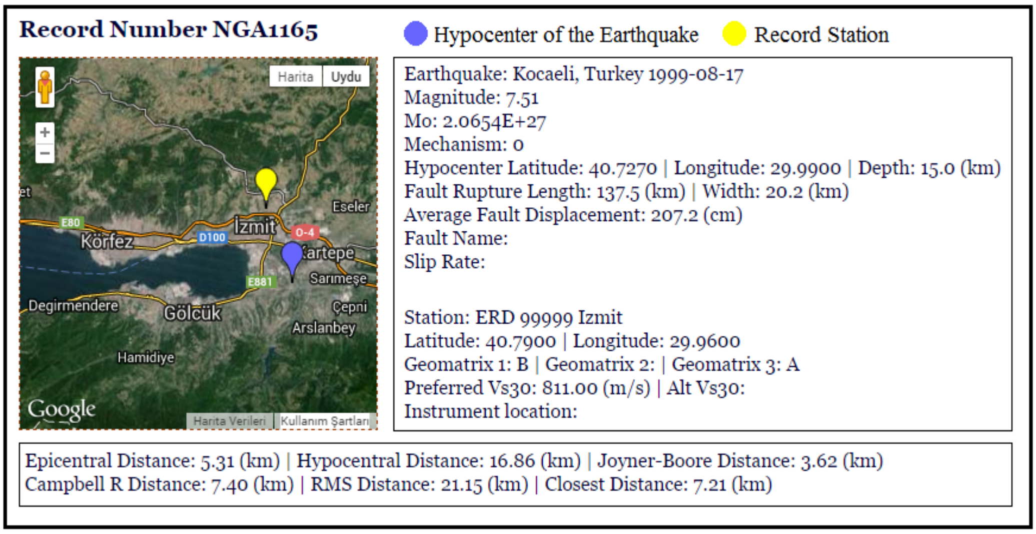
Fig. 9 IZT090 component of 1999 Kocaeli Earthquake (IZMIT, 090 (ERD))

and longitude of the observation station are 40.7900 deg and 29.9600 deg. The peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGV) of IZT090 component of the record is 2.16 cm/s^2 (0.22 g), 29.8 cm/s and 17.12 cm, respectively (URL 4).

The parameters of the soil and bedrock are presented in Table 1. The seismic record is applied to the system as a bedrock motion. It should be noted that, the IZT090 component of the seismic record is vertical component. The analyses are carried out with DTASSA software by considering a constant time integration step equal to 0.005 s.

The soil layer velocities are 400 m/s, 500 m/s and 800 m/s. The first two layers are moderate stiff but altered and the last layer is stiff. These classifications have been made depending on the seismic velocities (Keçeli 2012).

The time interval directly affects the results, because the damping filter block diagram uses this time step. In the analysis process, minimum time interval is used in transport delay.



Record Number NGA1165

● Hypocenter of the Earthquake ● Record Station

Earthquake: Kocaeli, Turkey 1999-08-17
Magnitude: 7.51
Mo: 2.0654E+27
Mechanism: 0
Hypocenter Latitude: 40.7270 | Longitude: 29.9900 | Depth: 15.0 (km)
Fault Rupture Length: 137.5 (km) | Width: 20.2 (km)
Average Fault Displacement: 207.2 (cm)
Fault Name:
Slip Rate:

Station: ERD 99999 Izmit
Latitude: 40.7900 | Longitude: 29.9600
Geomatrix 1: B | Geomatrix 2: | Geomatrix 3: A
Preferred Vs30: 811.00 (m/s) | Alt Vs30:
Instrument location:

Epicentral Distance: 5.31 (km) | Hypocentral Distance: 16.86 (km) | Joyner-Boore Distance: 3.62 (km)
Campbell R Distance: 7.40 (km) | RMS Distance: 21.15 (km) | Closest Distance: 7.21 (km)

Fig. 10 The details of the processed seismic data by Pasific Engineering (URL 5)

Table 1 Parameters of soil layers and bedrock subjected to earthquake load

Layer number	Thickness (m)	Mass density (g/cm^3)	Shear wave velocity (m/s)	Quality factor
1	10	2.0	400	30
2	20	2.2	500	50
3	50	2.8	800	70
Bedrock	infinite	3.0	1000	-

5.1.1 System analysis with equivalent linear analysis

In this study, “Model A” is used to analyze soil system. “Model A” means that the soil system is taken into account without dividing soil layers into small sublayers. The block diagram for three-layered soil media is generated automatically and the subsystems are linked each other as indicated before. In DTASSA, the simulation may be started from the GUI and it may also be controlled interactively from the simulation window in real time.

In the analysis process, a tolerance of around 5% is adopted and minimum time interval is used in transport delay. The sampling reduction coefficient is selected as 10 for the analysis. The

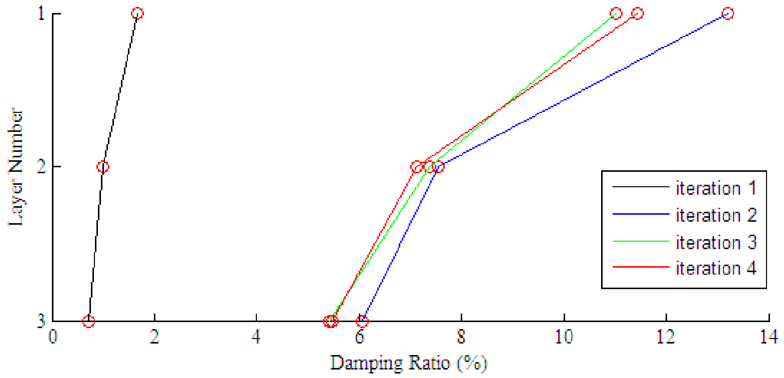


Fig. 11 Damping ratio alteration depending on the effective shear strain in analysis process

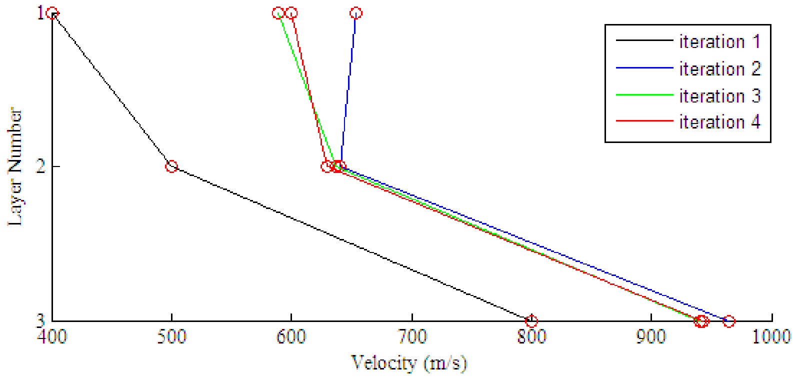


Fig. 12 Velocity alteration depending on the effective shear strain in analysis process

material curves are selected as suitable with SUA program (Robinson *et al*. 2006). The solution is converging in 5 iterations as shown in Figs. 11-12. The obtained damping ratio distribution while the analysis is running is shown in Fig. 10 and the shear wave velocity distribution is shown in Fig. 11.

The analysis results are presented in Figs. 13-15. The upgoing waves of the layers are presented in Fig. 13, the downgoing waves of the layers are presented in Fig. 14, and calculated surface motion is presented in Fig. 15. As shown in Fig. 15, the peak ground acceleration value for the surface motion is -3.5340 m/s^2.

Verification of the numerical implementation of DTASSA can be obtained by comparing its results with those of SUA when both are applied to the same problem. SUA is a suite of MATLAB routines and developed by Robinson *et al.* (2006) to implement an equivalent site response analysis in frequency domain with the option of including an assessment of uncertainty.

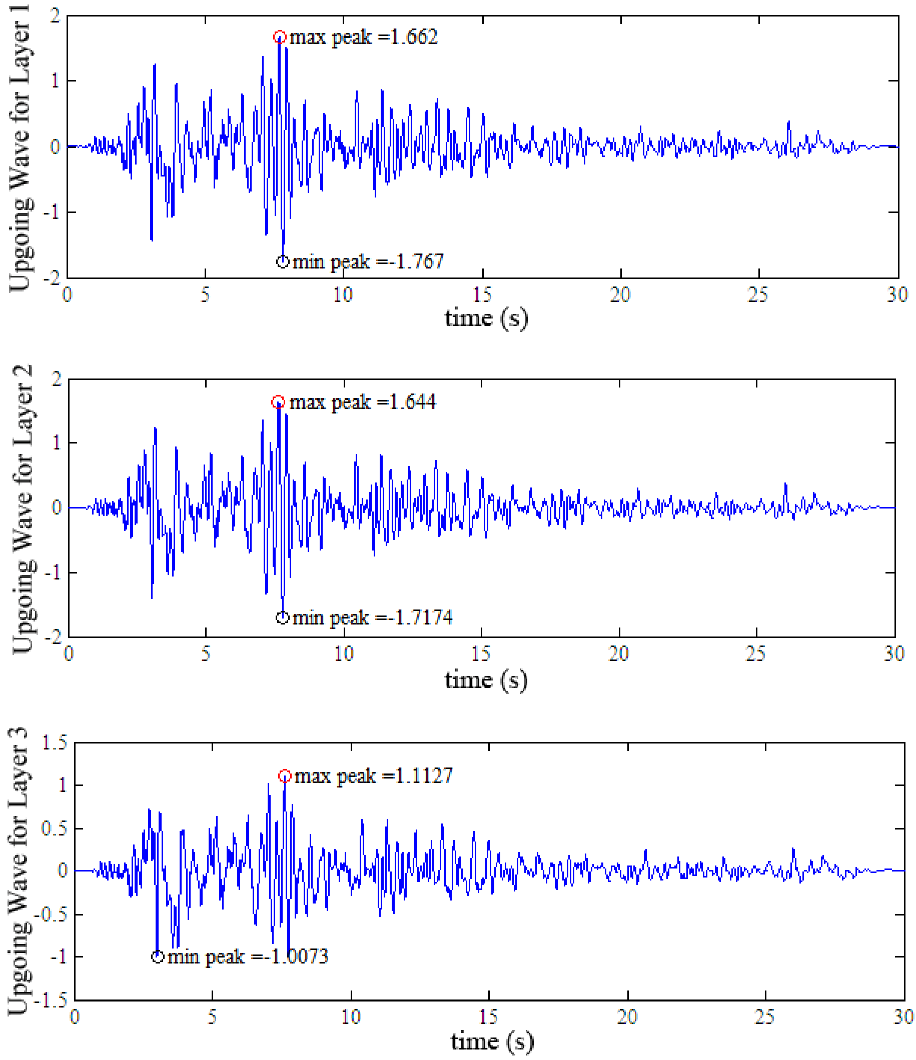


Fig. 13 Calculated upgoing waves of each soil layer for Model A equivalent linear analysis

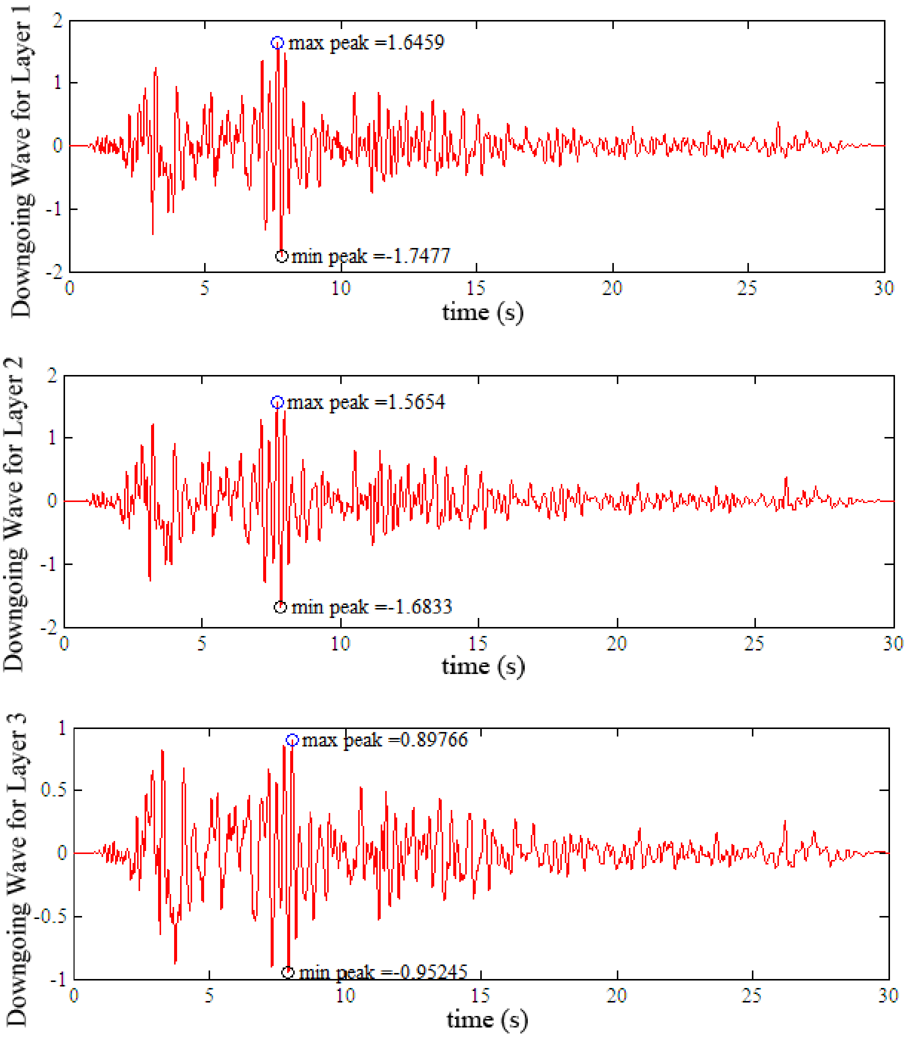


Fig. 14 Calculated downgoing waves of each soil layer for Model A equivalent linear analysis

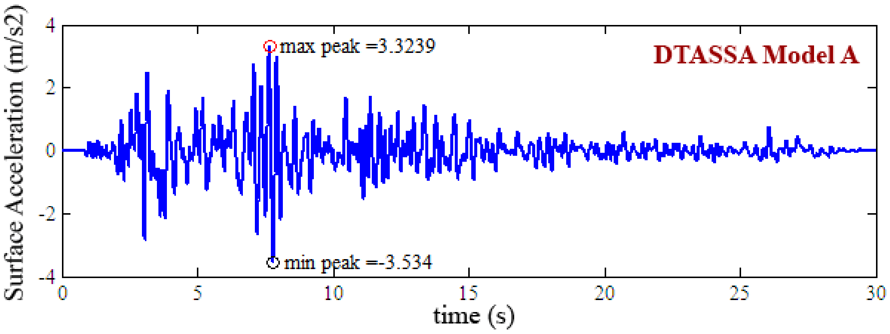


Fig. 15 Surface acceleration calculated with DTASSA-Model A iterative solution approach

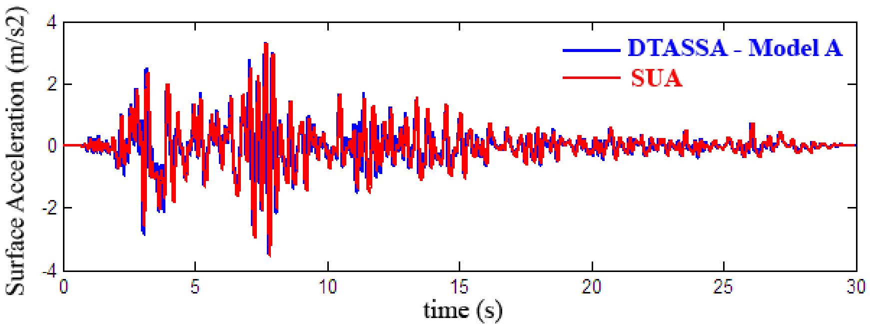


Fig. 16 Comparison between DTASSA-Model A iterative solution approach and SUA results

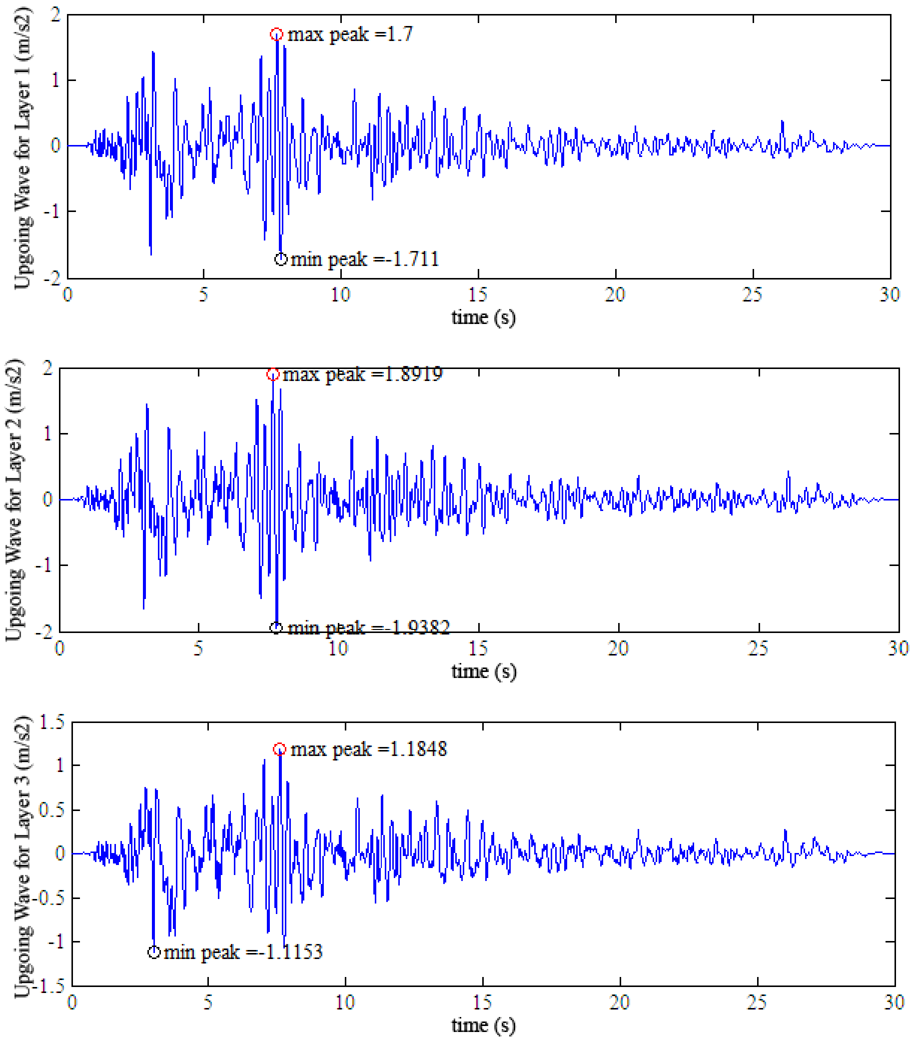


Fig. 17 Calculated upgoing waves of each soil layer for real time parameter updating approach

It has been developed for modelling the amplification of seismic waves due to propagation through regolith.

The same earthquake data and soil conditions are analyzed with SUA. The peak ground acceleration value for the surface motion is obtained as 3.5807 m/s^2.

A comparison between the surface acceleration for DTASSA and SUA is presented in Fig. 16. A good harmony may be observed from this figure. It can be said that the comparison between results is good suggesting that DTASSA generates comparable estimates of site response.

5.1.2 System analysis with real time parameter updating approach

The same soil model is analyzed under the same earthquake data by using the real time parameter approach tool in DTASSA program. In this analysis process, the damping ratio and shear wave velocities of each soil layer are updated depending on the material curves at each time step during simulation. The block diagram for seismic analysis of the soil media is generated automatically and the subsystems are linked each other as indicated before. The sampling reduction coefficient is selected as one for the analysis. The material curves are selected as suitable with SUA (2006) program. The analysis results are presented in Figs. 17-19. The upgoing waves of the layers are presented in Fig. 17, the downgoing waves of the layers are presented in Fig. 18, and calculated surface motion is presented in Fig. 19. As shown in Fig. 19, the peak ground acceleration value for the surface motion is 3.4221 m/s^2. The same surface motion is presented in original Simulink window as shown in Fig. 20.

5.2 Second numerical application

In second application, a sixteen-layered site subjected to the acceleration–time histories, recorded during 1989 Loma Prieta Earthquake is considered. DMH090 component of 18 October 1989 Loma Prieta earthquake is chosen for the analysis (URL 6). The soil model and earthquake data is the same with the examples used in EERA (Bardet *et al.* 2000) and NERA (Bardet and Tobita 2001) manuals. The considered numerical model is a 150-ft soil profile consisting of clay and sand overlying a half-space. The parameters of the soil and bedrock are presented in Table 2. The soil layers between 1st and 10th stratums are loose and soft layers. The soil layers between 11th and 16th stratums are moderate stiff but altered. These classifications have been made depending on the seismic velocities (Keçeli 2012).

EERA is a computer program for equivalent-linear earthquake site response analyses of layered soil deposits. The analysis tool of DTASSA for iterative solution approach is compared with this program. NERA is a computer program for nonlinear earthquake site response analyses of layered soil deposits. The analysis tool of DTASSA for real time parameter updating approach is compared with this program.

The seismic record used for the analyses is presented in Fig. 21. The details of the source data and observation station are given in Fig. 22. The latitude and longitude of the hypocenter are 37.0407 deg and -121.883 deg. The depth is 17.5 km. The latitude and longitude of the observation station are 37.7400 deg and -122.432 deg. The peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGV) of DMH090 component of the record is 1.11 cm/s^2 (0.113 g), 13.1 cm/s and 3.36 cm, respectively (URL 7).

The seismic record is applied to the system as a rock outcrop motion. The analyses are carried out with DTASSA software by considering a constant time integration step equal to 0.02 s.

In analysis process, the block diagram for sixteen-layered soil media is generated automatically

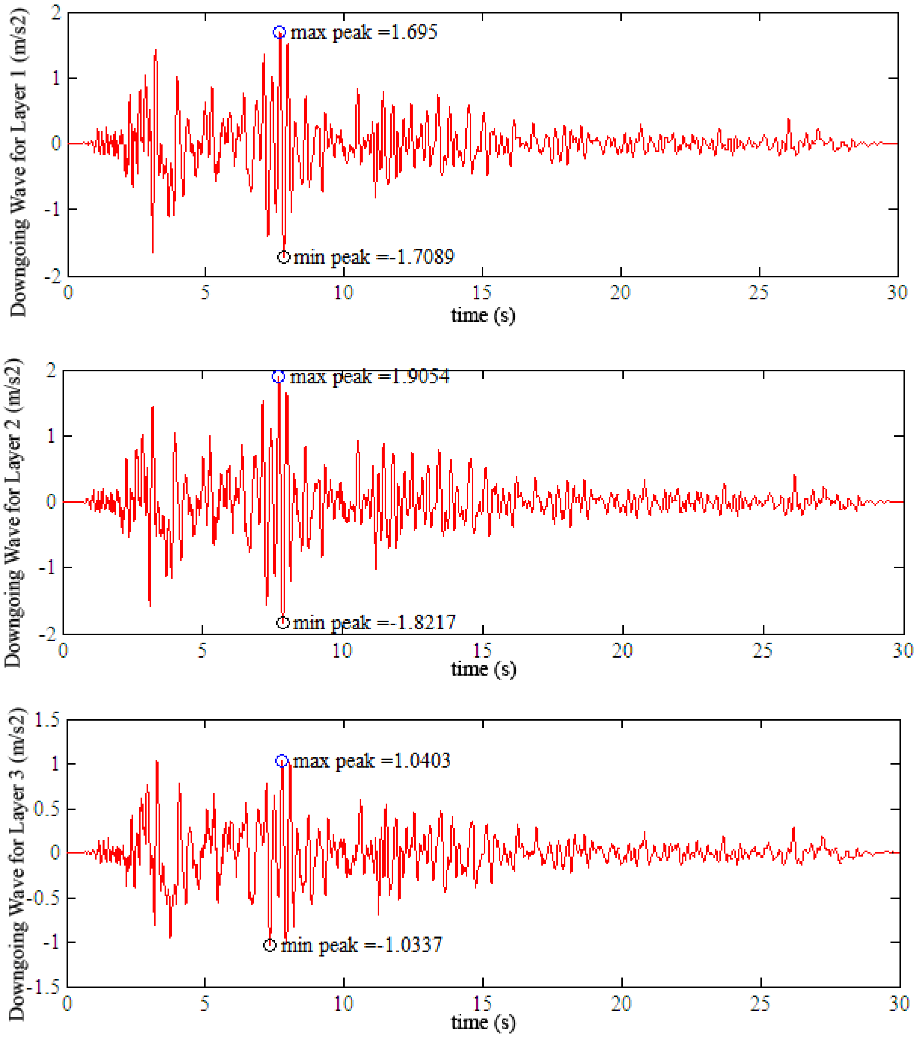


Fig. 18 Calculated downgoing waves of each soil layer for real time parameter updating approach

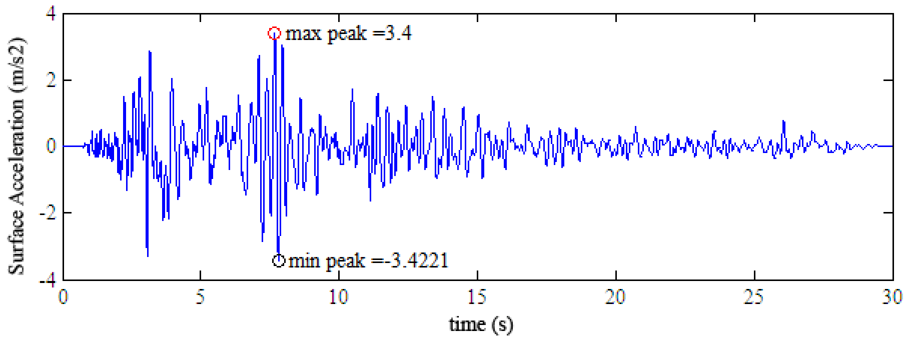


Fig. 19 Surface acceleration calculated with DTASSA-real time parameter updating approach

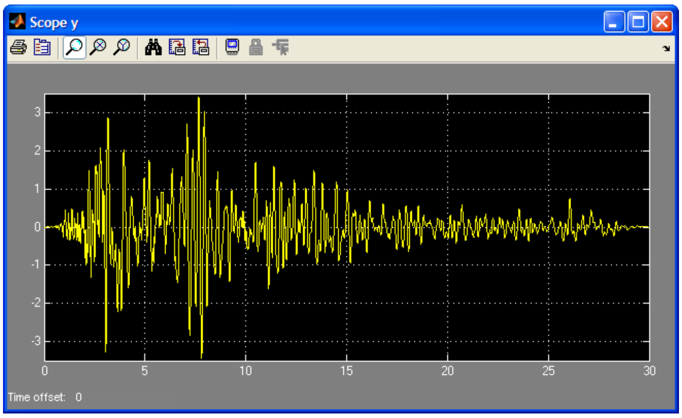


Fig. 20 Surface acceleration calculated with DTASSA-real time parameter updating approach in Simulink window

Table 2 Parameters of soil layers and bedrock subjected to earthquake load

Layer No.	Soil material type	Thickness (m)	Mass density (g/cm^3)	Velocity (m/s)	Quality factor
1	2	1.5	1.966	304.8	5
2	2	1.5	1.966	274.32	5
3	2	3.0	1.966	274.32	5
4	2	3.0	1.966	289.56	5
5	1	3.0	1.966	304.8	5
6	1	3.0	1.966	304.8	5
7	1	3.0	1.966	335.28	5
8	1	3.0	1.966	335.28	5
9	2	3.0	2.045	396.24	5
10	2	3.0	2.045	396.24	5
11	2	3.0	2.045	426.72	5
12	2	3.0	2.045	426.72	5
13	2	3.0	2.045	457.2	5
14	2	3.0	2.045	457.2	5
15	2	3.0	2.045	487.68	5
16	2	3.0	2.045	548.64	5
Bedrock		-	2.202	1219.2	-

and the subsystems are linked each other as indicated before. In the analysis process, minimum time interval is used in transport delay. The sampling reduction coefficient is selected as 2 for the analysis. The material curves are defined into the system same with the material models used in EERA and NERA programs given in Figs. 23 and 24.

5.2.1 System analysis with equivalent linear analysis

Firstly, the system is analyzed with DTASSA by using equivalent linear analysis. The surface

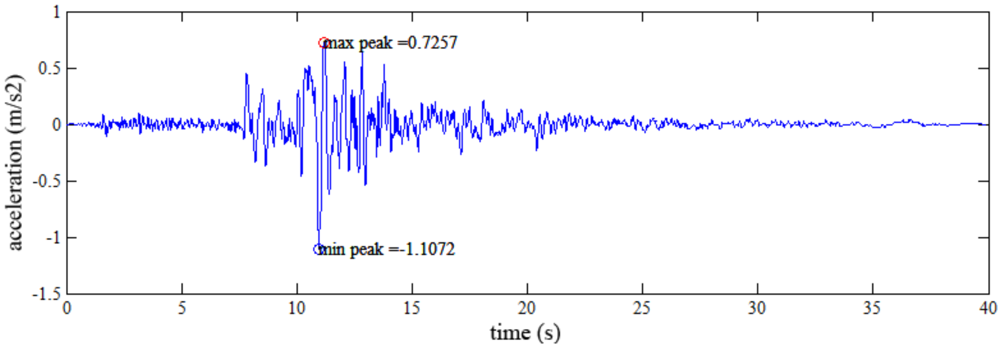
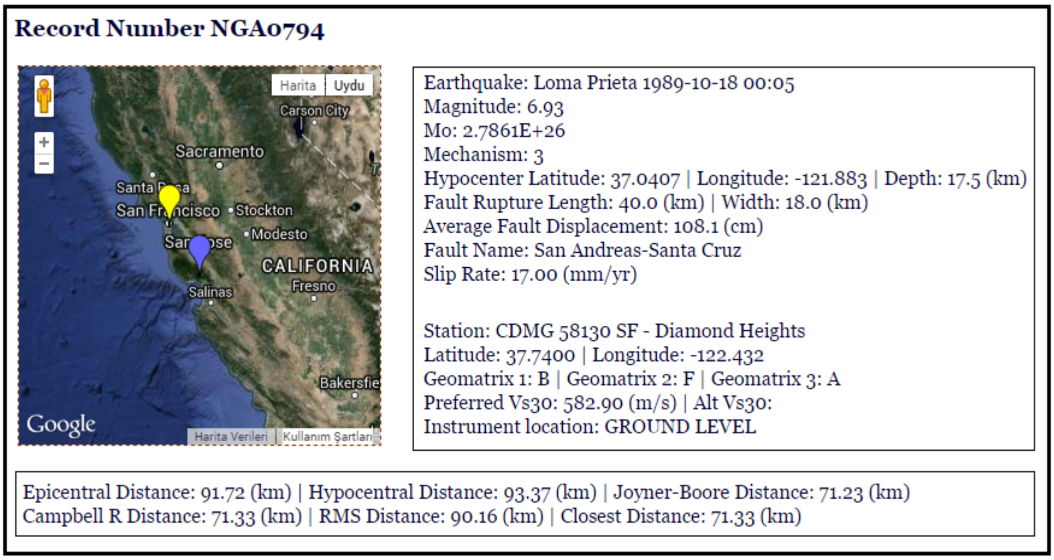


Fig. 21 DMH090 component of 1989 Loma Prieta Earthquake (CDMG STATION 58130)



Record Number NGA0794

Earthquake: Loma Prieta 1989-10-18 00:05
Magnitude: 6.93
Mo: 2.7861E+26
Mechanism: 3
Hypocenter Latitude: 37.0407 | Longitude: -121.883 | Depth: 17.5 (km)
Fault Rupture Length: 40.0 (km) | Width: 18.0 (km)
Average Fault Displacement: 108.1 (cm)
Fault Name: San Andreas-Santa Cruz
Slip Rate: 17.00 (mm/yr)

Station: CDMG 58130 SF - Diamond Heights
Latitude: 37.7400 | Longitude: -122.432
Geomatrix 1: B | Geomatrix 2: F | Geomatrix 3: A
Preferred Vs30: 582.90 (m/s) | Alt Vs30:
Instrument location: GROUND LEVEL

Epicentral Distance: 91.72 (km) | Hypocentral Distance: 93.37 (km) | Joyner-Boore Distance: 71.23 (km)
Campbell R Distance: 71.33 (km) | RMS Distance: 90.16 (km) | Closest Distance: 71.33 (km)

Fig. 22 The details of the processed seismic data by Pasific Engineering (URL8)

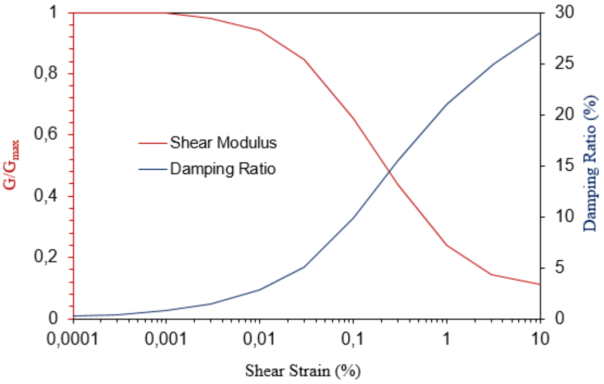


Fig. 23 Material curve 1 used in EERA and NERA programs (Bardet *et al*. 2000)

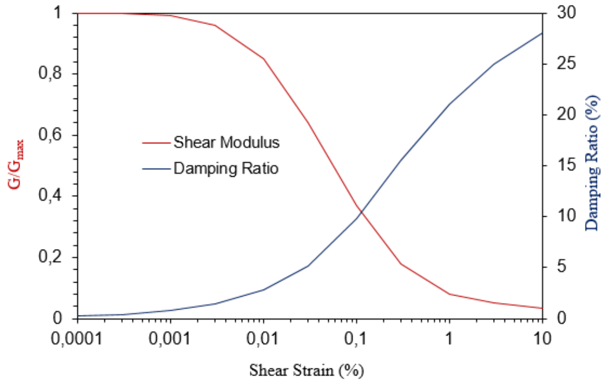


Fig. 24 Material curve 2 used in EERA and NERA programs (Bardet *et al*. 2000)

acceleration obtained by using DTASSA iterative solution approach is presented in Fig. 25. As shown in this figure, the peak ground acceleration value for the surface motion calculated by using DTASSA is 0.24817 g.

Verification of the numerical implementation of DTASSA can be obtained by comparing its results with those of EERA when both are applied to the same problem. EERA is developed in EXCEL to implement an equivalent site response analysis in frequency domain (Bardet *et al*. 2000). The same earthquake data and soil conditions are analyzed with EERA. The peak ground acceleration value for the surface motion is 0.19041 g.

A comparison between the surface acceleration for DTASSA iterative solution approach and EERA is presented in Fig. 26. A good harmony may be observed from this figure. It can be said that the comparison between results is good suggesting that DTASSA iterative solution approach tool generates comparable estimates of site response.

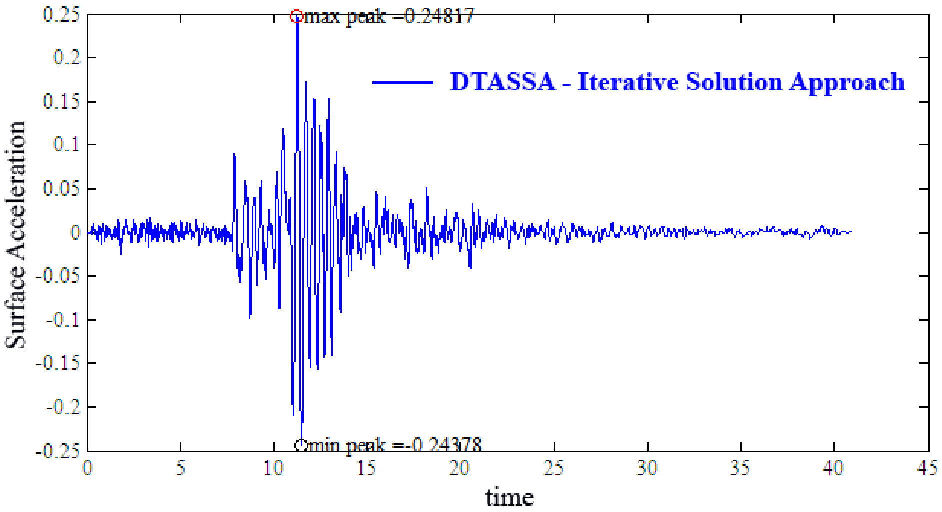


Fig. 25 Surface acceleration calculated with DTASSA by using iterative solution approach

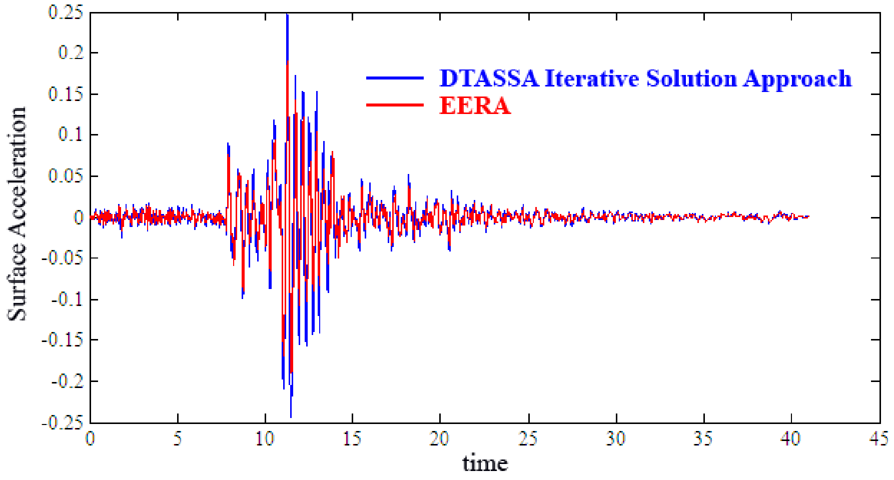


Fig. 26 Comparison between DTASSA- iterative solution approach and EERA results

5.2.2 System analysis with real time parameter updating approach

After iterative solution approach is applied to the soil, the system is reanalyzed with DTASSA by using real time parameter updating approach. The analysis results obtained by using DTASSA are presented in Fig. 27. As shown in this figure, the peak ground acceleration values for the surface motion calculated by using DTASSA is obtained as 0.21485 g.

Verification of the numerical implementation of DTASSA real time parameter updating approach tool can be obtained by comparing its results with those of NERA when both are applied to the same problem. NERA is developed in EXCEL to implement a nonlinear site response analysis in time domain. The same earthquake data and soil conditions are analyzed with NERA. The peak ground acceleration value for the surface motion is obtained as 0.17407 g.

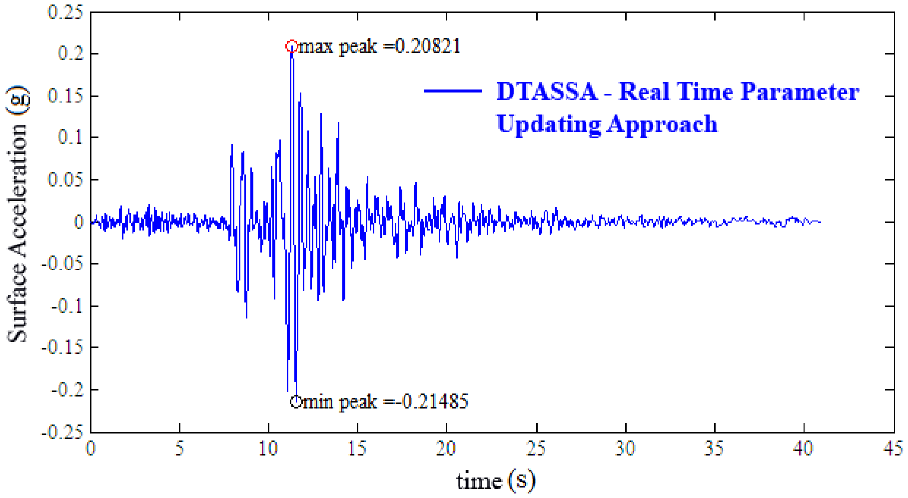


Fig. 27 Surface acceleration calculated with DTASSA by using real time parameter updating approach

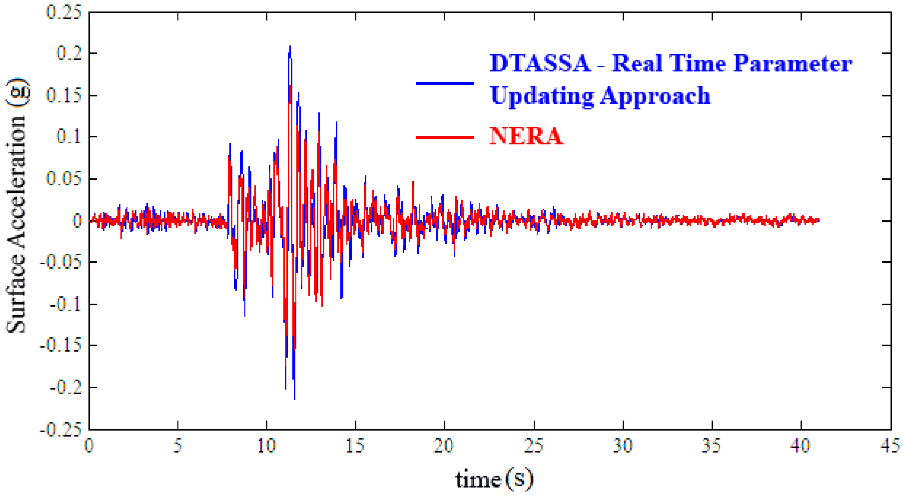


Fig. 28 Comparison between DTASSA - real time parameter updating approach and NERA results

A comparison between the surface acceleration for DTASSA-real time parameter updating approach tool and NERA is presented in Fig. 28. A good harmony may be observed from this figure. It can be said that the comparison between results is good suggesting that DTASSA-real time parameter updating approach tool generates comparable estimates of site response.

6. Conclusions

The aim of this study is to present dynamic simulation tools for monitoring seismic soil behavior in real time. The block diagrams for discrete-time analysis of seismic site amplification in layered media for vertically propagating shear waves have been constructed in the first part of this paper. The simulation models are developed by utilizing Simulink which is a software add-on to MATLAB. In this part, solution techniques considering material nonlinearities of soil are presented. The equivalent linear analysis which mostly used in literature and real time parameter updating approach which firstly used here by using the capabilities of Simulink effectively are studied to observe the seismic soil behavior. In analysis process, the system parameters may be changed real time and system response depending on this change may be observed while simulation is running. A graphical user interfaced (GUI) program called DTASSA standing for Discrete-Time Analysis of Seismic Site Amplification is presented in this study. It contains all proposed tools and techniques given in this study. In DTASSA, automatic block diagram producing system is developed and seismic site amplification for multiple soil layers may easily be investigated. Some numerical applications have been carried out to check the reliability of proposed tools and techniques. The results of DTASSA are compared with SUA, EERA and NERA programs for the particular example problems. In the numerical applications, it is seen that there is a negligible difference in the surface acceleration and the PGA values are very close to each other. The comparison between the results shows that proposed tools generates comparable estimates of site response.

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CC

Appendix I

```
function [y] = fcn(u,i)
    eml.extrinsic('f_nonlinear');
    f_nonlinear(u,i);
    y=u;


    function [y] = f_nonlinear(u,i)
    global malz_oz Q qs vs Gred2 Gsec_st
    global sim_adi
    %
    jk=malz_oz(i);
    %
    eml.extrinsic('material_data', ‘update_parameters_model_1');
    [Materials]=malz_verileri;

    if u>1e-4 & u<0.1
            eval(['sonum2(i)=interp1(log10(Materials.Model_',num2str(jk),'.damp(:,1)),Materials.
        Model_',num2str(jk),'.damp(:,2),log10(abs(u)));']);

            eval(['Gred2(i)=interp1(log10(Materials.Model_',num2str(jk),'.G(:,1)),Materials.Model
        _',num2str(jk),'.G(:,2),log10(abs(u)));']);
    Q(i)=1/(2*sonum2(i));
           assignin('base','Q',Q);
           pay=Gsec_st(i)/Gred2(i);
           vs(i)=sqrt(pay/qs(i));
           assignin('base','vs',vs);
           update_parameters;
           set_param(sim_adi,'SimulationCommand','update');
           y = u;
    end
```

```
function update_patameters
    global n r tau Q T dt dt_ilk teta alfa t_kats vs qs vr    qr hs

    for j=1:n-1
        r(j)    = f_r(vs(j) , qs(j), vs(j+1) , qs(j+1) );
    end
    r(n)    = f_r(vs(n) , qs(n), vr , qr);
    assignin('base','r',r);

    for j=1:n
        tau(j) = f_tau(hs(j),vs(j));
    end
    assignin('base','tau',tau);

    for j=1:n
        T(j)=pi*tau(j)/(Q(j)*log(2));
    end
    tmin_2=min(T)/t_kats;
    T(1:n)=tmin_2;

    dt=dt_ilk;
    while dt>min(T)
        dt=dt/2;
    end
    assignin('base','dt',dt);
    assignin('base','T',T);

    for j=1:n
        teta(j)=log(2)*Q(j)*T(j)/tau(j);
    end
    assignin('base','teta',teta);

    for j=1:n
        [alfa(j)]=f_alfa(teta(j));
    end
    assignin('base','alfa',alfa);
```