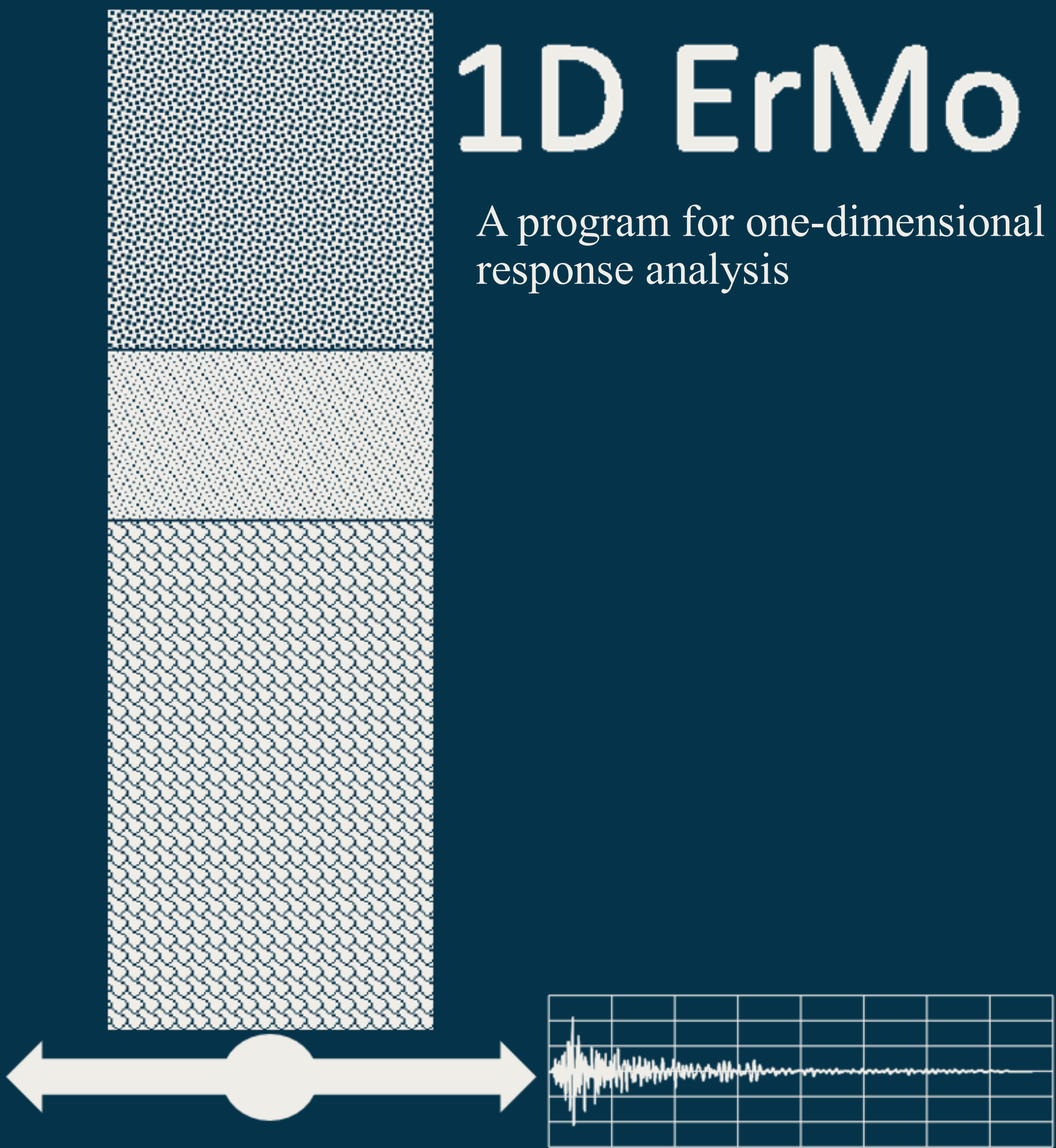
GeoMechanica
Geotechnical Engineering Services



1D ErMo

A program for one-dimensional earth response analysis

Contents

1D ErMo

A program for calculating ground response subject to seismic excitation.

1. Introduction

Design of earthquake resistant structures requires knowing the motion characteristics at the ground surface due to seismic excitations. This manual introduces a software tool called 1D ErMo designed for the analysis of ground response to earthquake acceleration and motion through a 2D representation of the soil column using springs and dampers. This document provides an exposition of the theory behind the software and its application to real life earthquakes. It aims to equip users with the necessary knowledge to conduct comprehensive seismic response simulations, thereby advancing the understanding and application of geotechnical earthquake engineering principles.

2. Theory

The program uses a 2D representation of the soil medium based on connected springs and dampers. These springs and dampers represent soil stiffness and damping respectively. In addition, the springs and dampers are attached to mass which represents the soil inertia and resistance for movement. For a soil profile like that shown in figure 1-a, the idealized spring-damper-mass system is shown in figure 1-b.

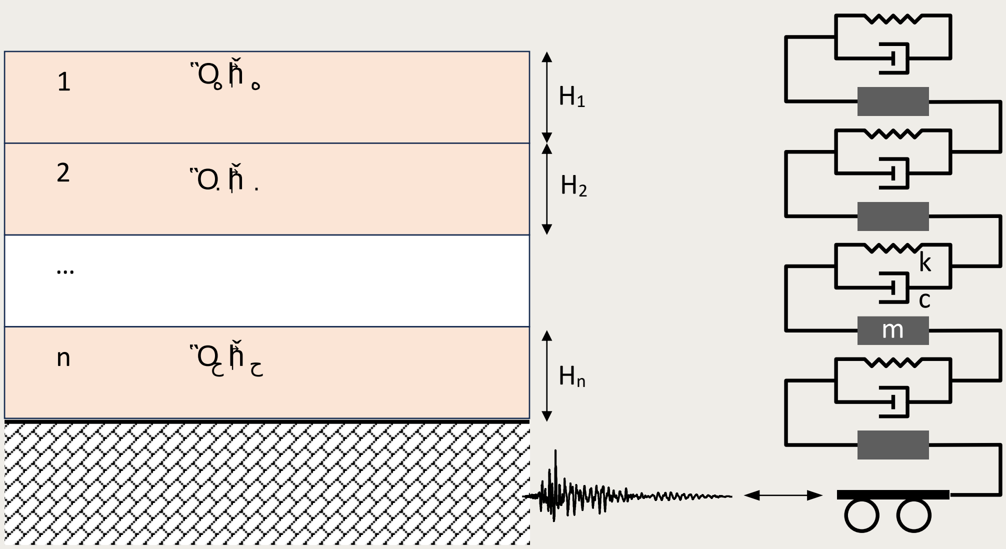


Figure 1: Layers of soil and the equivalent 1D model to analyze earthquake response.

For the system shown in figure 1-b, the stiffness, damping and mass of each layer is calculated as follows respectively,

$$\text{Ω̃}_{i} \quad \frac{\text{Ὁ}_{i}}{\text{Ὁ}_{i}} \qquad (1)$$

$$\text{ώ̃}_{i} \quad \frac{\text{ζΩ̃}_{i}\; \text{Ἰ} \;\; \text{Ἰρ π π}}{\text{ Ἰ }} \qquad (2)$$

$$\text{ά}_{i} \quad \frac{\text{Ἰ}_{i}\; \frac{\text{ώ̃}_{i}}{\text{ζ}}}{\text{Ὁ}} \qquad (3)$$

In equation 2, ‒ is the percentage of damping from the stiffness of the spring. In equation 3, Ὁ is the gravitational constant (Ὁ ωᶊ ρά Ἰί .

Each soil layer can be divided into sublayers to improve accuracy of the model. The stiffness, damping, and mass matrices are calculated for each sublayer and combined to form the global matrices as:

$$\text{ὐ} \quad \begin{bmatrix} \text{Ω̃}_{o} & -\text{Ω̃}_{o} & 0 & 0 & é \\ \text{Ω̃}_{o} & \text{Ω̃}_{o} \;\; \text{Ω̃} & 0 & 0 & é \\ 0 & \text{Ω̃} & \text{Ω̃} \;\; \text{Ω̃}_{l} & -\text{Ω̃}_{l} & é \\ 0 & 0 & \text{Ω̃}_{l} & é & é \\ é & é & é & é & \text{Ω̃}_{r} \end{bmatrix} \qquad (4)$$

$$[C]= \begin{bmatrix} \text{ώ̃}_{o} & -\text{ώ̃}_{o} & 0 & 0 & é \\ \text{ώ̃}_{o} & \text{ώ̃} \;\; \text{ώ̃} & 0 & 0 & é \\ 0 & \text{ώ̃} & \text{ώ̃} \;\; \text{ώ̃}_{l} & -\text{Ω̃}_{l} & é \\ 0 & 0 & \text{ώ̃}_{l} & é & é \\ é & é & é & é & \text{ώ̃}_{r} \end{bmatrix} \qquad (5)$$

$$\text{ὒ} \quad \begin{bmatrix} \text{ά}_{o} & -\text{π} & 0 & 0 & é \\ \text{π} & \text{ά}_{o} \;\; \text{ά}_{.} & 0 & 0 & é \\ 0 & \text{π} & \text{ά} \;\; \text{ά}_{l} & -0 & é \\ 0 & 0 & \text{π} & é & é \\ é & é & é & é & \text{ά}_{r} \end{bmatrix} \qquad (6)$$

Once the matrices are assembled, the acceleration is applied at the rock base and the equation of motion is defined as

$$\text{ὒ} \;\; \text{ό} \quad \text{ὅ} \;\; \text{ό} \quad \text{ὐ} \;\; \text{ό ὸ} \quad \text{Ὁ ὸ} \qquad (7)$$

Where, ό , ό , ό ὸ are the vectors of global acceleration, velocity, and displacement, respectively. Ὁ ὸ is the vector of global forces and Ὁ$_{i}$ = ό$_{>}$ ^{z} ά$_{i}$ 8The equation is solved in the time domain using a trapezoidal integration algorithm. To find the acceleration, velocity and displacement at the ground level. Once solved, these values can be applied in structural analysis software to assess the behavior of any structure subject to earthquake motions.

3. Engineering Manual

This section demonstrates how to use 1D ErMo to obtain ground motions. The program GUI makes it very easy and intuitive to analyze soil layers under any type of motion. The first step is to prepare a CSV file the contains the earthquake data. The CSV file should be formatted such as the time is in the first column of the sheet and the ground acceleration is in the second column. One source to obtain acceleration data can be found in https://ngawest2.berkeley.edu/.

3.1. Preparing and importing an earthquake motion obtained from PEER

An example CSV file is obtained from the website for the 1989 Loma Prieta earthquake. you can find this file in the application installation folder under the name “RSN755_LOMAP_CYC28 [illegible] Orig”. The data needs processing before it can be used in 1D ErMo. Open a spreadsheet program (preferably Excel) and chose File → Open and select the file. The program will show a window as shown in figure 3. Click on next and make sure the columns separate the data properly as shown in figure 4. Once opened by excel make the column empty as shown in figure 5. Two important information should be identified, which are DT and NPTS. These refer to the time increment and number of data points respectively. The data is sorted as such the first row contains the first 5 points of data and the second row contains the data from 5 to 10 and so on. This arrangement can be different from one PEER file to another. In this example, the time increment is 0.005 seconds and 7999 datapoints are available. This means that the duration of the earthquake is almost 40 seconds. Now choose empty cell in excel and paste the following formula “=INDEX($B$1:F**1604**,1+INT((ROW(A1)-1)/5),MOD(ROW(A1)-1,**5**)+1)”. Two important numbers in this formula that need to be adjusted for other data. The number 1604 (in red) which the number of rows the data is stored in and the number 5 (in blue) which is the number of columns that data is stored in. adjust these numbers accordingly. The excel sheet should look something like that shown in figure 5. Drag the formula in this cell for 7999 (NPTS). In the column to the left of the new data add time increments. To the right of the data multiply the newly generated cell with gravitational acceleration ([illegible]) you should have data that looks like what is shown in figure 6. A plot of time against acceleration for the Loma Prieta earthquake is shown in figure 7. Now the time and acceleration columns are copied and pasted in a new excel sheet named “Loma Prieta Processed”. Make sure to remove columns’ headi

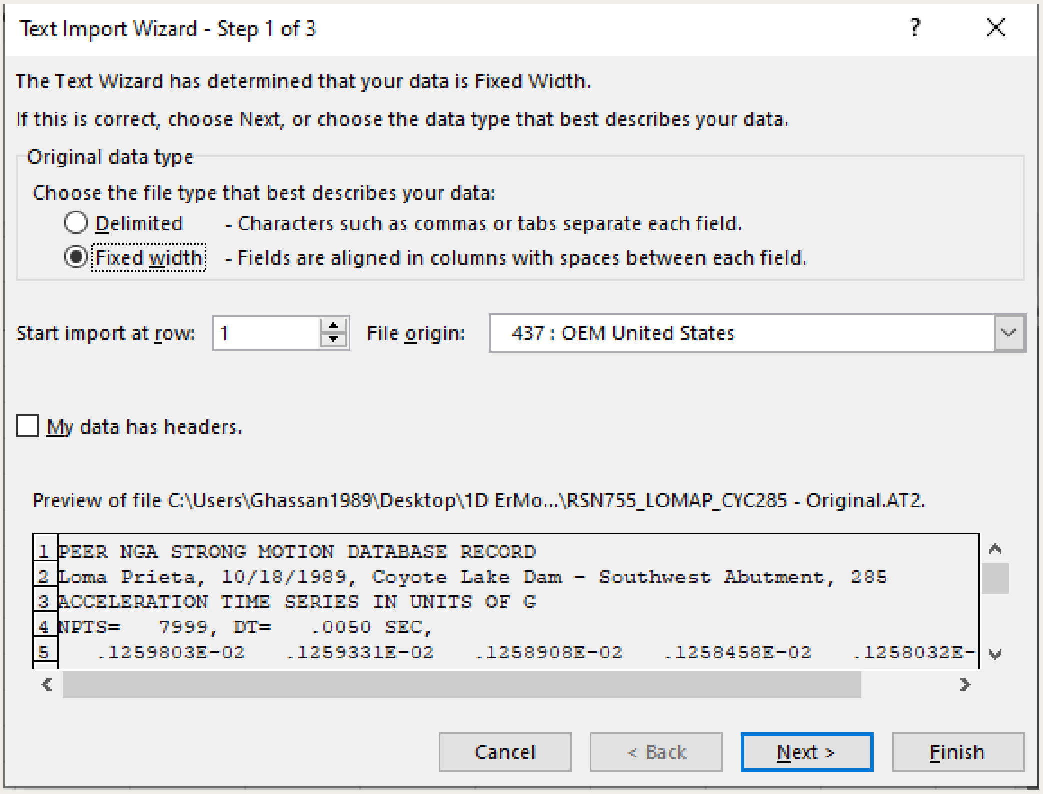


Figure 2: Window shown by excel once the PEER acceleration file is opened

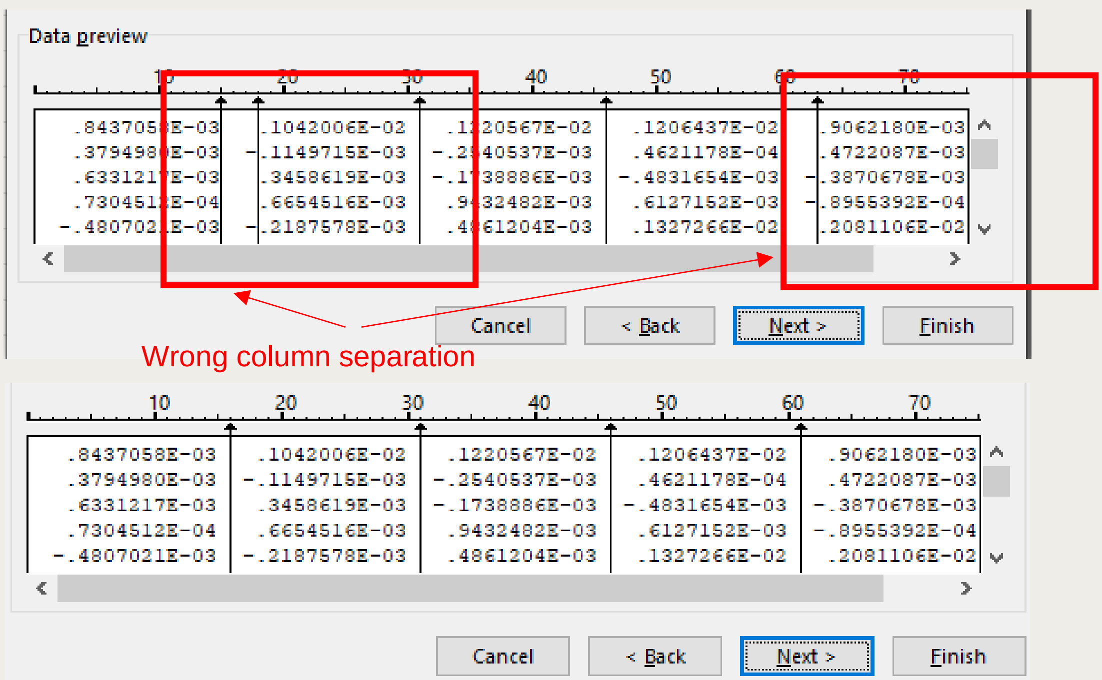
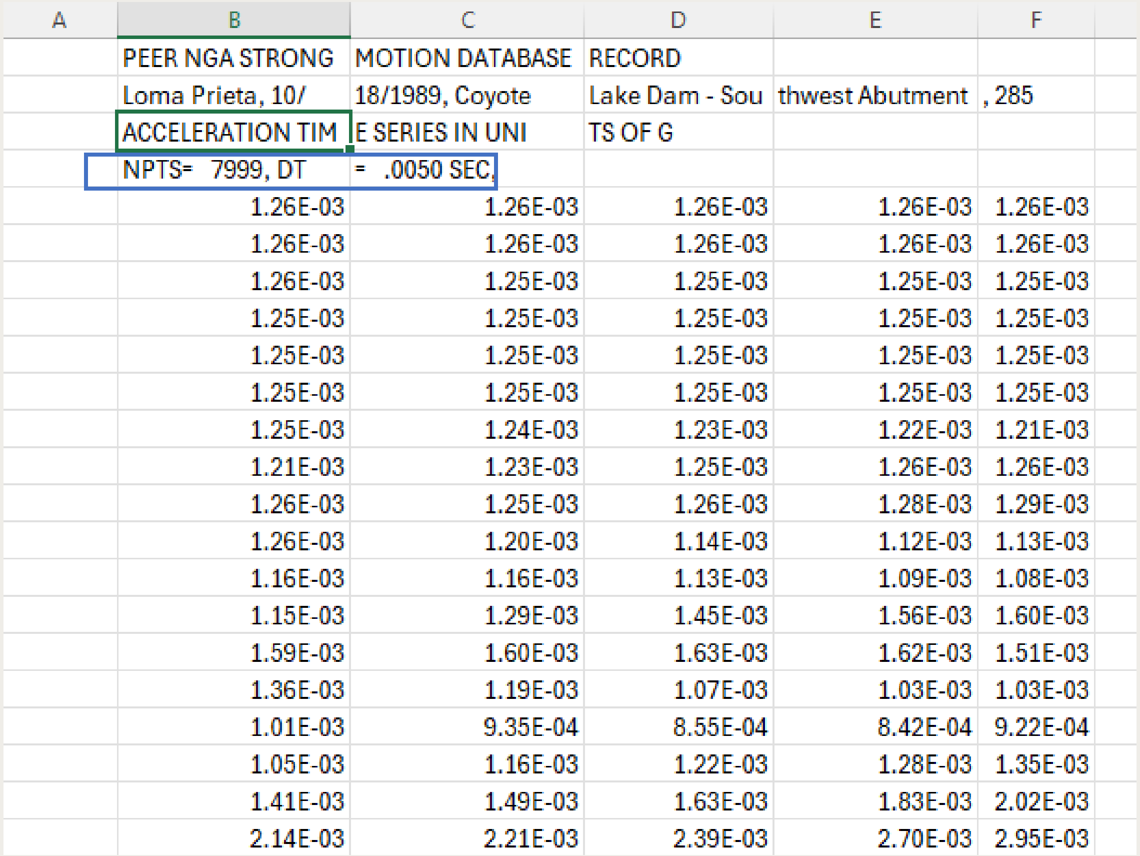
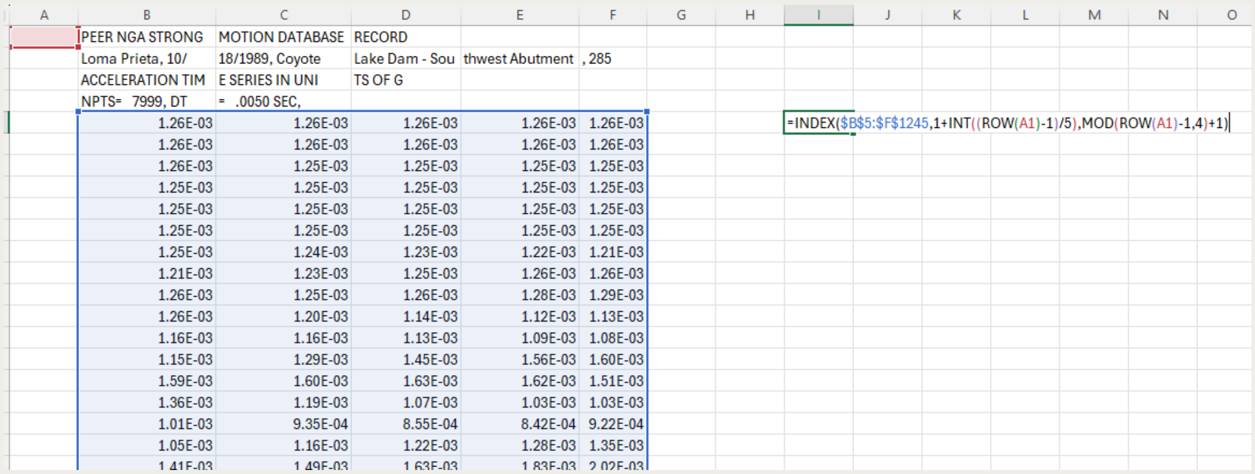


Figure 3: Adjusted column separator to mitigate error made by excel when reading the file



A	B	C	D	E	F
	PEER NGA STRONG	MOTION DATABASE	RECORD		
	Loma Prieta, 10/	18/1989, Coyote	Lake Dam - Sou	thwest Abutment	, 285
	ACCELERATION TIM	E SERIES IN UNI	TS OF G		
	NPTS= 7999, DT	= .0050 SEC,			
	1.26E-03	1.26E-03	1.26E-03	1.26E-03	1.26E-03
	1.26E-03	1.26E-03	1.26E-03	1.26E-03	1.26E-03
	1.26E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03
	1.25E-03	1.24E-03	1.23E-03	1.22E-03	1.21E-03
	1.21E-03	1.23E-03	1.25E-03	1.26E-03	1.26E-03
	1.26E-03	1.25E-03	1.26E-03	1.28E-03	1.29E-03
	1.26E-03	1.20E-03	1.14E-03	1.12E-03	1.13E-03
	1.16E-03	1.16E-03	1.13E-03	1.09E-03	1.08E-03
	1.15E-03	1.29E-03	1.45E-03	1.56E-03	1.60E-03
	1.59E-03	1.60E-03	1.63E-03	1.62E-03	1.51E-03
	1.36E-03	1.19E-03	1.07E-03	1.03E-03	1.03E-03
	1.01E-03	9.35E-04	8.55E-04	8.42E-04	9.22E-04
	1.05E-03	1.16E-03	1.22E-03	1.28E-03	1.35E-03
	1.41E-03	1.49E-03	1.63E-03	1.83E-03	2.02E-03
	2.14E-03	2.21E-03	2.39E-03	2.70E-03	2.95E-03

Figure 4: PEER acceleration file opened in excel for data processing



A	B	C	D	E	F	G	H	I
	PEER NGA STRONG	MOTION DATABASE	RECORD					
	Loma Prieta, 10/	18/1989, Coyote	Lake Dam - Sou	thwest Abutment	, 285			
	ACCELERATION TIM	E SERIES IN UNI	TS OF G					
	NPTS= 7999, DT	= .0050 SEC,						
	1.26E-03	1.26E-03	1.26E-03	1.26E-03	1.26E-03			=INDEX($B$5:$F$1245,1+INT((ROW(A1)-1)/5),MOD(ROW(A1)-1,4)+1)
	1.26E-03	1.26E-03	1.26E-03	1.26E-03	1.26E-03			
	1.26E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03			
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03			
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03			
	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03			
	1.25E-03	1.24E-03	1.23E-03	1.22E-03	1.21E-03			
	1.21E-03	1.23E-03	1.25E-03	1.26E-03	1.26E-03			
	1.26E-03	1.25E-03	1.26E-03	1.28E-03	1.29E-03			
	1.26E-03	1.20E-03	1.14E-03	1.12E-03	1.13E-03			
	1.16E-03	1.16E-03	1.13E-03	1.09E-03	1.08E-03			
	1.15E-03	1.29E-03	1.45E-03	1.56E-03	1.60E-03			
	1.59E-03	1.60E-03	1.63E-03	1.62E-03	1.51E-03			
	1.36E-03	1.19E-03	1.07E-03	1.03E-03	1.03E-03			
	1.01E-03	9.35E-04	8.55E-04	8.42E-04	9.22E-04			
	1.05E-03	1.16E-03	1.22E-03	1.28E-03	1.35E-03			
	1.41E-03	1.49E-03	1.63E-03	1.83E-03	2.02E-03			

Figure 5: Formula to make the data points in one column.

A	B	C	D	E	F	G	H	I	J
	PEER NGA STRONG	MOTION DATABASE	RECORD						
	Loma Prieta, 10/	18/1989, Coyote	Lake Dam - Sou	thwest Abutment	, 285				
	ACCELERATION TIM	E SERIES IN UNI	TS OF G						
	NPTS= 7999, DT	= .0050 SEC,					time	Acc (g)	Acc in m/s2
	0.00125980	0.00125933	0.00125891	0.00125846	0.00125803		0.000	0.00126	0.012358667
	0.00125759	0.00125717	0.00125674	0.00125629	0.00125582		0.005	0.001259	0.012354037
	0.00125531	0.00125468	0.00125390	0.00125296	0.00125191		0.010	0.001259	0.012349887
	0.00125092	0.00125019	0.00124994	0.00125034	0.00125107		0.015	0.001258	0.012345473
	0.00125145	0.00125114	0.00125012	0.00124834	0.00124678		0.020	0.001258	0.012341294
	0.00124707	0.00124969	0.00125251	0.00125291	0.00125024		0.025	0.001258	0.012336987
	0.00124588	0.00123985	0.00122968	0.00121644	0.00120639		0.030	0.001257	0.012332867
	0.00120935	0.00122701	0.00124924	0.00126355	0.00126370		0.035	0.001257	0.0123286
	0.00125635	0.00125235	0.00125978	0.00127860	0.00128662		0.040	0.001256	0.012324175
	0.00125823	0.00120034	0.00114279	0.00111685	0.00113106		0.045	0.001256	0.012319545
	0.00115861	0.00116127	0.00113072	0.00108698	0.00107718		0.050	0.001255	0.012314542
	0.00114671	0.00129119	0.00144785	0.00155572	0.00159686		0.055	0.001255	0.012308411
	0.00159118	0.00159995	0.00163359	0.00161719	0.00151400		0.060	0.001254	0.012300769
	0.00135597	0.00119015	0.00107198	0.00102982	0.00103358		0.065	0.001253	0.012291557
	0.00101390	0.00093528	0.00085525	0.00084163	0.00092231		0.070	0.001252	0.012281257
	0.00104902	0.00115670	0.00122122	0.00128354	0.00134664		0.075	0.001251	0.012271476
	0.00140685	0.00149465	0.00163361	0.00183081	0.00202306		0.080	0.00125	0.012264325
	0.00213646	0.00221267	0.00239271	0.00269655	0.00295452		0.085	0.00125	0.012261951
	0.00293234	0.00255828	0.00199462	0.00150463	0.00121851		0.090	0.00125	0.012265865
	0.00114744	0.00119391	0.00120462	0.00115448	0.00106396		0.095	0.001251	0.012273016
	0.00096174	0.00085466	0.00075252	0.00064544	0.00054649		0.100	0.001251	0.012276675
	0.00050157	0.00056937	0.00075546	0.00100459	0.00120643		0.105	0.001251	0.012273693

Figure 6: Final earthquake motion data after processing.

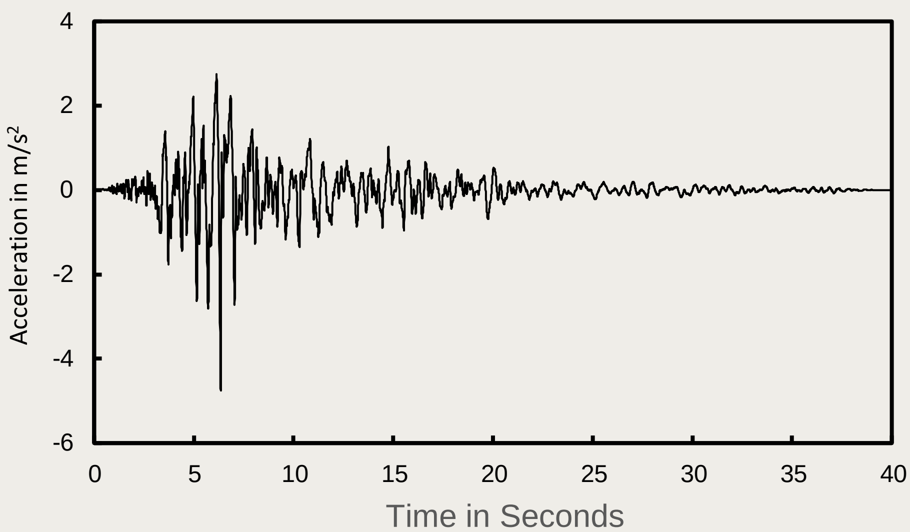


Figure 7: Time History record of the Loma Prieta earthquake.

The time and acceleration are now ready to be imported to the 1D ErMo application. First make sure you add the time increment in time step size entry box. In this example it is 0.005. Then, click on the import button shown in the 1D ErMo controls (see Figure 8). This will open a window that will allow you to locate and import the acceleration data. Once the acceleration data is imported, a plot will appear in the main window showing the acceleration vs. time curve.

Figure 8: Control panel of 1D ErMo. From left to right: Import soil profile, delete a soil layer, import earthquake motion, and calculate.

3.2. Preparing the soil profile

Th second input needed in 1D ErMo is to input a soil profile with the shear modulus in ὺ ΰ⁄ά ᶻ and the unit weight in ὺ ΰ⁄ά ᶾ. This can be done in two ways. Either manually from the program interface or preparing and importing an excel sheet with the soil layers info. The first method is proper for non-discretized soil layers while the second option is more proper for soil layers that are discretized to sublayers to enhance accuracy.

The soil shear wave velocity data considered in this example is shown in figure 9. The average shear wave velocity line is considered for calculating the soil shear modulus as

Ὃ ” ὺ (7)

With ” assumed to be ρ ψ πὺ⁄ά ᶾ. The shear modulus can be calculated from the formula and is shown in figure 9. The soil profile can be divided into 3 layers and using a ὼ ἁ ρά ἧ 120 sublayers can be used to descritize the three layers. A spreadsheet was prepared with the the sublayers and the corresponding shear modulus. The spreadsheet must be 4 columns and should look something like that shown in figure 10.

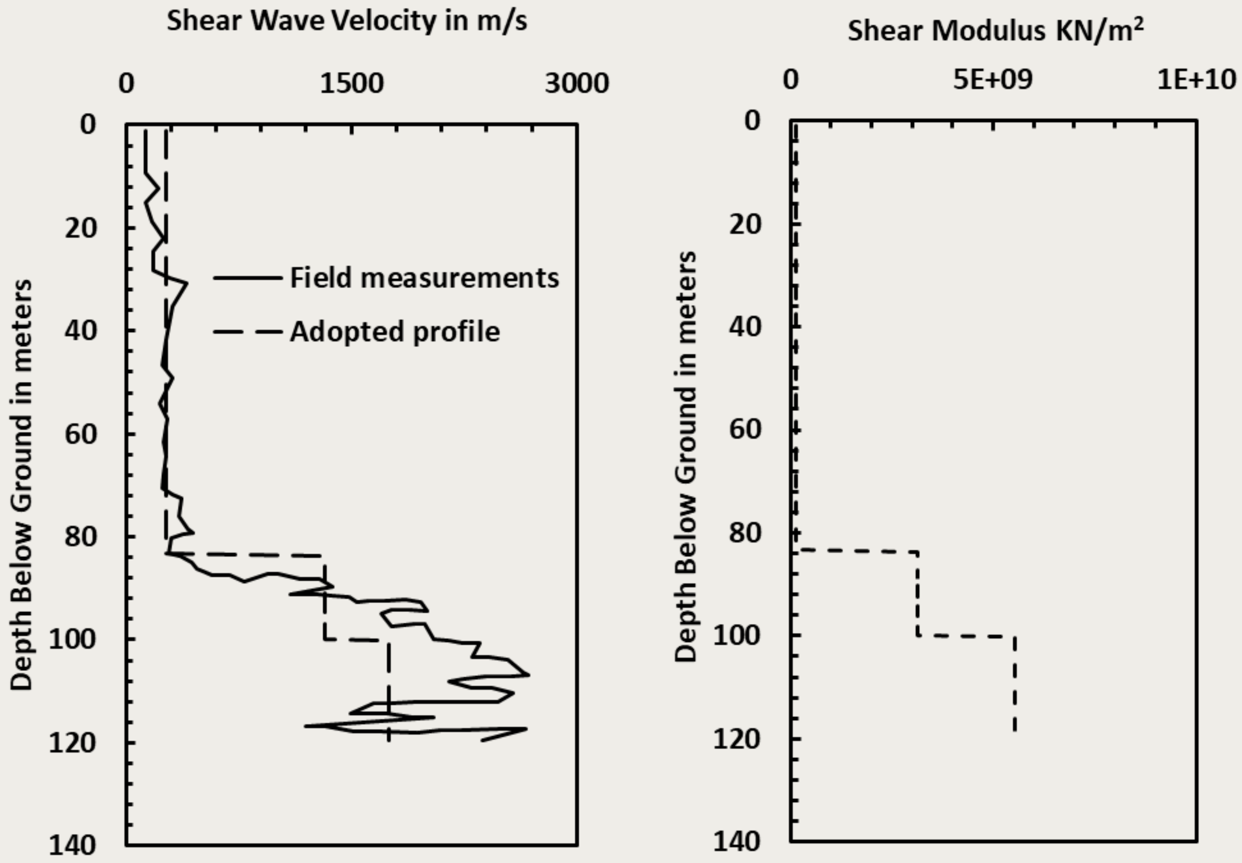


Figure9: Soil profileshowing shear wave velocity and shear modulus.

	A	B	C	D	E
1	layer num	z	γ	G	
2	1	1	17658	1.34E+08	
3	2	1	17658	1.34E+08	
4	3	1	17658	1.34E+08	
5	4	1	17658	1.34E+08	
6	5	1	17658	1.34E+08	
7	6	1	17658	1.34E+08	
8	7	1	17658	1.34E+08	
9	8	1	17658	1.34E+08	
10	9	1	17658	1.34E+08	
11	10	1	17658	1.34E+08	
12	11	1	17658	1.34E+08	
13	12	1	17658	1.34E+08	
14	13	1	17658	1.34E+08	
15	14	1	17658	1.34E+08	
16	15	1	17658	1.34E+08	
17	16	1	17658	1.34E+08	
18	17	1	17658	1.34E+08	
19	18	1	17658	1.34E+08	
20	19	1	17658	1.34E+08	
21	20	1	17658	1.34E+08	
22	21	1	17658	1.34E+08	
23	22	1	17658	1.34E+08	

Figure10: Spreadsheet of soil layers prepared for 1D ErMo Export

All input parameters are ready, the damping is set to 5% at a target frequency of 10 Hz. Analysis is run to obtain the acceleration, velocity, and displacement at the ground surface. Click on the calculate button and wait until new tabs for the results appear which indicate the program has finished solving and the results are plotted on the plot area located under the at surface tab. A screenshot showing the acceleraiton at the gorund surface is shown in figure 11. You can click on export and the program will export the results to an escel file which can be used for further processing and with other software packages (e.g. structutral analysis software). Another plot can also show the plots across the layers at certain time step.

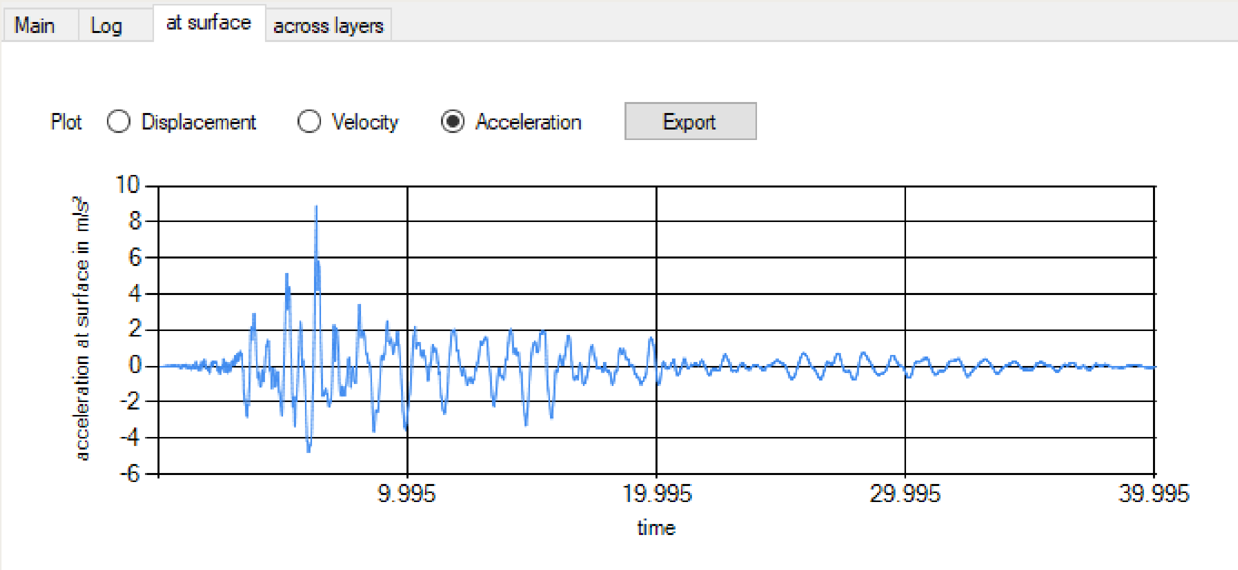


Figure11: Results of 1D ErMo showing acceleration at ground surface.

The same earthquake accelration and soil profile are modeled in PLAXIS 2D. the reslts of the displacmenet, velocity and acceleraiton compared to 1D ErMo are showin in figure 12. Both programs produced similar results. You can view the resuls in th PLAXIS u a vò.

4. Comparison with other programs

4.1. Comparison with ProShake 2.0

Proshake 2.0 is a program that is used for the calculation of 1D ground response similar to 1D ErMo. However, the 2 programs approach the problem differently. in this section, the two approaches are compared in obtaining the maximum surface acceleration, velocity and displacement due to seismic excitation. Different earthquake acceleration records are used in the comparison and the output of the two programs is presented.

The soil profile was homogenous and 30 m to bedrock. The shear modulus of the soil was 7.4E+6 Pascals. The unit weight was 19 KN/m$^{3.}$ In 1D ErMo, the soil was divided to 300 elements with each element having a 0.1 m thickness. The damping value in 1D ErMo is applied at frequency of 1 Hz. The earthquake acceleration data used for comparison were EL Centro 1940, Petrolia 1992, Taft 1952 and Topanga 1994. The records are shown in figures 12. The ground acceleration records were inserted in Proshake 2.0 and 1D ErMo and analyses were carried out using both programs. Results of surface acceleration, velocity and displacement are plotted respectively in figures 13, 14, 15, and 16.

4.2.Comparison with PLAXIS

The finite element code PLAXIS Can be used for 1D ground response calculation. A model was set with the same soil properties in the previous comparison with Proshake 2.0. The same four earthquake acceleration records shown in figure 12 were applied to the whole soil column. The results of the comparison are shown in figures 17, 18, 19 and 20.

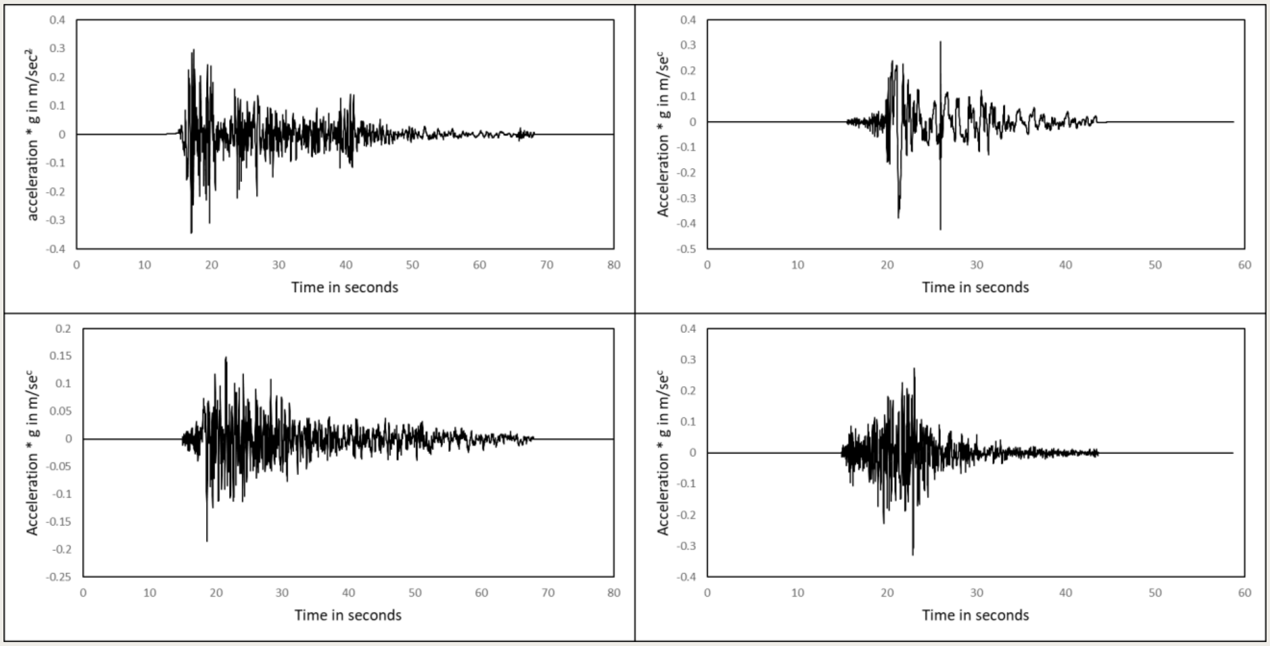


Figure 12: Earthquake acceleration records used in comparison. top left: El Centro 1940. top right: Petrolia 1992. bottom left: TAFT 1952. Bottom right: Topanga 1994.

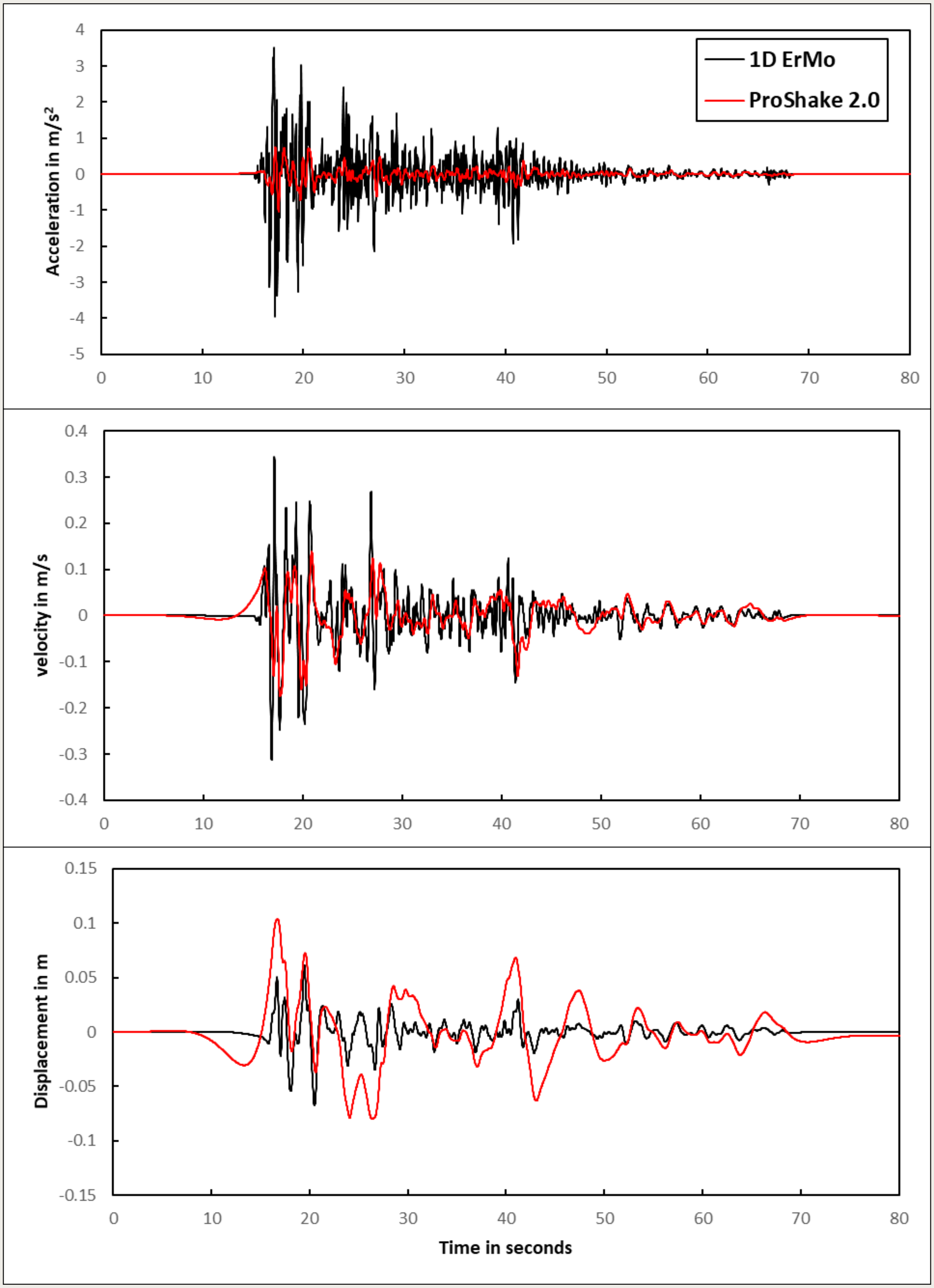


Figure 13: Results at surface of EL Centro earthquake analyses at 20% damping

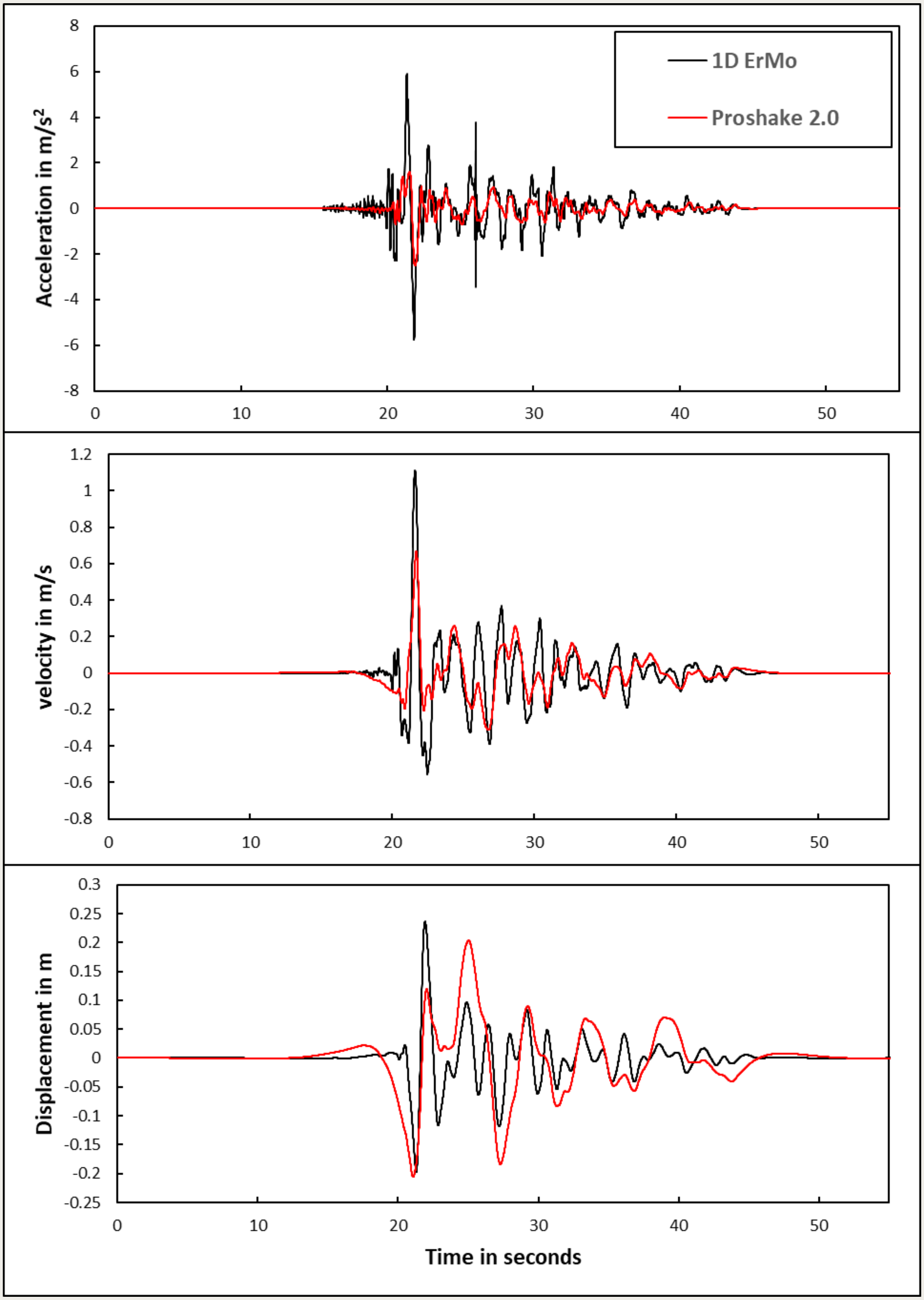


Figure 14: Results at surface of Petrolia earthquake analyses at 10% damping.

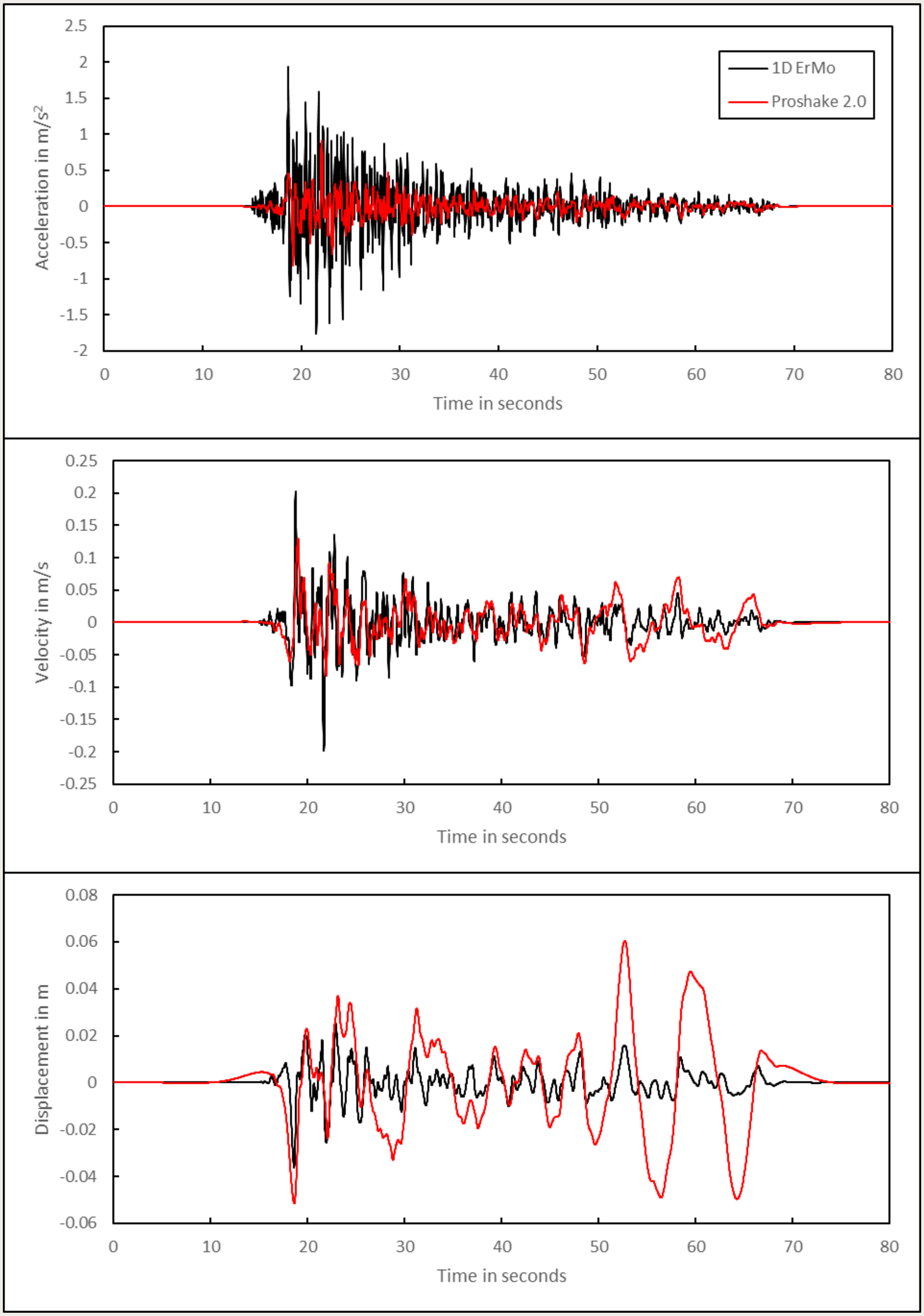


Figure 15: Results at surface of TAFT earthquake analyses at 20% damping.

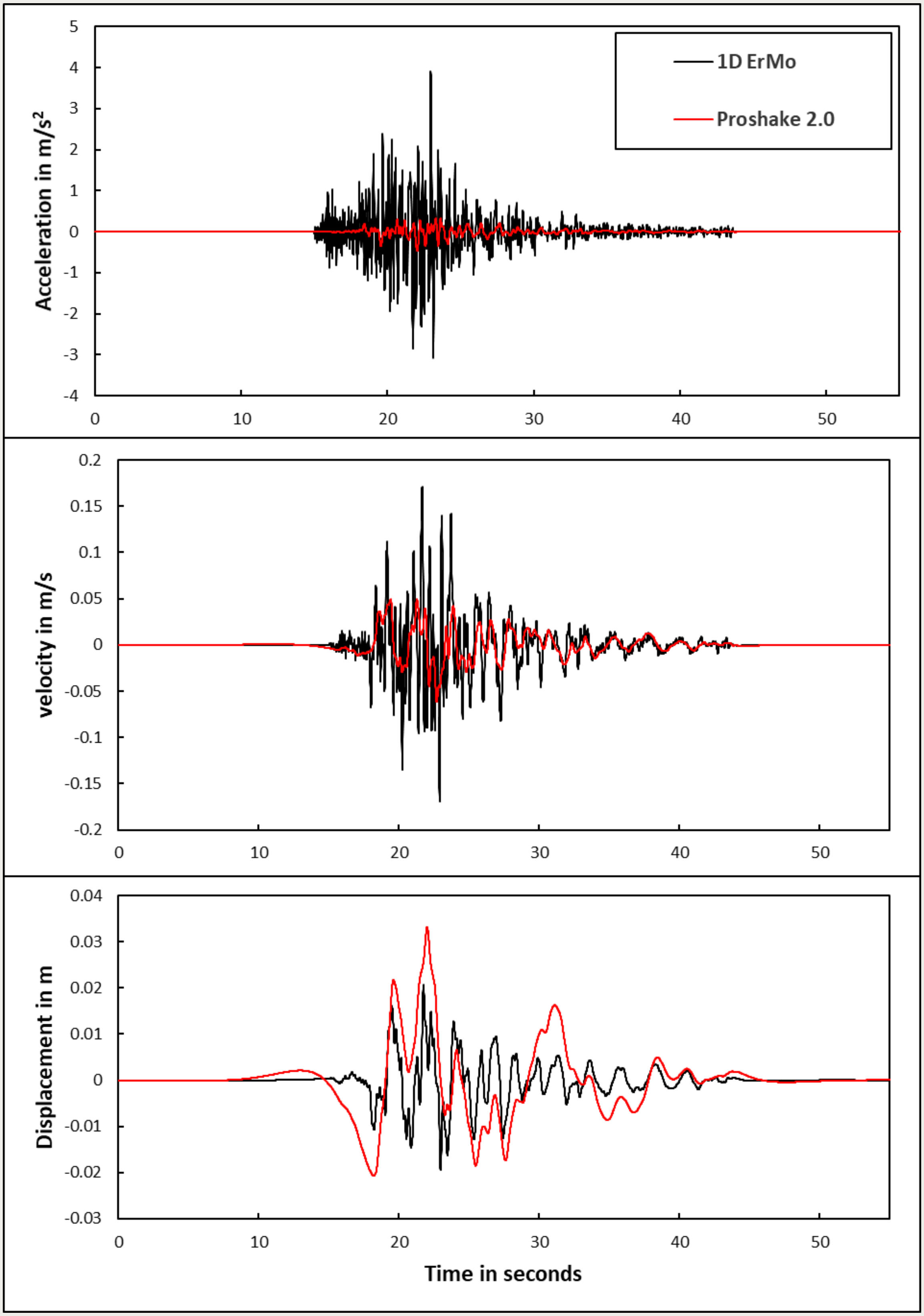


Figure 16: Results at surface of Topanga earthquake analyses at 20% damping.

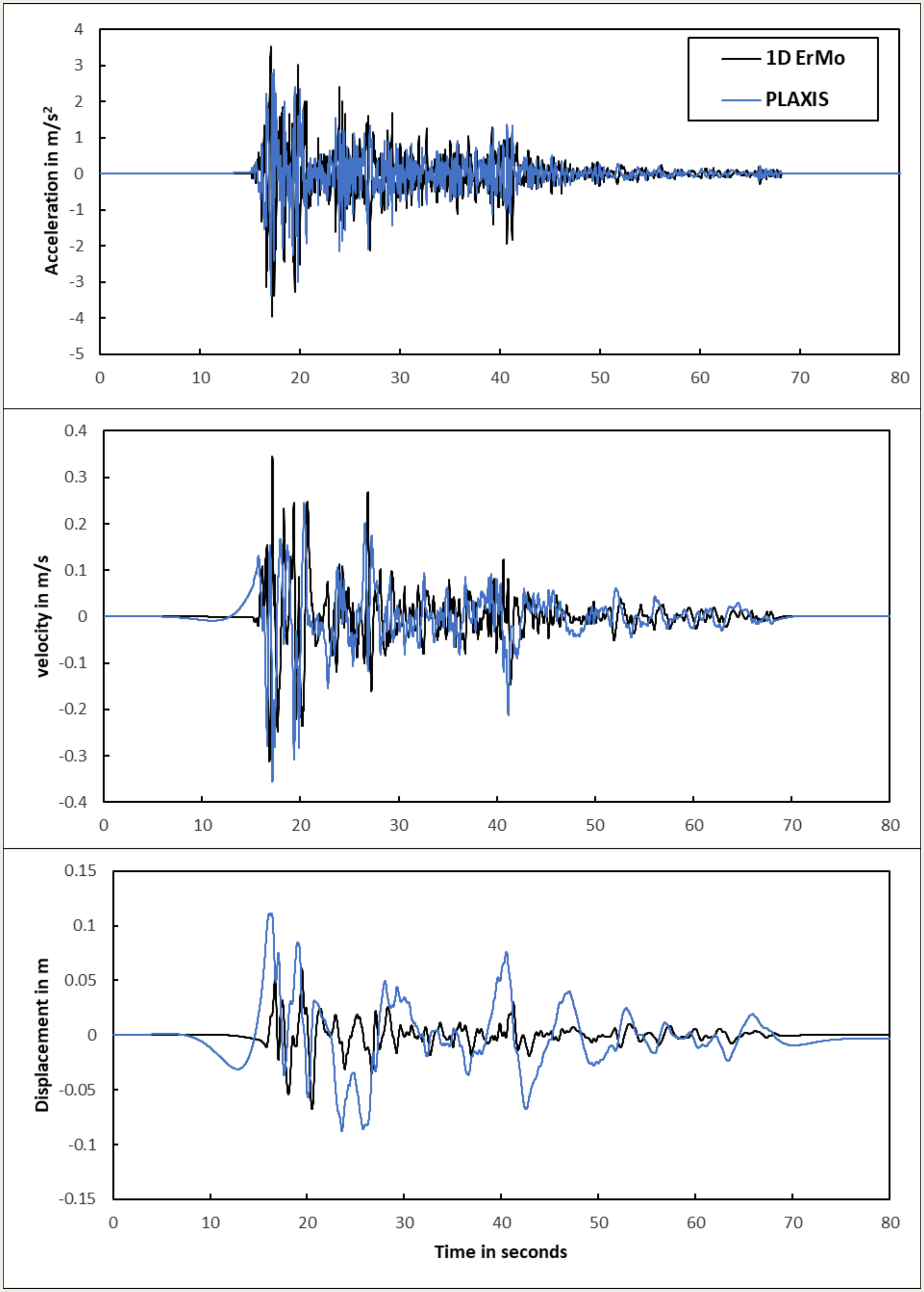


Figure 17: Results at surface of EL Centro earthquake analyses at 20% damping.

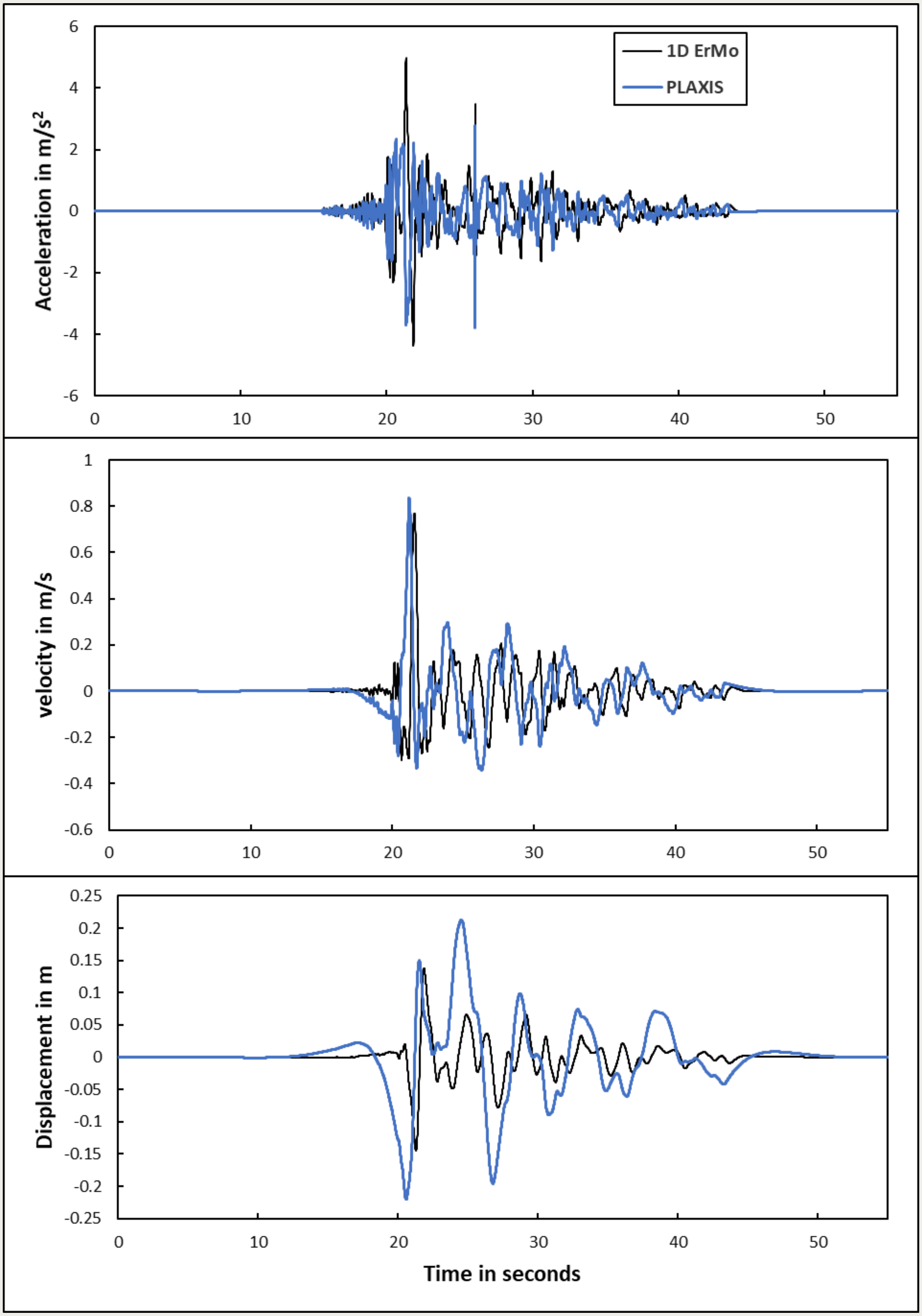


Figure 18: Results at surface of Petrolia earthquake analyses at 20% damping.

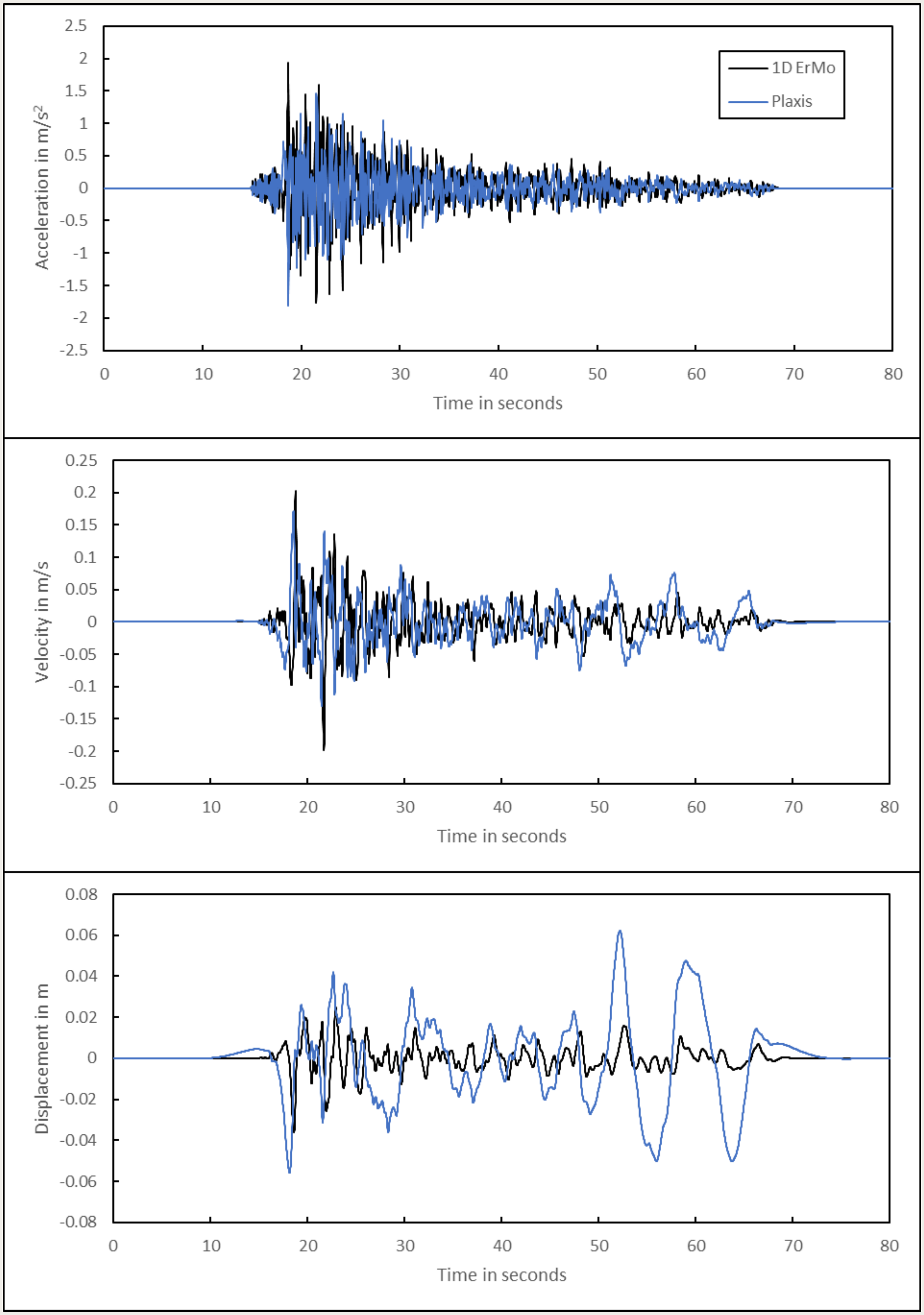


Figure 19:Results at surface of TAFT earthquake analyses at 20% damping.

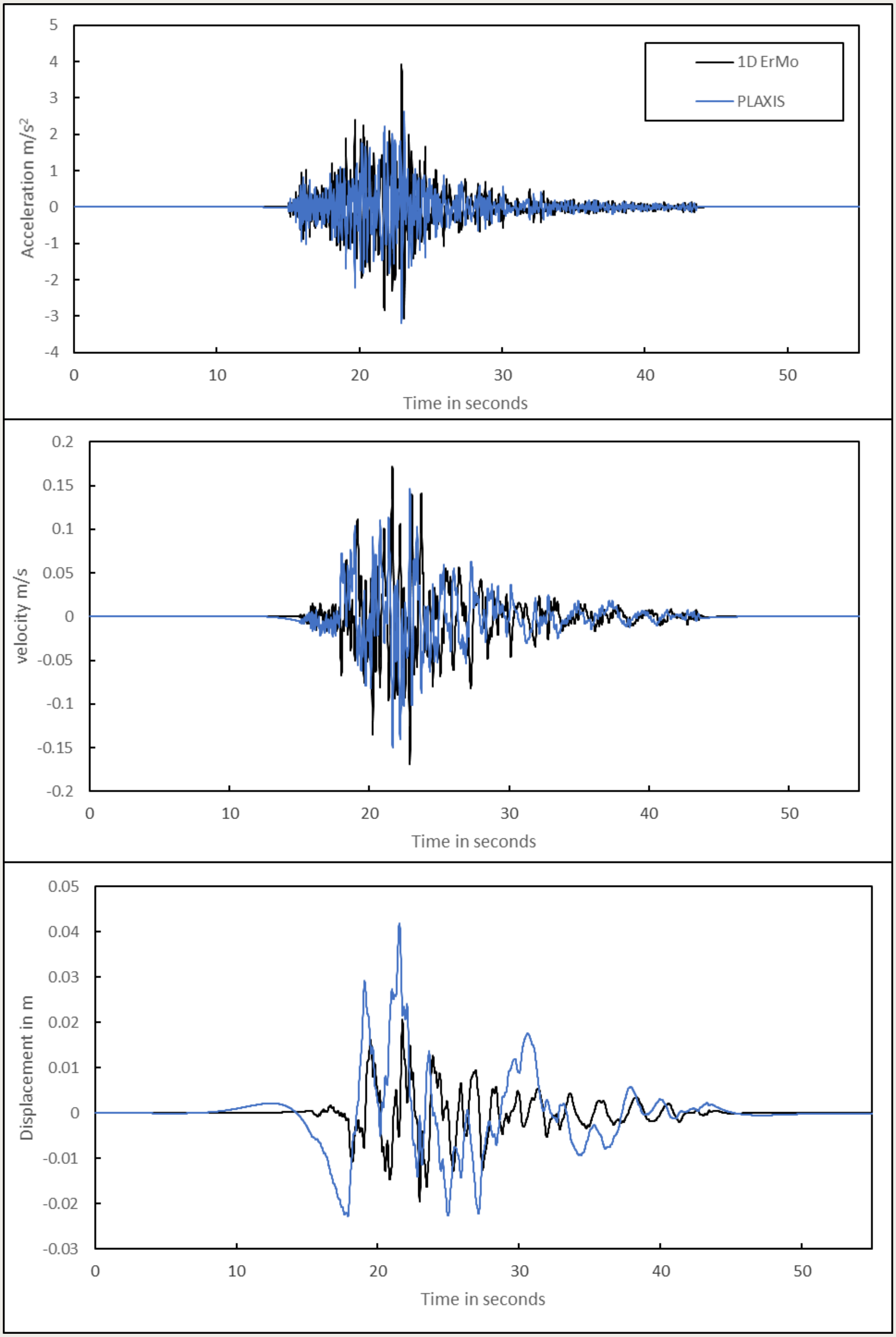


Figure 20: Results at surface of Topanga earthquake analyses at 20% damping.