University of California and

Lawrence Berkeley National Laboratory

Real-ESSI Short Course Examples

Day 1: Overview

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Day 3: Nonlinearity

4. December, 2017

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Chapter 1

Introduction

Real-ESSI is constructed with x2go remote desktop on Amazon Web Service (AWS). To use the Real-ESSI cloud service, users need to install the x2go client on their operating systems.

1.1 Install x2go client

Before connect to Real-ESSI cloud, users should install the client-side of x2go.

1.1.1 Install the client-side of x2go

Install x2go client on Ubuntu

```
sudo apt install -y x2goclient
```

Install x2go client on Mac Users can download the package through this link: `http://code.x2go.org/releases/X2GoClient_latest_macosx_10_9.dmg`.

Install x2go client on Windows Users can download the package through this link: `http://code.x2go.org/releases/X2GoClient_latest_mswin32-setup.exe`.

Install x2go client on other operating systems If you are using a different operating system, please refer to x2go website for the installation. The x2go website for client installation is `https://wiki.x2go.org/doku.php/download:start`

1.1.2 Configure the client-side of x2go

For all operating systems, users will see the same session when they open the x2goclient new-session, as shown in Fig. 1.1.

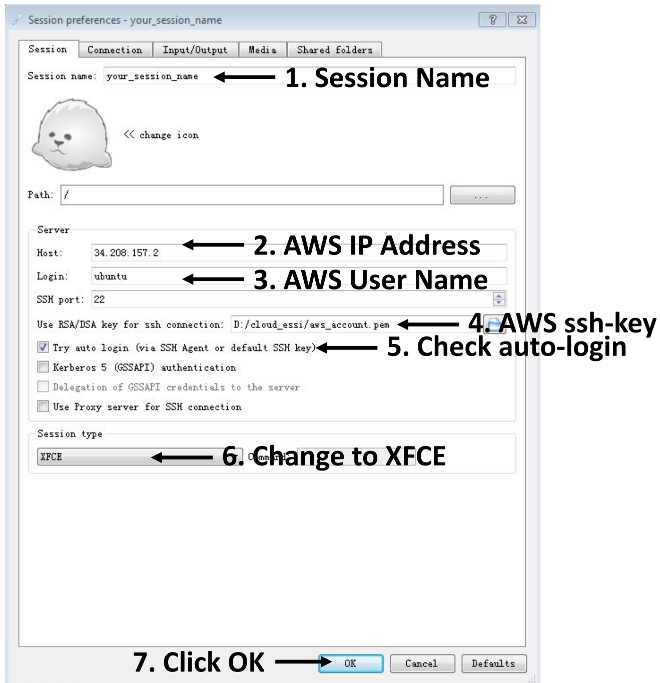


Figure 1.1: Configuration of x2go client

1. Users can name their own session name.
2. AWS IP address will be provided in the Real-ESSI Short-Course.
3. AWS User Name is "ubuntu".
4. AWS ssh-key will be provided in the Real-ESSI Short-Course.
5. Please check the auto-login.
6. Please change the session type to XFCE.
7. Click OK to finish the configuration.

1.2 AWS Regions

1.2.1 AWS Price by Regions

Choosing an AWS region is the first decision you have to make when you set up your AWS components. Most AWS customers choose one based on proximity to themselves or to their end users, which sounds like a sensible thing to do. However, proximity alone is not enough. The price is also important. An example of AWS price by regions is shown in Fig. 1.2. The example is for 10 t2.medium instances running Amazon Linux in the same Availability Zone. Each instance has 20GB of EBS SSD storage.

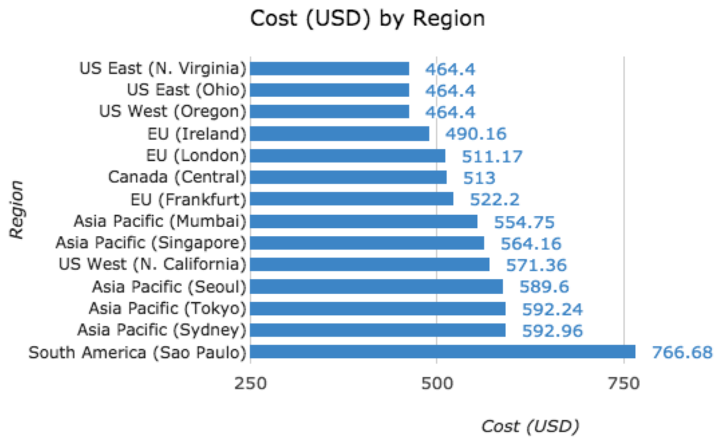


Figure 1.2: AWS Price by Regions

1.2.2 AWS Latency by Regions

Regions have different latencies and data transfer speeds. An example of AWS latencies by regions is shown in Fig. 1.3. The example is a test that measures latency between EC2 instances in different regions. For example, from North California it took 2ms to ping EC2 instances in North California, and it took 41ms to ping EC2 instances in Oregon.

Inter-region EC2 latency (ping)

TO

FROM	N. Virginia	Ohio	Oregon	N. California	Sao Paolo	Ireland	Frankfurt	Mumbai	Tokyo	Seoul	Singapore	Sydney
N. Virginia	2	26	323	149	257	140	169	423	291	340	522	449
Ohio	23	4	487	101	299	159	189	592	267	316	481	408
Oregon	159	133	211	41	349	247	280	515	178	228	409	307
N. California	147	101	375	2	376	289	300	494	215	261	384	310
Sao Paolo	261	299	427	376	2	390	383	603	508	567	756	677
Ireland	139	161	449	287	381	1	44	266	415	464	535	590
Frankfurt	170	187	470	301	377	43	5	233	434	493	675	600
Mumbai	419	592	472	495	602	265	235	2	278	264	135	476
Tokyo	296	270	313	219	508	417	438	278	2	66	138	205
Seoul	338	316	392	262	566	463	494	263	66	1	144	262
Singapore	525	481	479	385	753	528	695	137	139	143	4	333
Sydney	449	408	456	311	683	589	606	476	205	265	334	1

** all values are in milliseconds*

Concurrency Labs

Figure 1.3: AWS Latency by Regions

Chapter 2

Day 1 Overview

2.1 Nuclear Power Plant with 3D motions from SW4

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

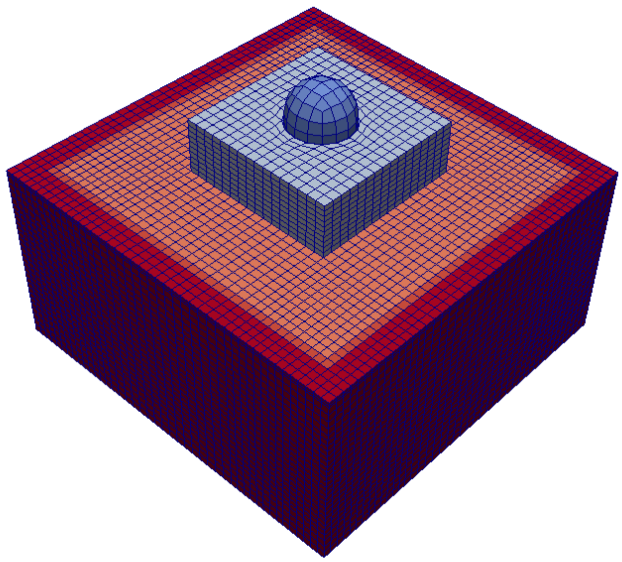


Figure 2.1: Simulation Model

The Modeling parameters are listed.

- Soil
  - Unit weight, γ, 21.4 kPa
  - Shear velocity, Vs, 500 m/s
  - Young's modulus, E, 1.3 GPa
  - Poisson's ratio, ν, 0.25
  - Shear strength, S_u, 650 kPa
  - von Mises radius, k, 60 kPa
  - kinematic hardening, H_a, 30 MPa
  - kinematic hardening, C_r, 25
- Structure
  - Unit weight, γ, 24 kPa
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.21

The input motion at the bottom is a 3D wave from SW4.

SIMULATION TIME: With 32 cores on AWS EC2 c4.8xlarge instance, the running time for this example is 17 hours.

2.2 Nuclear Power Plant with 1D motions from Deconvolution

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

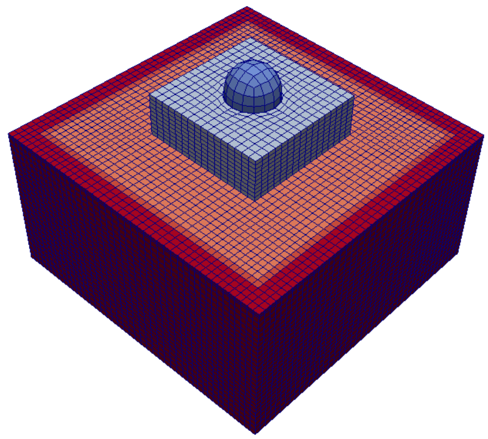


Figure 2.2: Simulation Model

The input motion at the bottom is the deconvolution of the Northridge earthquake records.

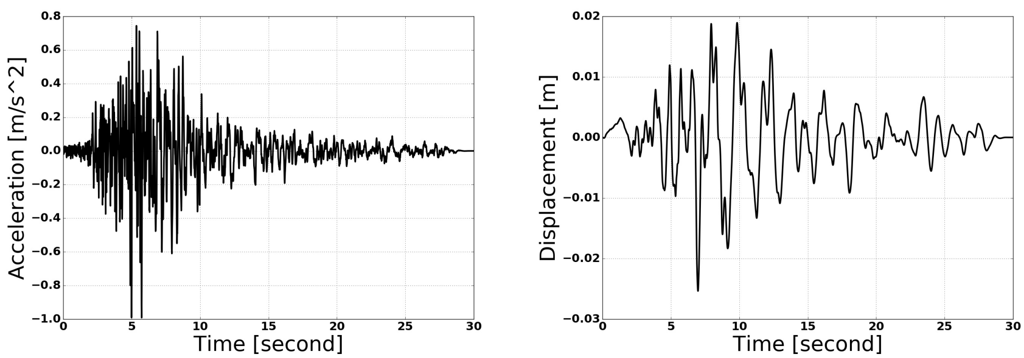


Figure 2.3: Motion Deconvolution

The Modeling parameters are listed.

- Soil
  - Unit weight, γ, 21.4 kPa
  - Shear velocity, Vs, 500 m/s
  - Young's modulus, E, 1.3 GPa
  - Poisson's ratio, ν, 0.25
  - Shear strength, S_u, 650 kPa
  - von Mises radius, k, 60 kPa
  - kinematic hardening, H_a, 30 MPa
  - kinematic hardening, C_r, 25

- Structure
  - Unit weight, γ, 24 kPa
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.21

2.3 Nuclear Power Plant with 3×1D motions from Deconvolution

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

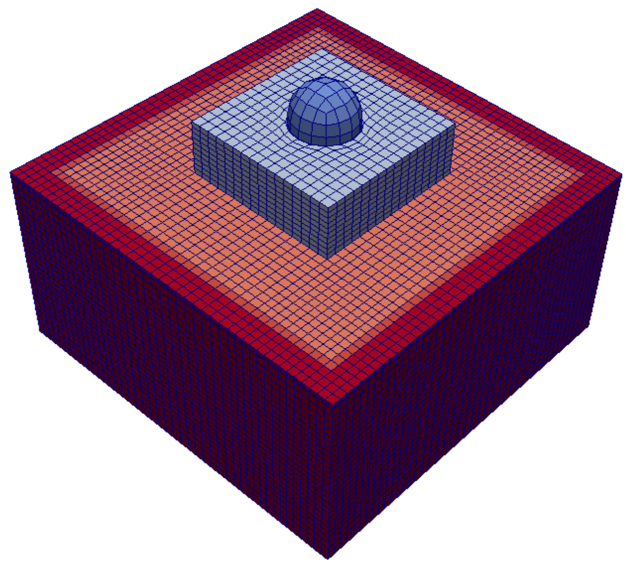


Figure 2.4: Simulation Model

The input motion at the bottom is the deconvolution of the Northridge earthquake records.

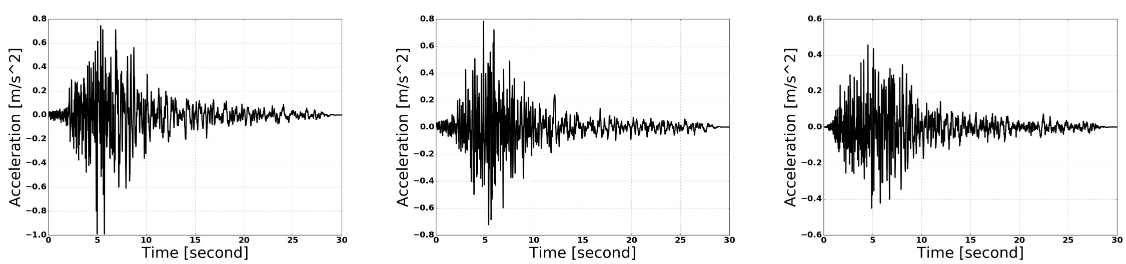


Figure 2.5: Acceleration Deconvolution, from left to right in x, y, z directions respectively.

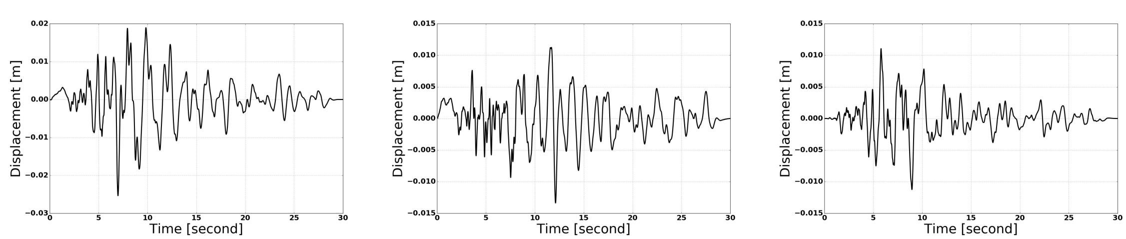


Figure 2.6: Displacement Deconvolution, from left to right in x, y, z directions respectively.

The Modeling parameters are listed.

- Soil

  - Unit weight, γ, 21.4 kPa
  - Shear velocity, Vs, 500 m/s
  - Young's modulus, E, 1.3 GPa
  - Poisson's ratio, ν, 0.25
  - Shear strength, S_u, 650 kPa
  - von Mises radius, k, 60 kPa
  - kinematic hardening, H_a, 30 MPa
  - kinematic hardening, C_r, 25

- Structure
  - Unit weight, γ, 24 kPa
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.21

2.4 Single element Models: illustrate the elastic-plastic behavior

The compressed package of Real-ESSI input files for this example with von-Mises material model are available HERE.

The compressed package of Real-ESSI input files for this example with Drucker-Prager material model are available HERE.

The Modeling parameters are listed.

- von-Mises linear hardening material model
  - Mass Density, ρ, 0.0 kg/m^3
  - Young's modulus, E, 20 MPa
  - Poisson's ratio, ν, 0.0
  - von Mises radius, k, 100 kPa
  - kinematic hardening rate, K_{kine}, 2 MPa
  - isotropic hardening rate, K_{iso}, 0 Pa
- Drucker-Prager nonlinear hardening material model
  - Mass Density, ρ, 0.0 kg/m^3
  - Young's modulus, E, 20 MPa
  - Poisson's ratio, ν, 0.0
  - Drucker-Prager, k, 0.179527
  - nonlinear kinematic hardening, H_a, 20 MPa
  - nonlinear kinematic hardening, C_r, 100
  - isotropic hardening rate, K_{iso}, 0 Pa
  - initial confining stress, p_0, 1 Pa

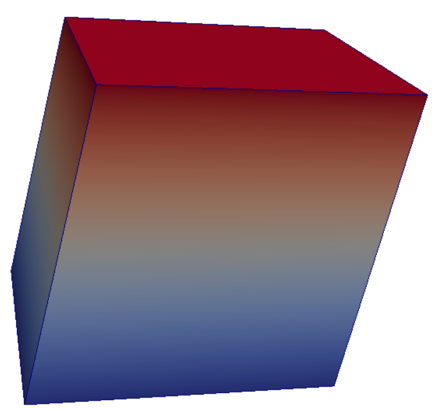


Figure 2.7: Simulation Model of Single Element

The illustrative nonlinear material behavior is shown in Fig. 2.8.

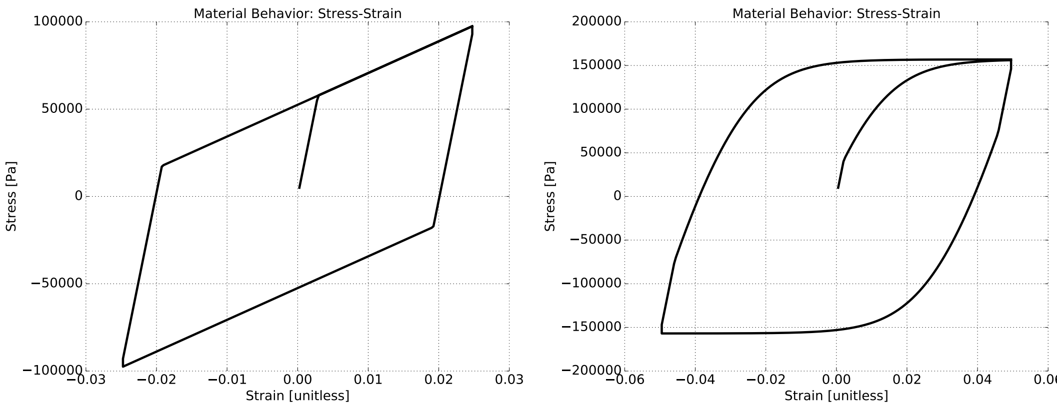


Figure 2.8: Illustration of Nonlinear Material Behavior

2.5 Pushover for Nonlinear Frame

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

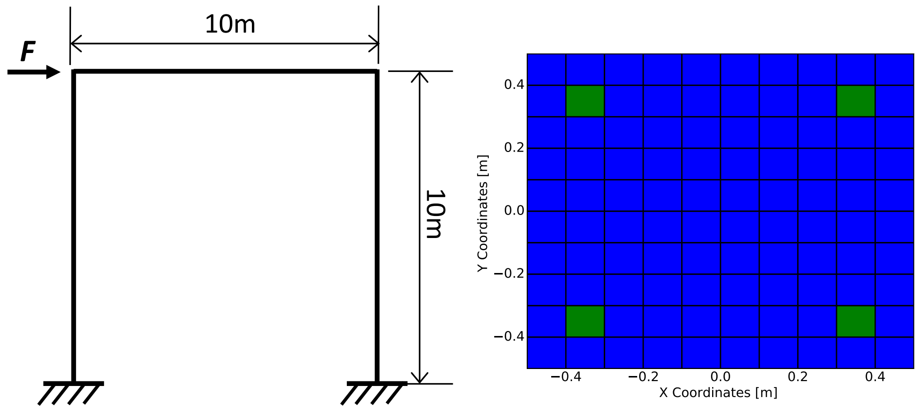


Figure 2.9: Model of Pushover Simulation and the Cross Section of Fiber Beam (Concrete and Rebar)

The illustrative result is shown in Fig. 2.10.

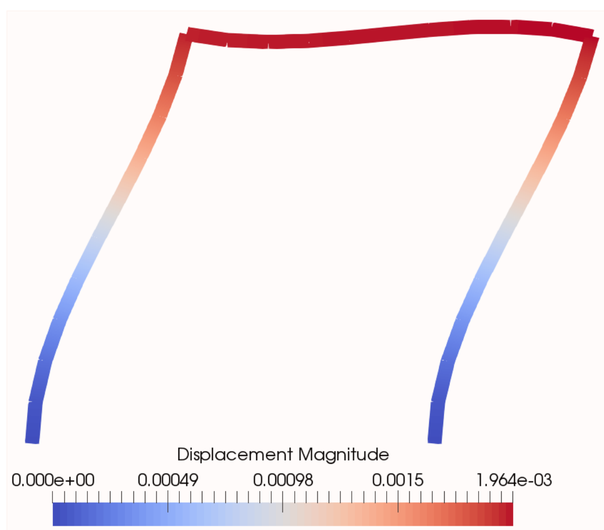


Figure 2.10: Illustration results of Fiber Pushover

The Modeling parameters are listed.

- Uniaxial concrete
  - Compressive strength, 24 MPa
  - Strain at compressive strength, 0.001752
  - Crushing strength, 0.0 Pa
  - Strain at compressive strength, 0.003168
  - lambda, 0.5
  - Tensile strength, 0 Pa

  - Tension softening stiffness, 0 Pa

- Uniaxial steel
  - Yield strength, 413.8 MPa
  - Young's modulus, 200 GPa
  - Strain hardening ratio, 0.01
  - R0, 18.0
  - cR1, 0.925
  - cR2, 0.15
  - a1, 0.0
  - a2, 55.0
  - a3, 0.0
  - a4, 55.0

2.6 Preprocess examples with Gmsh

2.6.1 Cantilever Example

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

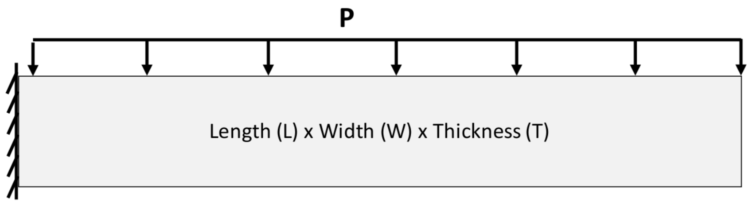


Figure 2.11: Simulation Model Cantilever

The illustration results is shown in Fig. 2.12.

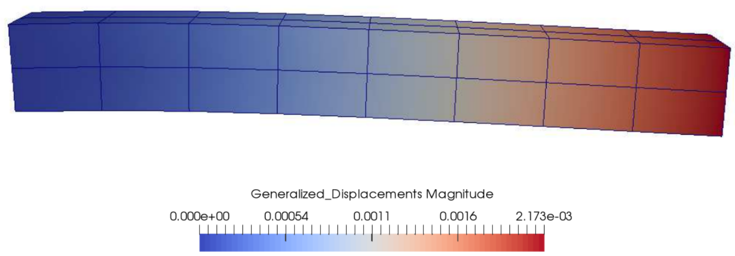


Figure 2.12: Simulation Model Cantilever Illustration Results

2.6.2 Brick-shell-beam Example

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

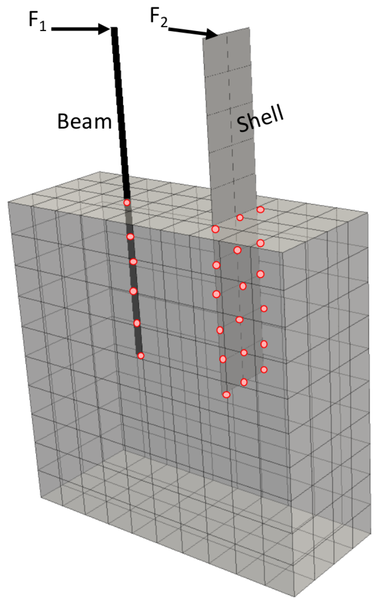


Figure 2.13: Simulation Model Brick-Shell-Beam

The illustration results is shown in Fig. 2.14.

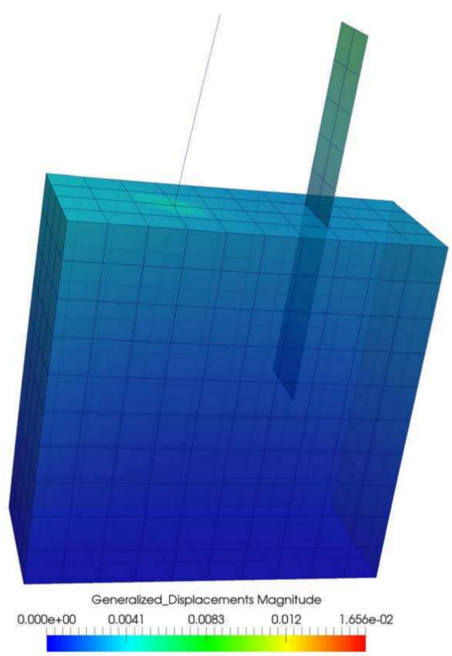


Figure 2.14: Brick-Shell-Beam Illustration Results

2.6.3 DRM 2D Example

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

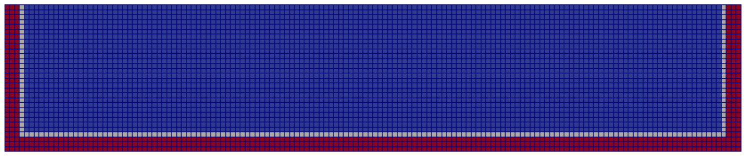


Figure 2.15: Simulation Model DRM 2D

The illustration results of free field DRM 2D Model under 1D motion is shown in Fig. 2.16.

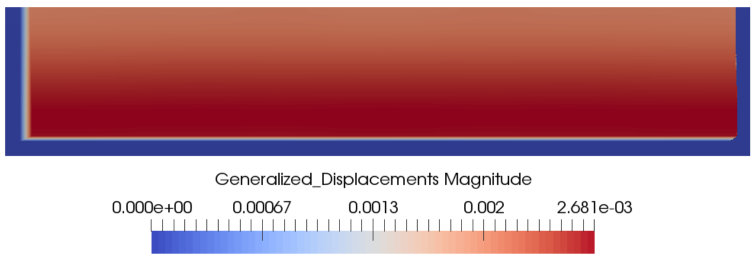


Figure 2.16: Simulation Model DRM 2D

2.6.4 DRM 3D Example

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

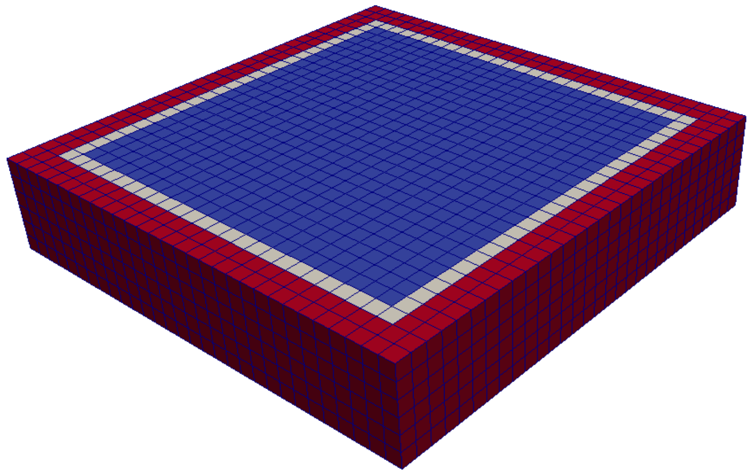


Figure 2.17: Simulation Model DRM 3D

The illustration results of free field DRM 3D Model under 1D motion is shown in Fig. 2.18.

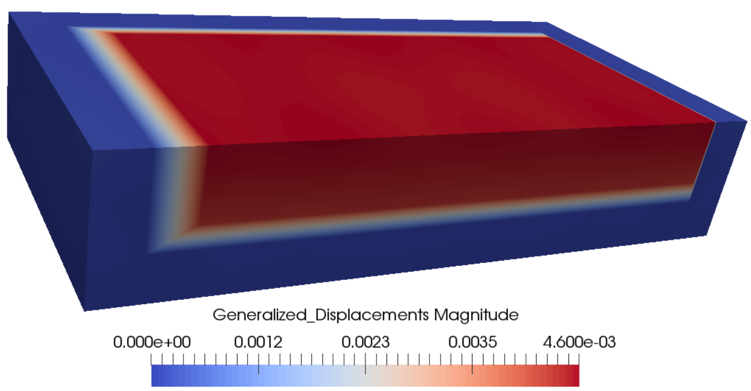


Figure 2.18: Simulation Model DRM 2D

2.7 Postprocess examples with Paraview

2.7.1 Slice Visualization

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

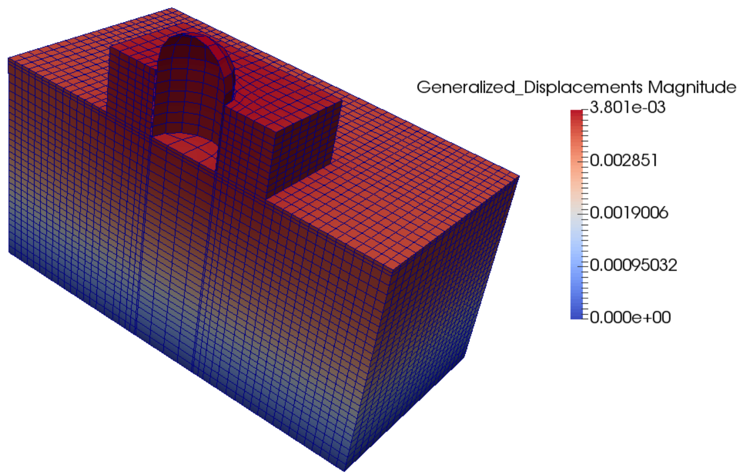


Figure 2.19: Slice Visualization with Paraview

2.7.2 Stress Visualization

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

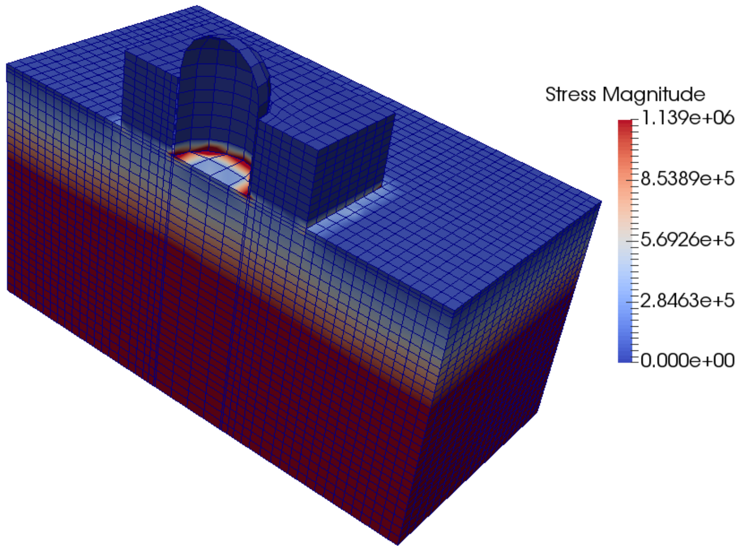


Figure 2.20: Stress Visualization with Paraview

2.7.3 Eigen Visualization

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

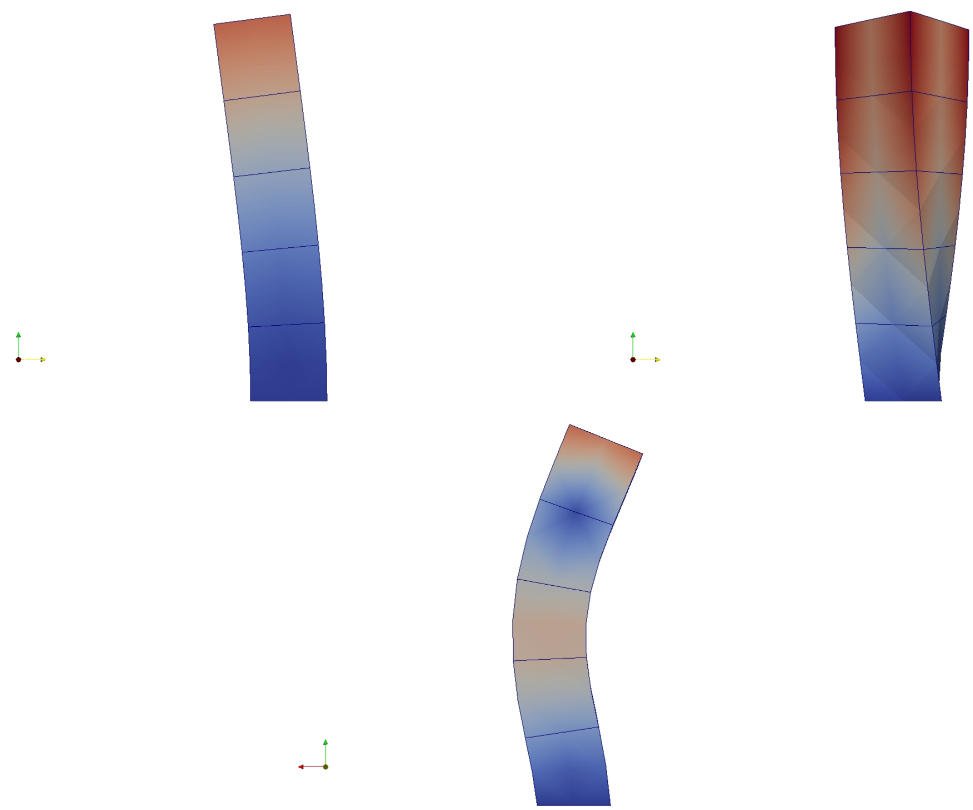


Figure 2.21: Eigen Mode Visualization with Paraview

2.8 Check Model and Visualization of Boundary Conditions

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

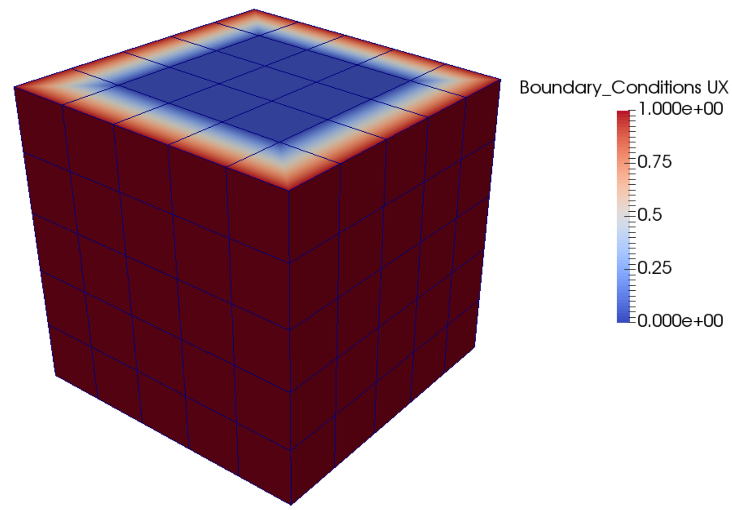


Figure 2.22: Partition Information Visualization with Paraview

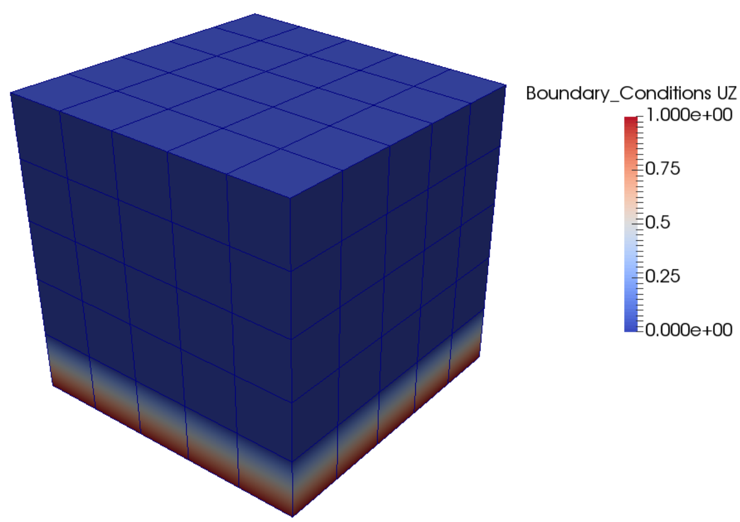


Figure 2.23: Partition Information Visualization with Paraview

2.9 Restart Simulation

2.9.1 Restart in the next stage

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

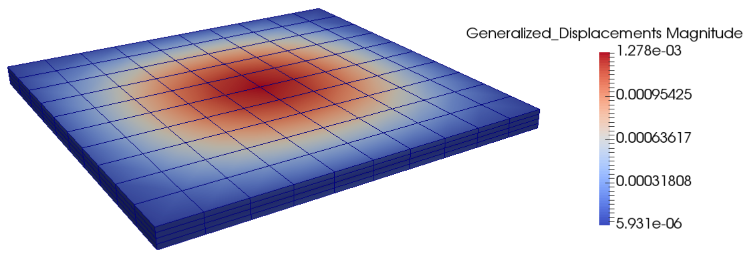


Figure 2.24: Restart Simulation

This group of examples illustrate the restart functionality between loading stages. There are three test cases in this example. The two loading stages in the first test case is splitted into two test cases to show the restart feature.

- The first test case run through two loading stages.
- The second test case only run the first loading stage and saves model state at the end.
- The third test case restart the simulation from the saved model state of the second test case. Then, with the restarted model state, the test cases run the second loading stage only.

Finally, the results of the third test case are exactly the same to the first test case.

2.9.2 Restart inside the stage

For the case of inconvergence, restart with the previous loading stage.

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

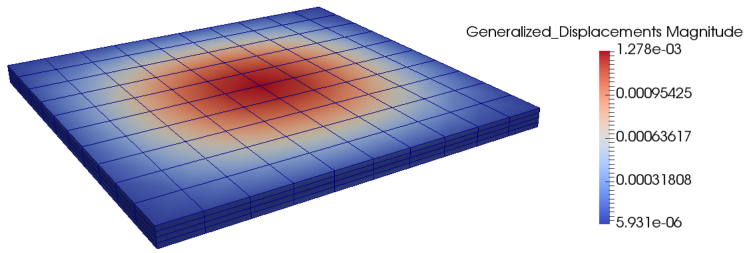


Figure 2.25: Restart Simulation

This group of examples illustrate the restart functionality inside one loading stage when the simulation cannot converge in the nonlinear analysis. The nonlinear material model, von-Mises Armstrong-Frederick, is used in all test cases.

There are three test cases in this example.

- The first test case run through the whole simulation with a relatively big tolerance of the unbalanced force.
- The second test case failed in the middle of the simulation with a relatively small tolerance of the unbalanced force. When the second test failed, the model reverted to the last commit model state and saved model state.
- The third test case load the saved model state, increased the tolerance of the unbalanced force, and added the remaining load to the model to continue the simulation.

Finally, the results of the third test case are exactly the same to the first test case.

Note that in the third test case only the remaining load should be added to the model. Whenever the new loading stage is used, the previous loading are all finished, which means that the static loading becomes constant and the dynamic loading vanishes.

Chapter 3

Day 2 Motions

3.1 Deconvolution 1D Motions

3.1.1 Free field 1D model, deconvolution 1D motion, model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1

Figure 3.1: Simulation Model

The illustration results of the simulation is shown in Fig. 5.1. As shown in the results, outside the DRM layer, there is no outgoing waves.

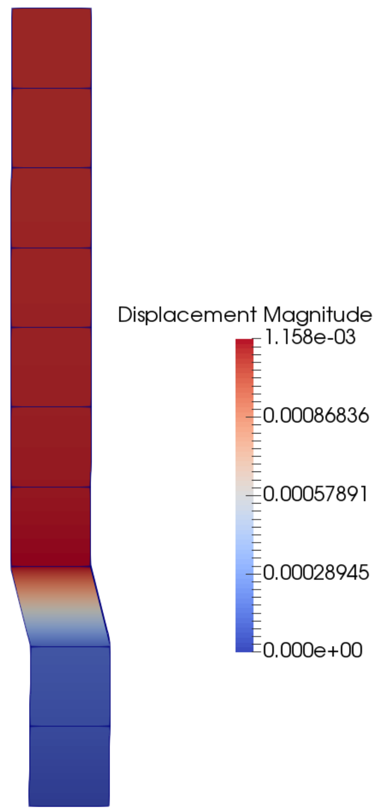


Figure 3.2: Simulation Model

3.1.2 Free field 3D model, deconvolution 1D motion, model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1

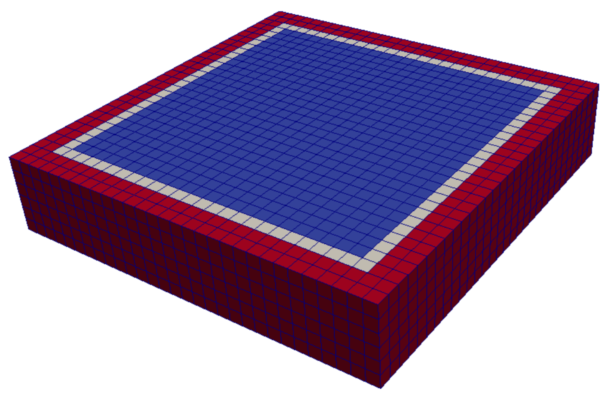


Figure 3.3: Simulation Model

The illustration results of free field DRM 3D Model under 1D motion is shown in Fig. 3.4.

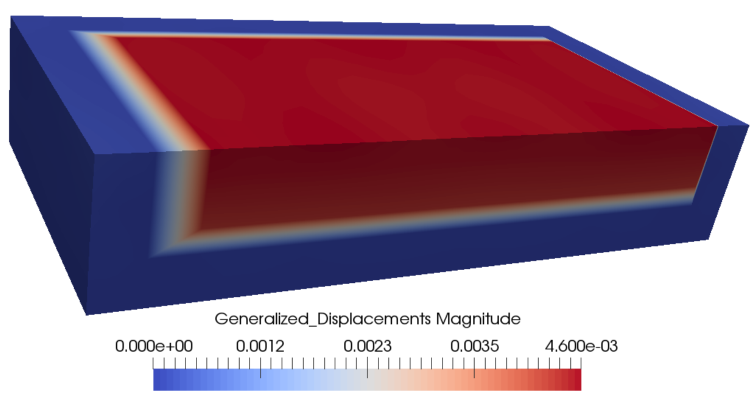


Figure 3.4: Simulation Model DRM 2D

3.1.3 ESSI 3D building model, deconvolution 1D model, solid model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Soil Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
- Elastic Structure Material Properties
  - Mass density, ρ, 2500 kg/m^3
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.1

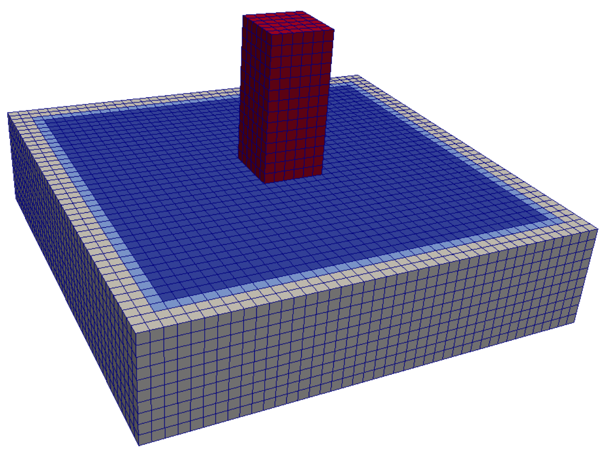


Figure 3.5: Simulation Model

The illustration results of DRM 3D Solid Structure Model under 1D motion is shown in Fig. 3.6.

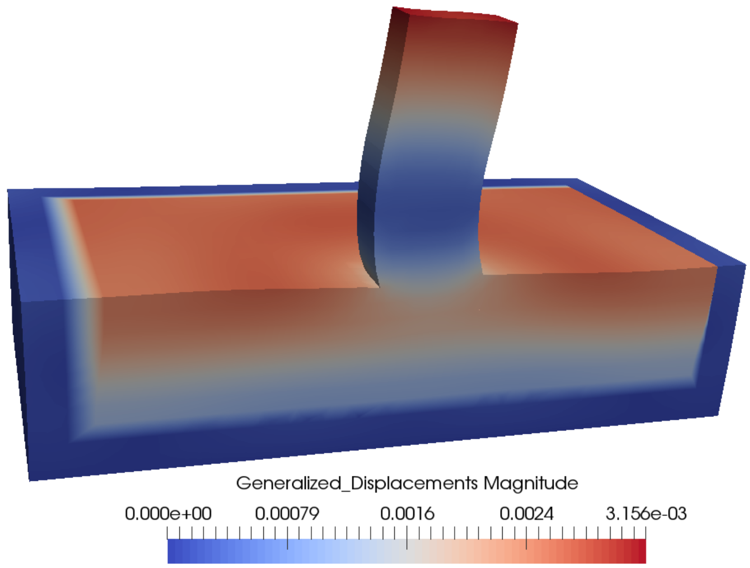


Figure 3.6: Simulation Model

3.1.4 ESSI 3D building model, deconvolution 1D model, shell model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Soil Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
- Elastic Structure Material Properties
  - Mass density, ρ, 2500 kg/m^3
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.1

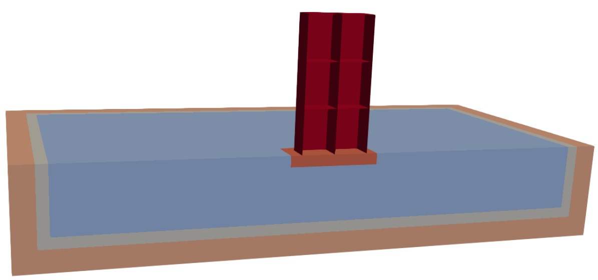


Figure 3.7: Simulation Model

The illustration results of DRM 3D shell Structure Model under 1D motion is shown in Fig. 3.8.

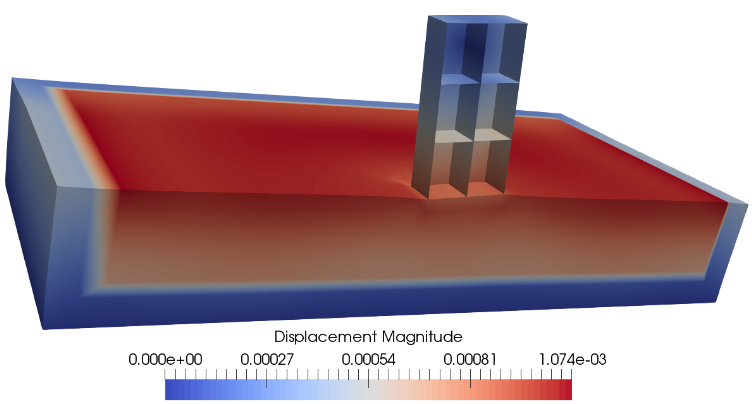


Figure 3.8: Simulation Model

3.2 Deconvolution 3×1D Motions

3.2.1 Free field 1D model, deconvolution 3×1D motion, model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1

Figure 3.9: Simulation Model

The illustration results of the simulation is shown in Fig. 5.1. As shown in the results, outside the DRM layer, there is no outgoing waves.

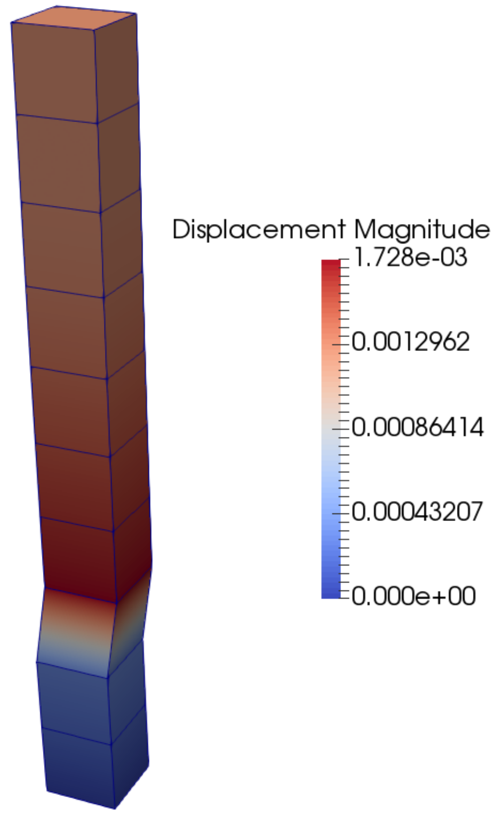


Figure 3.10: Simulation Model

3.2.2 Free field 3D model, deconvolution 3×1D motion, model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Soil Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1

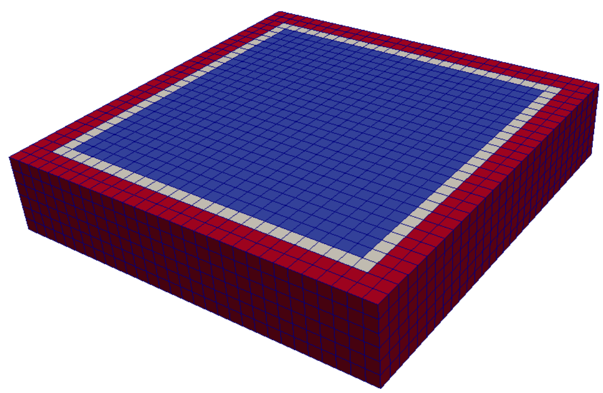


Figure 3.11: Simulation Model

The illustration results of the simulation is shown in Fig. 3.12. As shown in the results, outside the DRM layer, there is no outgoing waves.

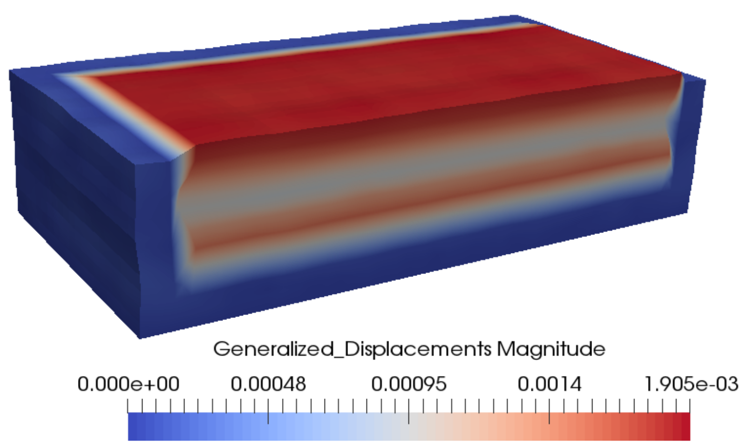


Figure 3.12: Simulation Model

3.2.3 Free field 3D model, deconvolution 3×1D motion, solid model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Soil Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
- Elastic Structure Material Properties
  - Mass density, ρ, 2500 kg/m^3
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.1

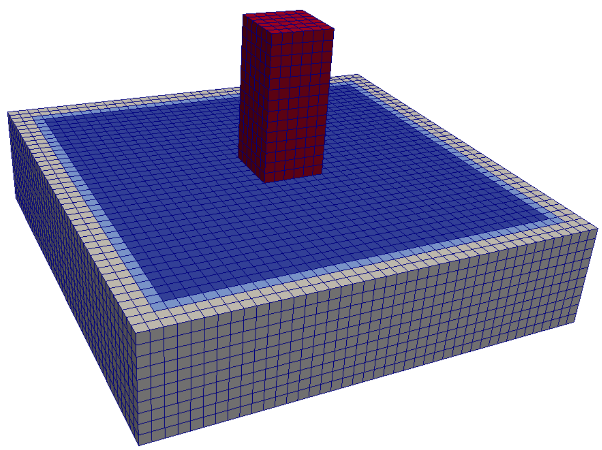


Figure 3.13: Simulation Model

The illustration results of the simulation is shown in Fig. 5.14. As shown in the results, outside the DRM layer, there is no outgoing waves.

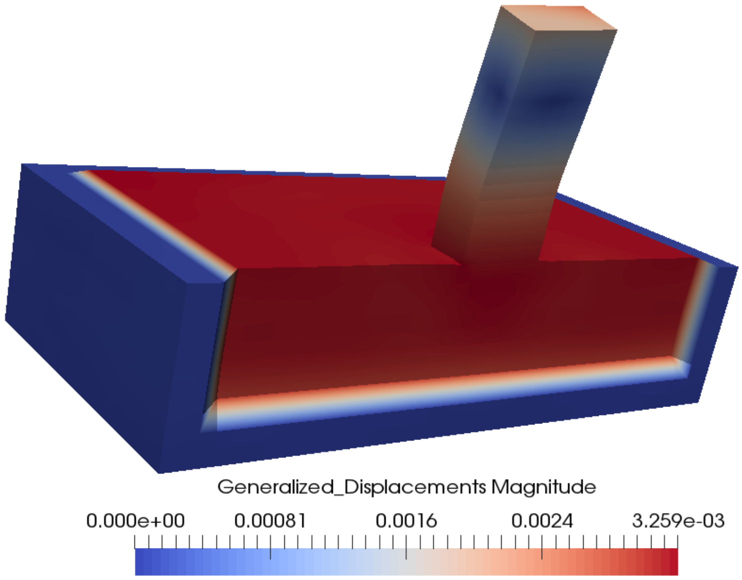


Figure 3.14: Simulation Model

3.2.4 ESSI 3D building model, deconvolution 3×1D motion, shell model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Elastic Soil Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
- Elastic Structure Material Properties
  - Mass density, ρ, 2500 kg/m^3
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.1

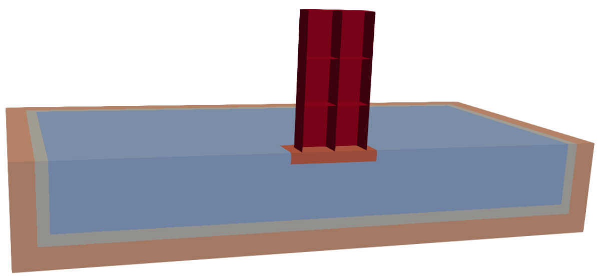


Figure 3.15: Simulation Model

The illustration results of DRM 3D shell Structure Model under 1D motion is shown in Fig. 3.16.

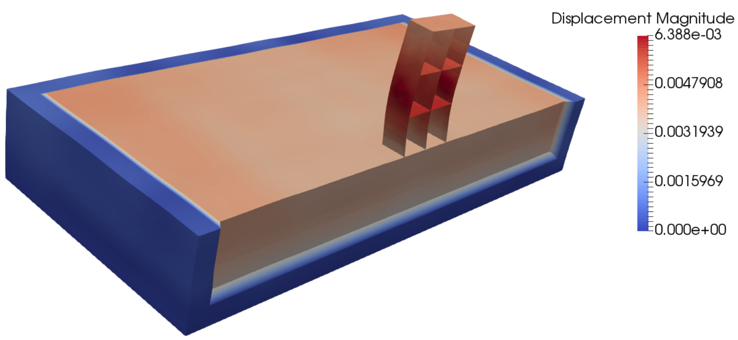


Figure 3.16: Simulation Model

3.3 Mesh Dependence of Wave Propagation Frequencies

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

Show the mesh dependence of high frequency wave with Ormsby wavelet.

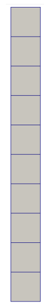


Figure 3.17: Simulation Model

The illustration results of mesh dependence is shown in Fig. 3.18.

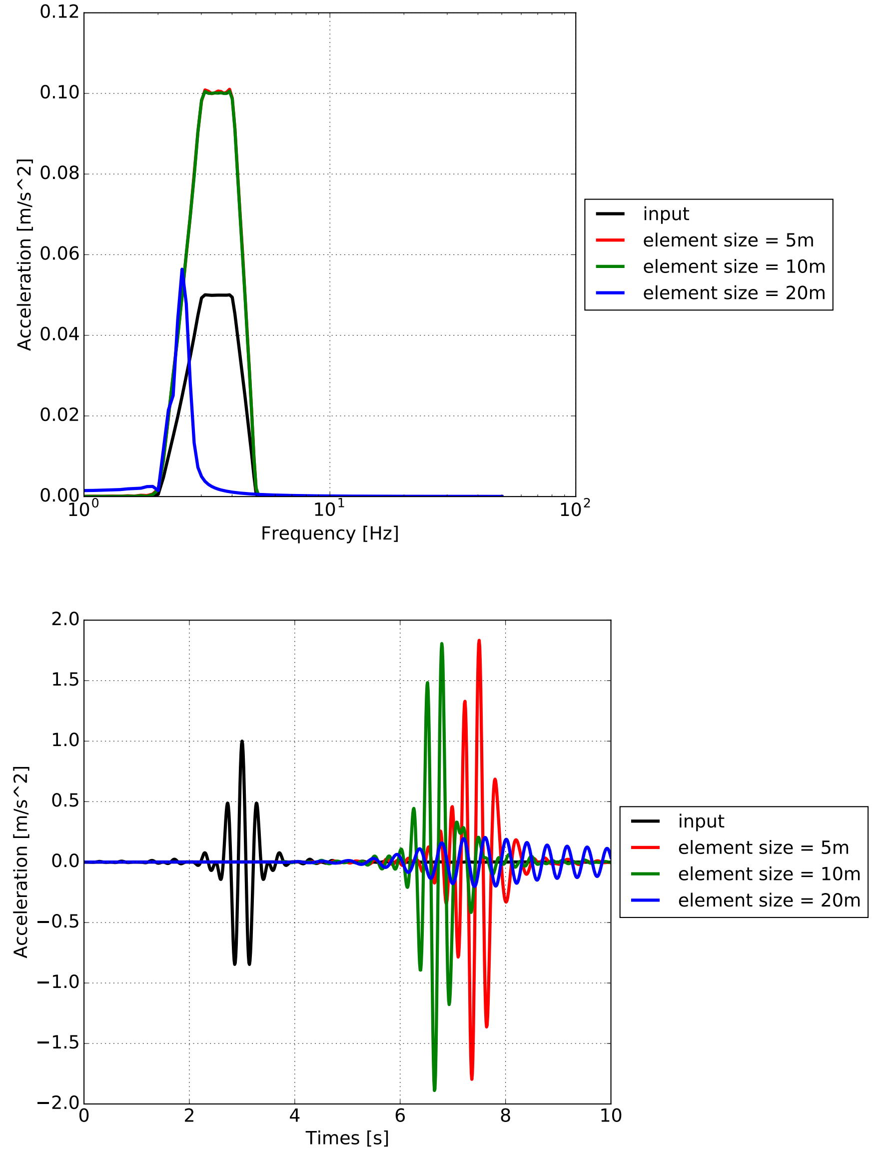


Figure 3.18: Convolution Results and Mesh Dependence

3.4 Apply 3D Motions from SW4

3.4.1 3D seismic motion by SW4

A 3D seismic motion field has been developed by SW4. The characteristic parameters of the seismic motion are given below:

- Geological model: length $3km$, width $3km$, height $1.7km$, grid size $50m$, width of super grid damping layer $30m$.
- Material model: Elastic material, First $1km$: $V_p = 4630.76m/s$, $V_s = 2437.56m/s$, $\rho = 2600kg/m^3$. $1km \sim 1.7km$: $V_p = 6000m/s$, $V_s = 3464m/s$, $\rho = 2700kg/m^3$
- Source type: point moment source, moment seismic moment $M_{xy} = 5e^{15}N \cdot m$, moment magnitude 4.5.
- Time function: Gaussian function, with dominant frequency $2.5Hz$ and maximum frequency $6.5Hz$.

The time series displacement and acceleration response at the center of the model is shown below in figure 3.19. And figure 3.20 gives corresponding FFT response.

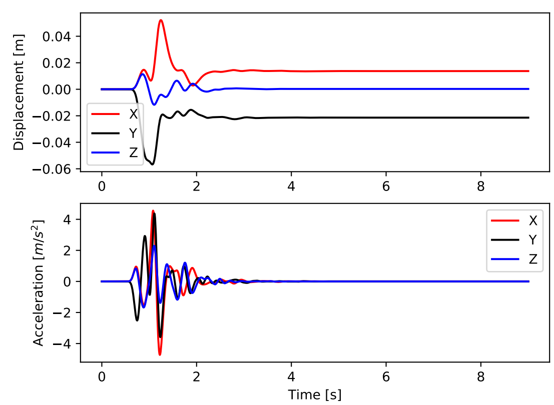


Figure 3.19: Time series response of 3D motion

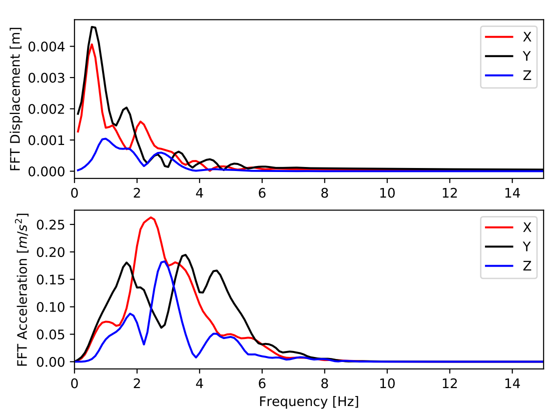


Figure 3.20: FFT response of 3D motion

During the simulation of SW4, the time series motions at many ESSI nodes (basically are some pre-defined record stations) of an ESSI box ($300m \times 300m \times 100m$) are recorded and written into **SAC** files. Then an transition program SW42ESSI has been developed to interpolate these motions to DRM nodes of localized ESSI model by specifying some geometric translational and rotational transformation, as shown in figure 3.21.

To launch SW42ESSI, following parameters are needed:

- DRM input: specify the name of DRM input files. This DRM file just contains the geometric information of DRM layer in ESSI model (e.g. DRM node IDs, nodal coordinates, etc).
- SW4 motion directory: specify the output directory of SW4, that contains SAC files.
- origin coordinates of ESSI box (x, y, z): the SW4 coordinates of the origin of ESSI box, i.e. the coordinates of ESSI nodes, whose station ID is (0, 0, 0).
- dimensions of ESSI Box (length, width, height): specify the dimension (length, width and height) of ESSI box.
- spacing of ESSI nodes: specify the grid spacing of ESSI nodes (i.e. motion recording stations)
- interval of time steps for sampling: specify the sampling frequency, if 1 is used here, ESSI simulation time step is the same as the simulation time step of SW4.
- reference point in ESSI model for translational transformation (x, y, z): specify the coordinate of reference point for translational transformation in ESSI model.
- reference point in SW4 model for translational transformation (x, y, z): specify the coordinate of reference point for translational transformation in SW4 model.
- conduct rotational transformation (yes/no): input yes and provide more rotational transformation parameters to enable rotational transformation. If input no, no more parameters are required.
- reference point in SW4 model for rotational transformation (x, y, z): specify the coordinate of reference point for rotational transformation in SW4 model.
- degrees of rotation along three axes (x, y, z): specify the degrees of rotation along three axes. The sign of rotation degrees follows right hand rule.

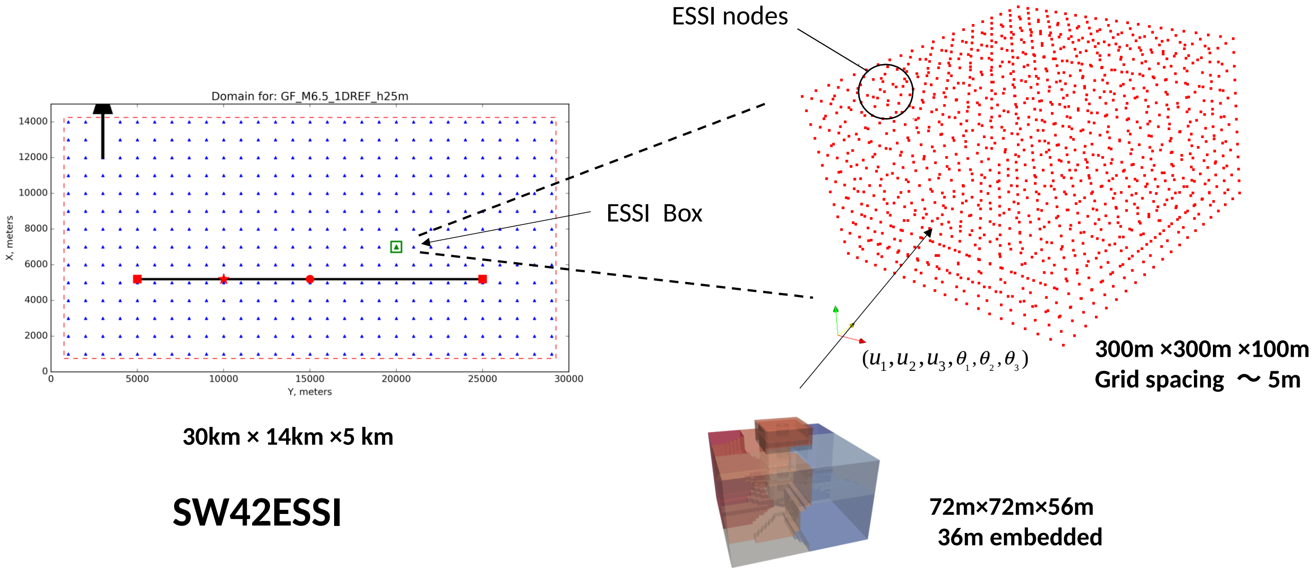


Figure 3.21: Illustration of transition from SW4 to Real ESSI

3.4.2 Free field 3D model, 3D motion, model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

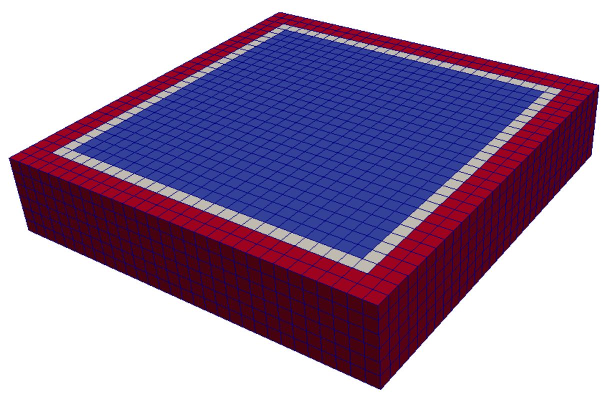


Figure 3.22: Simulation Model

The illustration results of free field DRM 3D Model under 3D motion is shown in figure 3.23.

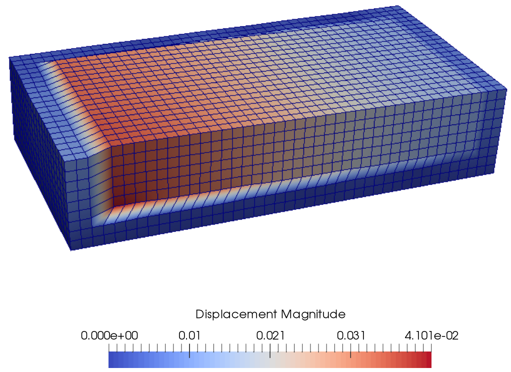


Figure 3.23: Simulation of 3D free field model under 3D seismic motion

3.4.3 ESSI 3D building model, 3D motion, solid model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

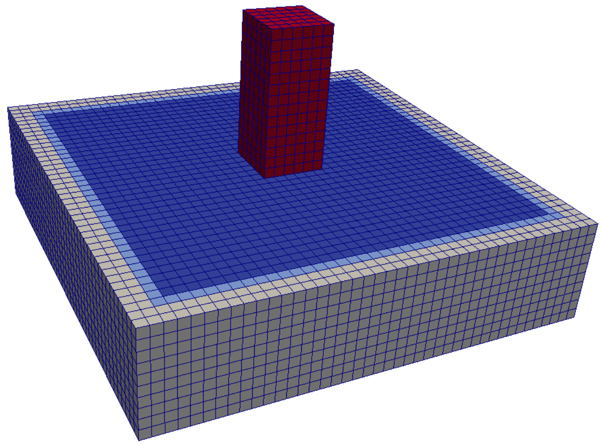


Figure 3.24: Simulation Model

The illustration results of DRM 3D Solid Structure Model under 3D motion is shown in figure 3.25.

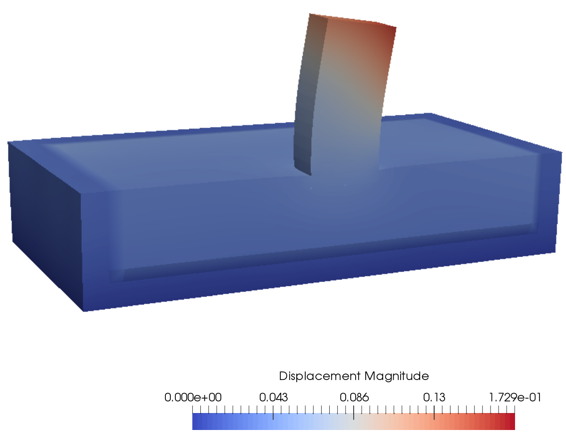


Figure 3.25: Simulation of 3D solid model under 3D seismic motions

3.4.4 ESSI 3D building model, 3D motion, shell model with DRM

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

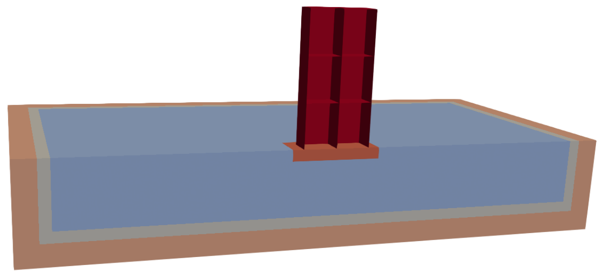


Figure 3.26: Simulation Model

The illustration results of DRM 3D shell Structure Model under 3D seismic motion is shown in figure 3.27.

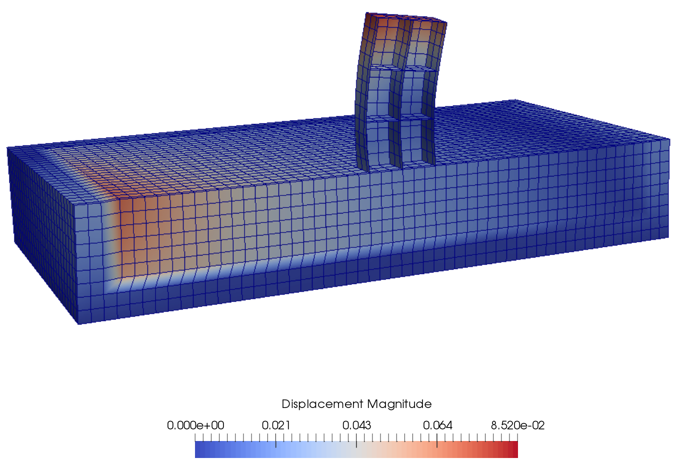


Figure 3.27: Simulation of 3D shell model under 3D motions

Chapter 4

Day 3 Nonlinearities

4.1 Single element Models: illustrate the elastic-plastic behavior

4.1.1 von-Mises material model

von-Mises perfectly plastic material model The Real-ESSI input files for von-Mises perfectly plastic example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

von-Mises Armstrong-Frederick material model The Real-ESSI input files for von-Mises Armstrong-Frederick example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Left: von-Mises linear hardening material model
  - Mass Density, ρ, 0.0 kg/m^3
  - Young's modulus, E, 20 MPa
  - Poisson's ratio, ν, 0.0
  - von Mises radius, k, 100 kPa
  - kinematic hardening rate, K_{kine}, 2 MPa
  - isotropic hardening rate, K_{iso}, 0 Pa
- Right: Drucker-Prager nonlinear hardening material model
  - Mass Density, ρ, 0.0 kg/m^3
  - Young's modulus, E, 20 MPa
  - Poisson's ratio, ν, 0.0
  - Drucker-Prager, k, 0.179527
  - nonlinear kinematic hardening, H_a, 20 MPa
  - nonlinear kinematic hardening, C_r, 100
  - isotropic hardening rate, K_{iso}, 0 Pa
  - initial confining stress, p_0, 1 Pa

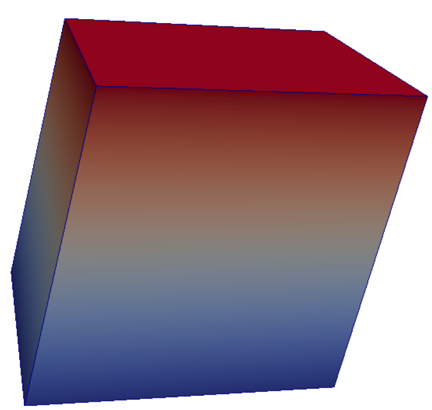


Figure 4.1: Simulation Model of Single Element

The illustration results are shown in Fig. 4.2.

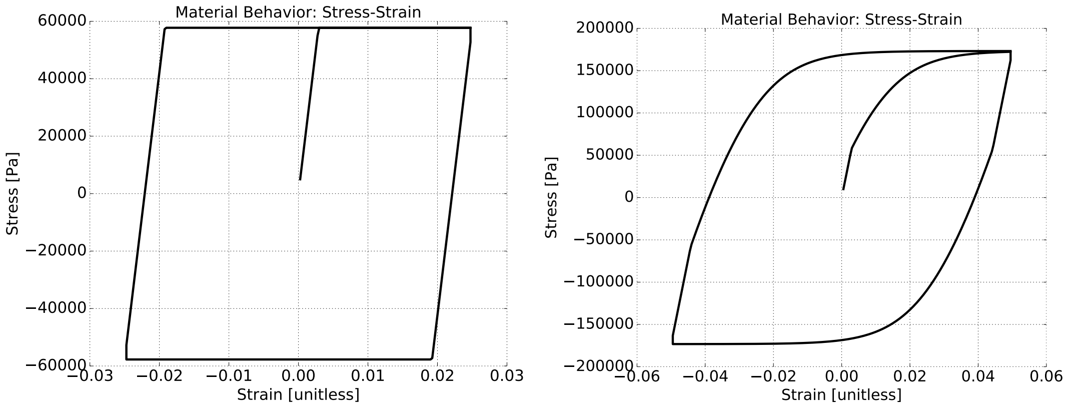


Figure 4.2: Simulation Results of Single Element

4.1.2 von-Mises G/Gmax material model

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- von-Mises G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
  - Total number of shear modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

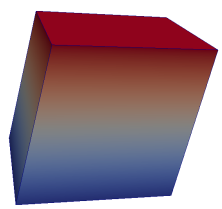
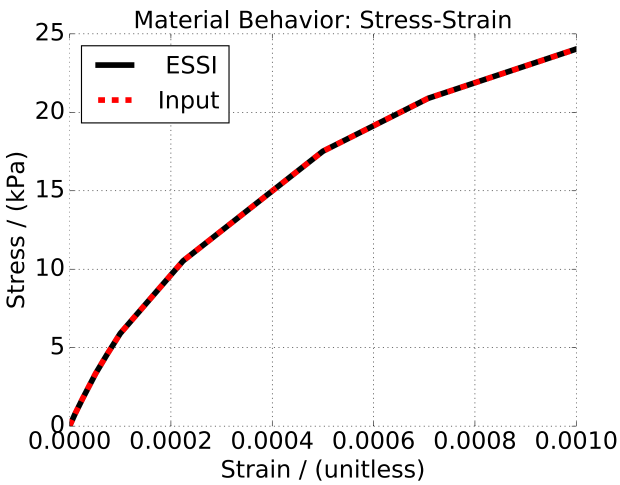
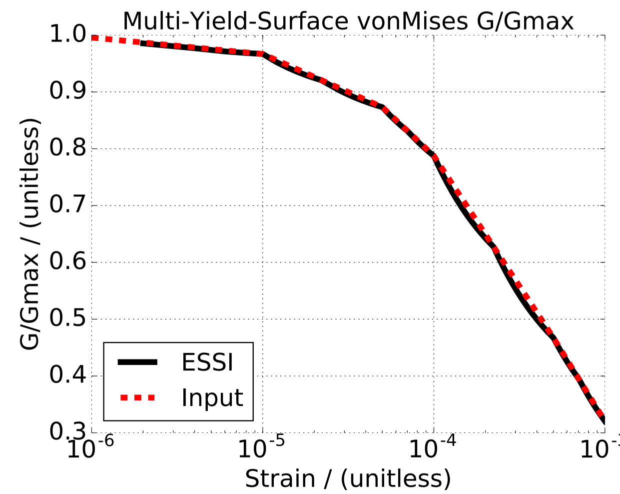


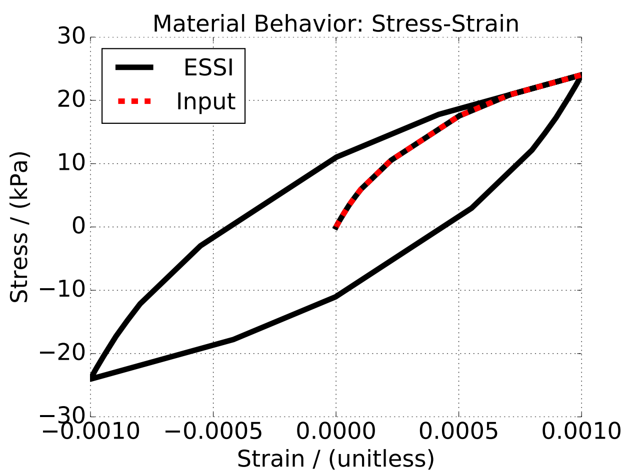
Figure 4.3: Simulation Model of Single Element



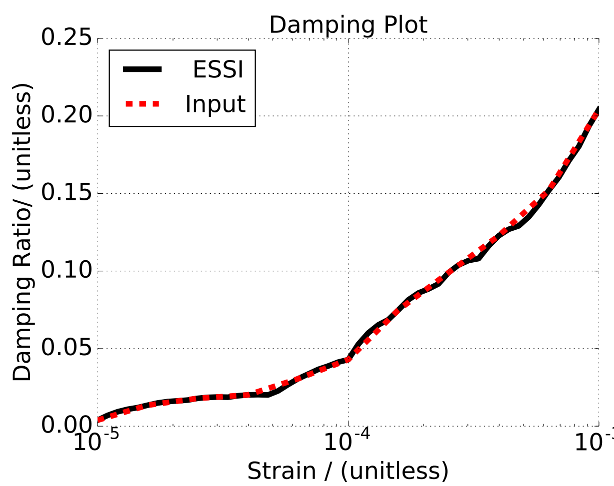
(a) Stress-Strain Curves



(b) G/Gmax Comparison



(c) One Cyclic Stress-Strain Curves



(d) Damping Plot Curves

Figure 4.4: Multi-Yield-Surface von-Mises

4.1.3 Drucker-Prager perfectly plastic material model

Drucker-Prager perfectly plastic material model The Real-ESSI input files for this Drucker-Prager perfectly plastic example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

Drucker-Prager Armstrong-Frederick Non-associate material model The Real-ESSI input files for this Drucker-Prager Armstrong-Frederick example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

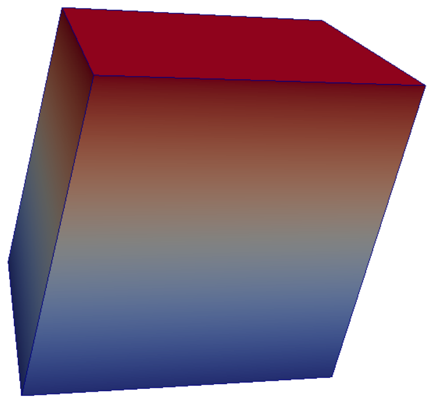


Figure 4.5: Simulation Model of Single Element

The illustration results are shown in Fig. 4.6.

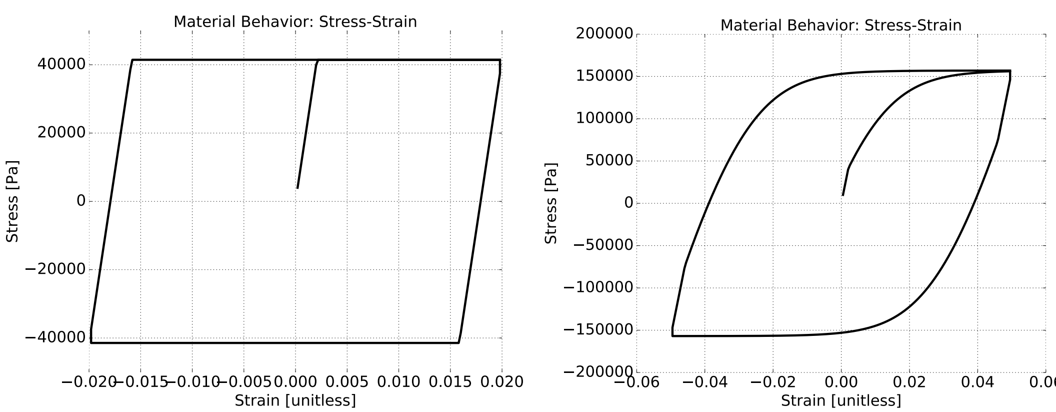


Figure 4.6: Simulation Results of Single Element

4.1.4 Drucker-Prager G/Gmax Non-associate material model

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Drucker-Prager G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 200 MPa
  - Poisson's ratio, ν, 0.1
  - Initial confining stress, p_0, 100 kPa
  - Reference pressure, p_{refer}, 100 kPa
  - Pressure exponential, n, 0.5
  - Cohesion, n, 1 kPa
  - Total number of Shear Modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

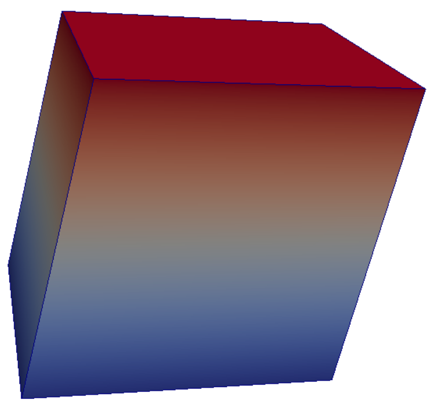


Figure 4.7: Simulation Model of Single Element

The illustration results are shown in Fig. 4.8.

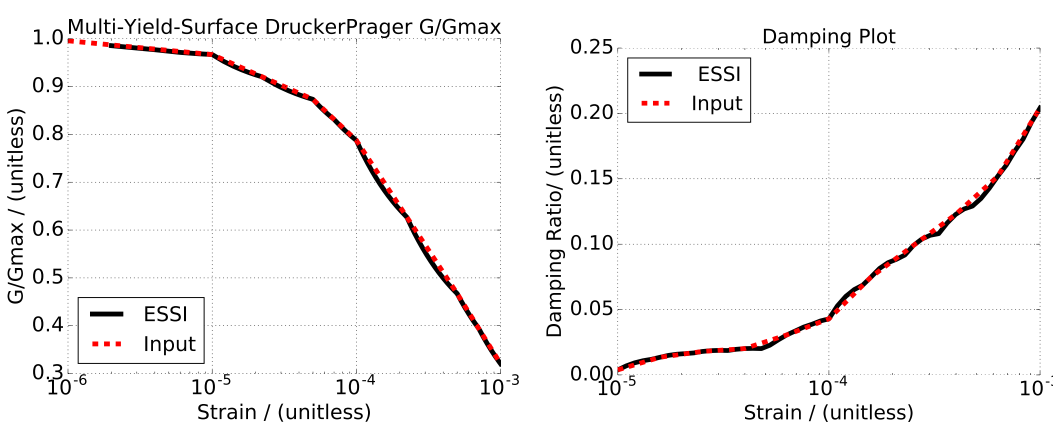


Figure 4.8: Simulation Results of Single Element

4.2 Wave Propagation through elastoplastic Soil

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

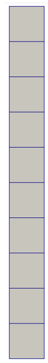


Figure 4.9: Wave Propagation through elastoplastic Soils

The displacement series at the surface are plotted in time and frequency domain.

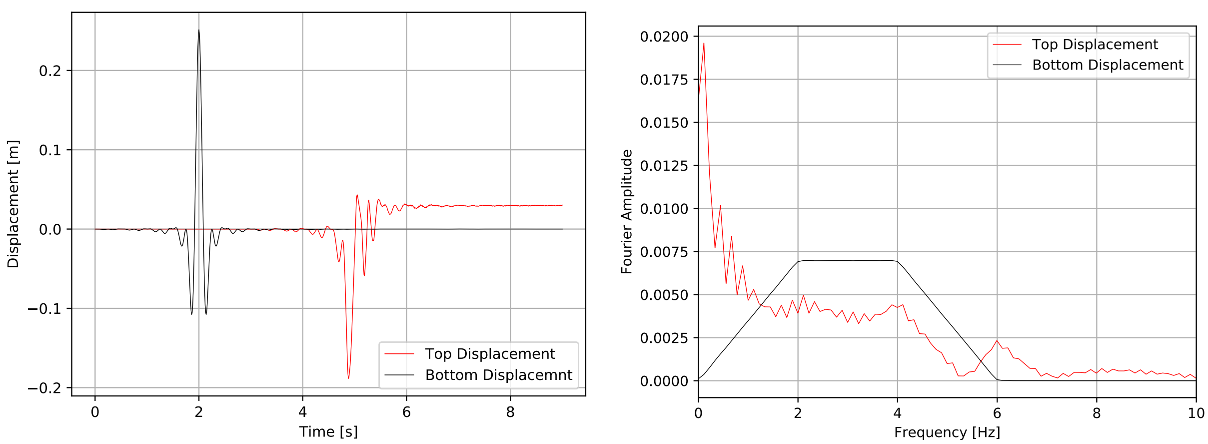


Figure 4.10: Simulation Results of Wave Propagation

Another Set of Solution with motion reduction The displacement series with motion reduction are plotted in time and frequency domain.

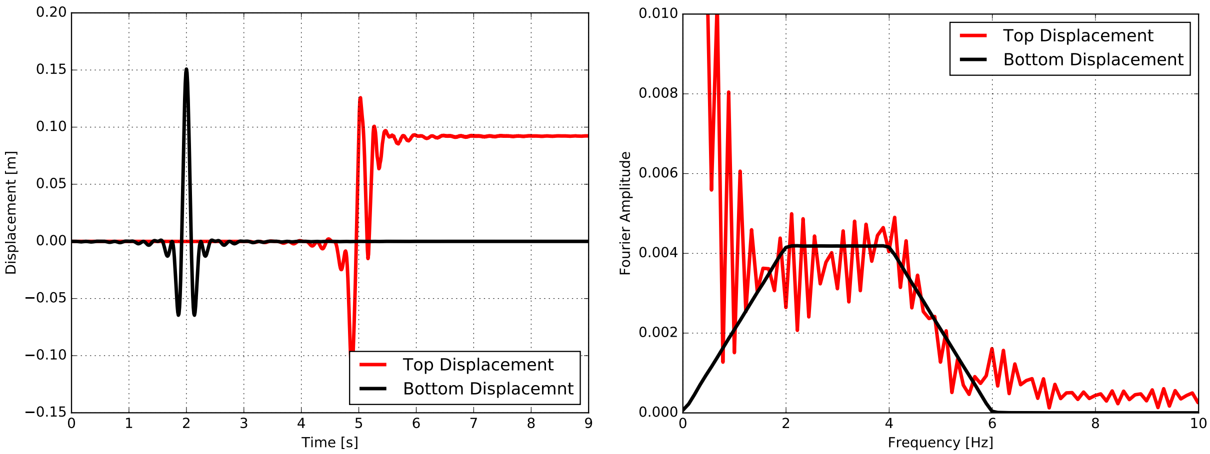


Figure 4.11: Simulation Results of Wave Propagation (motion reduction)

4.3 Contact Examples

4.3.1 Axial behavior: Stress Based Contact Element

Stress-Based Hard Contact Example The Real-ESSI input files for hard contact example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

Stress-Based Soft Contact Example The Real-ESSI input files for soft contact example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The axial behavior of hard contact and soft contact are illustrated in Fig. 4.12.

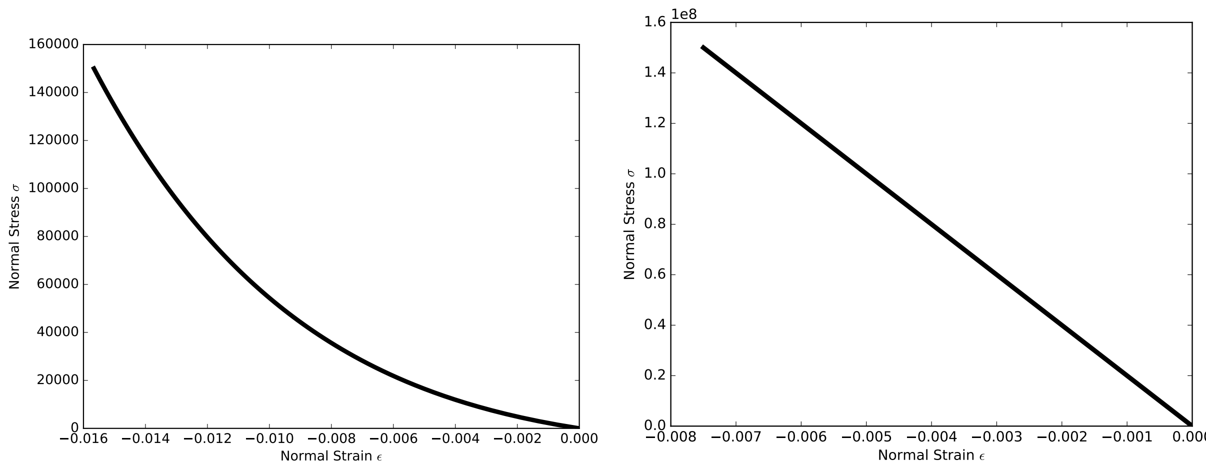


Figure 4.12: Simulation Results of Soft Contact and Hard Contact

4.3.2 Shear behavior: Stress Based Contact

Stress-Based Elastic-perfectly plastic contact The Real-ESSI input files for the the elastic-perfectly plastic example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

Stress-Based Elastic-hardening contact The Real-ESSI input files for the elastic-hardening contact example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

Stress-Based Elastic-hardening-softening contact The Real-ESSI input files for the elastic-hardening-softening example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The axial behavior of hard contact and soft contact are illustrated in Fig. 4.13.

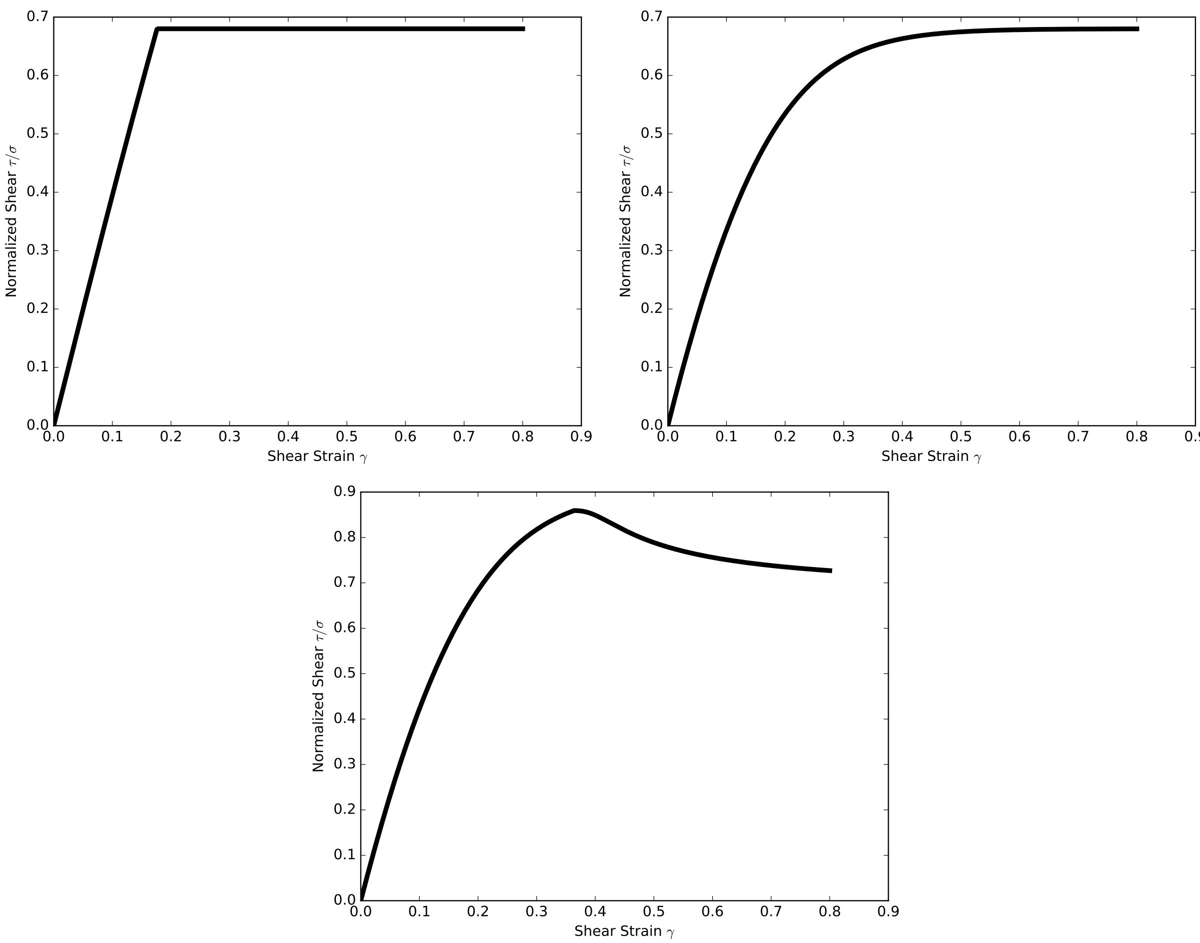


Figure 4.13: Simulation Results of Shear Bahaviors in Stress Based Contact Elements

4.3.3 Force Based Contact Example: Base Isolator

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

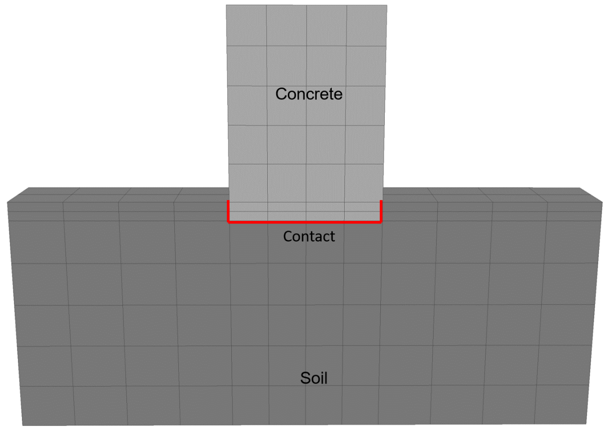


Figure 4.14: Simulation Model

The illustration results are show in Fig.4.15.

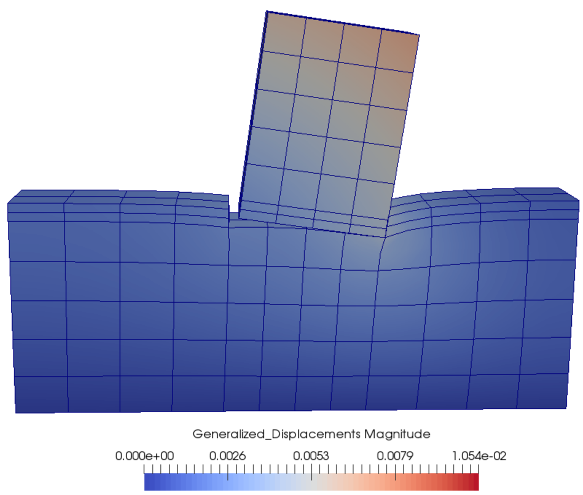


Figure 4.15: Simulation Results of Contact Examples

4.4 Frame Pushover

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Uniaxial concrete
  - Compressive strength, 24 MPa
  - Strain at compressive strength, 0.001752
  - Crushing strength, 0.0 Pa
  - Strain at compressive strength, 0.003168
  - lambda, 0.5
  - Tensile strength, 0 Pa
  - Tension softening stiffness, 0 Pa
- Uniaxial steel
  - Yield strength, 413.8 MPa
  - Young's modulus, 200 GPa
  - Strain hardening ratio, 0.01
  - R0, 18.0
  - cR1, 0.925
  - cR2, 0.15
  - a1, 0.0
  - a2, 55.0
  - a3, 0.0
  - a4, 55.0

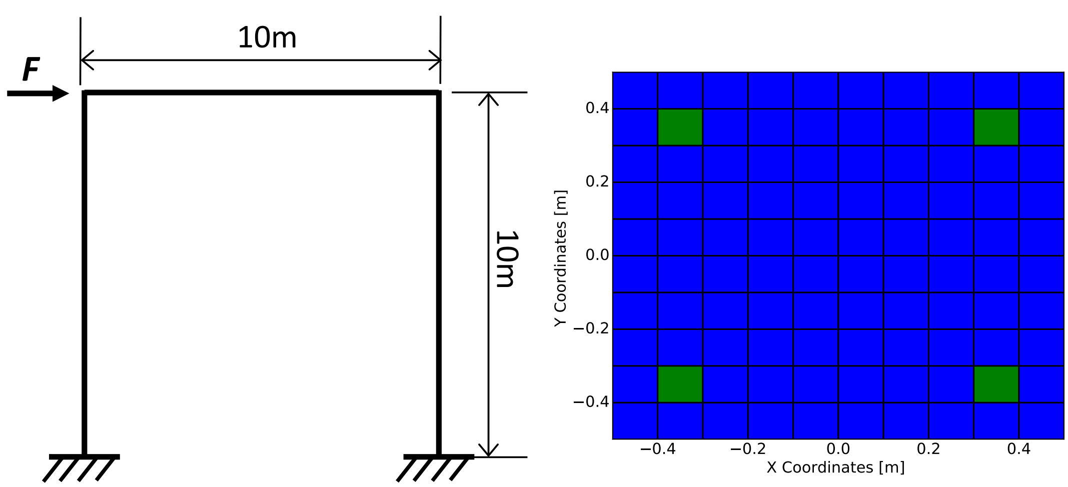


Figure 4.16: Model of Pushover Simulation and the Cross Section of Fiber Beam (Concrete and Rebar)

The illustrative result is shown in Fig. 4.17.

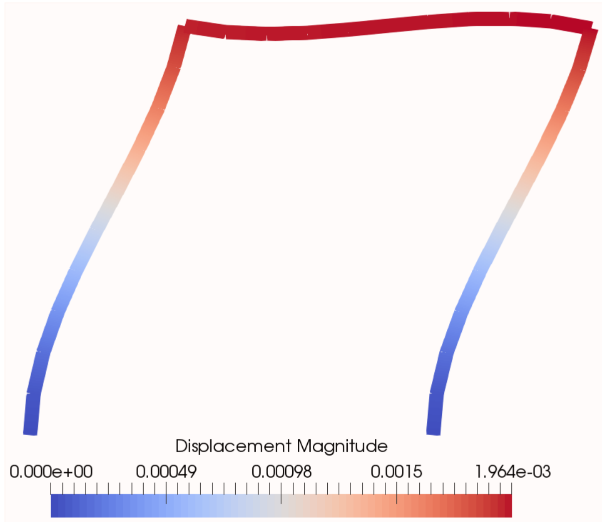


Figure 4.17: Illustration results of Fiber Pushover

4.5 Wall Pushover

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Concrete Wall
  - Young's modulus, 36.9 GPa
  - Poisson's ratio, 0.2
  - Tensile yield strength, 5 MPa
  - Compressive yield strength, 56 MPa
  - Plastic deformation rate, 0.4
  - Damage parameter Ap, 0.1
  - Damage parameter An, 1.5
  - Damage parameter Bn, 0.75
- Uniaxial steel
  - Yield strength, 457.5 MPa
  - Young's modulus, 200 GPa
  - Strain hardening ratio, 0.011042
  - a1, 0.0
  - a2, 55.0
  - a3, 0.0
  - a4, 55.0

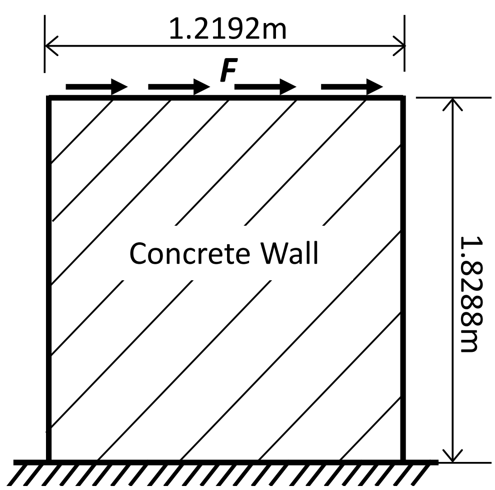


Figure 4.18: Illustrative Model of Wall Element Pushover Simulation

4.6 Viscous nonlinear behavior

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

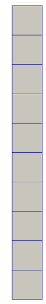


Figure 4.19: Simulation Model

The illustrative result is shown in Fig. 4.20 and Fig. 4.21.

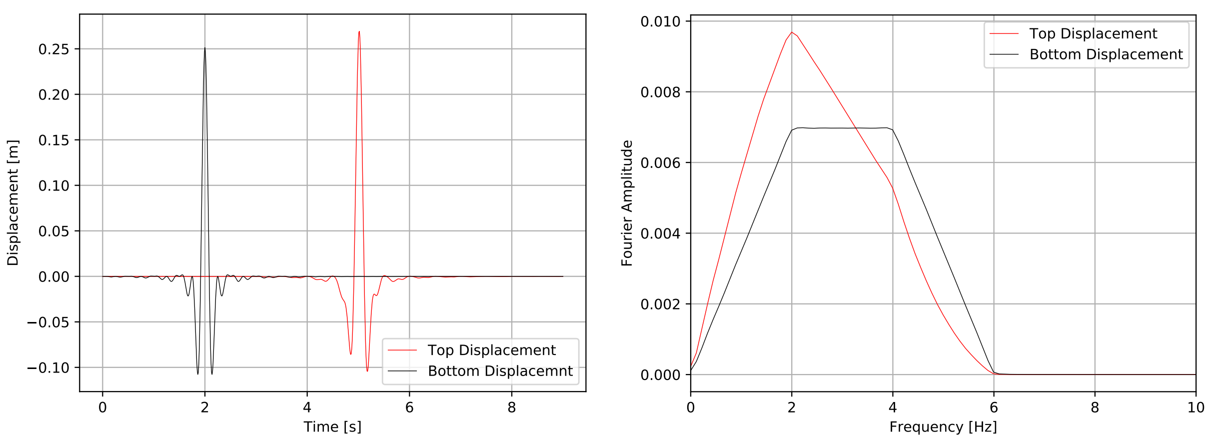


Figure 4.20: Illustration results of Low Viscous Damping

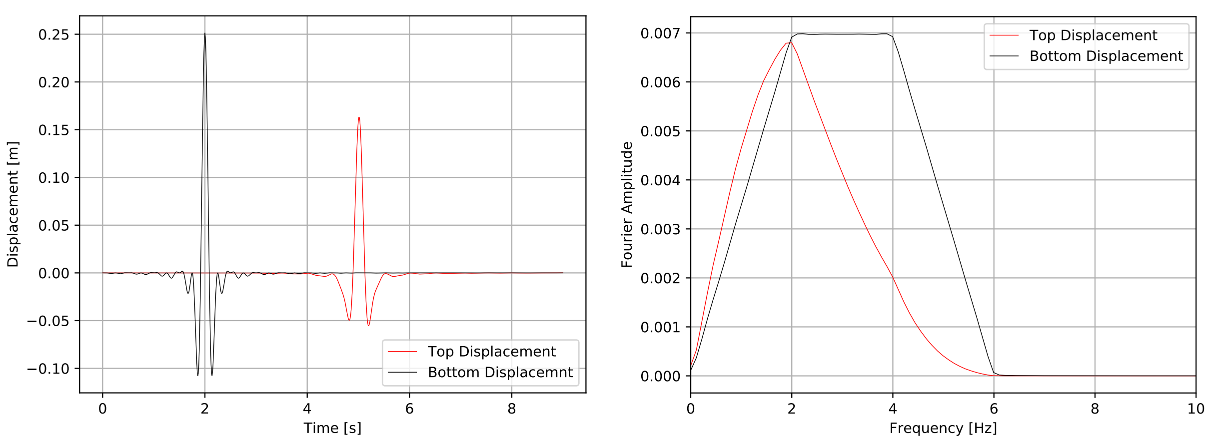


Figure 4.21: Illustration results of High Viscous Damping

4.7 Numerical Damping Example

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

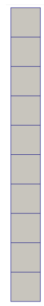


Figure 4.22: Simulation Model

The illustrative result is shown in Fig. 4.20 and Fig. 4.24 .

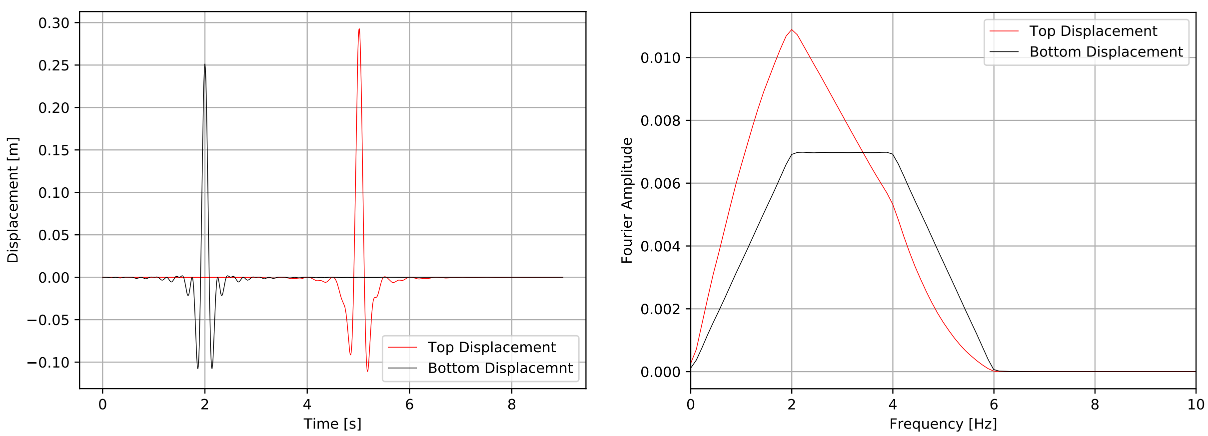


Figure 4.23: Illustration results of Low numerical Damping

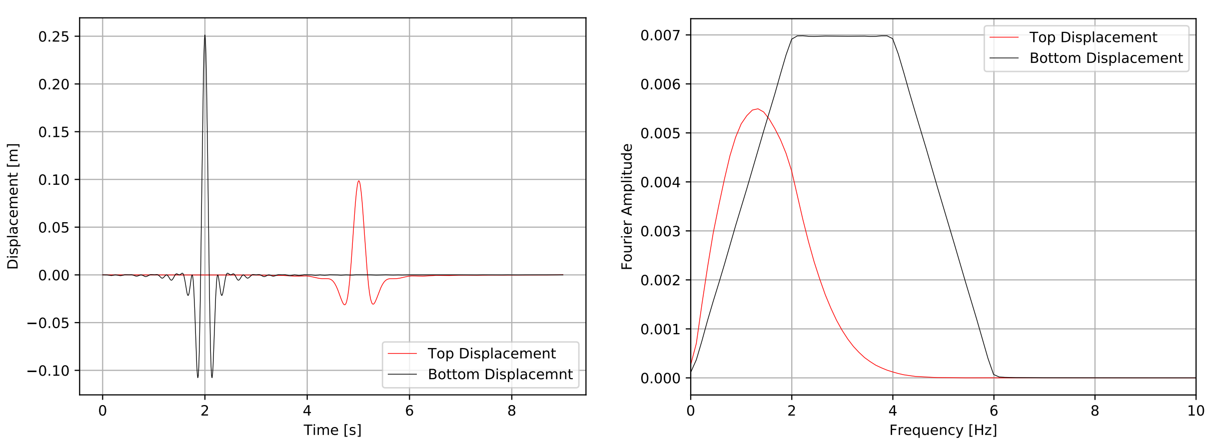


Figure 4.24: Illustration results of High numerical Damping

4.8 Realistic Nuclear Power Plant Example with Nonlinearities

The Real-ESSI input files for this example are available HERE. The compressed package of Real-ESSI input files for this example is available HERE.

The Modeling parameters are listed.

- Soil
  - Unit weight, γ, 21.4 kPa
  - Shear velocity, Vs, 500 m/s
  - Young's modulus, E, 1.3 GPa
  - Poisson's ratio, ν, 0.25
  - Shear strength, S_u, 650 kPa
  - von Mises radius, k, 60 kPa
  - kinematic hardening, H_a, 30 MPa
  - kinematic hardening, C_r, 25
- Structure
  - Unit weight, γ, 24 kPa
  - Young's modulus, E, 20 GPa
  - Poisson's ratio, ν, 0.21
- Contact
  - Initial axial stiffness, k_n^{init}, 1e9 N/m
  - Stiffening rate, S_r, 1000 /m
  - Maximum axial stiffness, k_n^{max}, 1e12 N/m
  - Shear stiffness, k_t, 1e7 N/m
  - Axial viscous damping, C_n, 100 $N \cdot s/m$
  - Shear viscous damping, C_t, 100 $N \cdot s/m$
  - Friction ratio, μ, 0.25

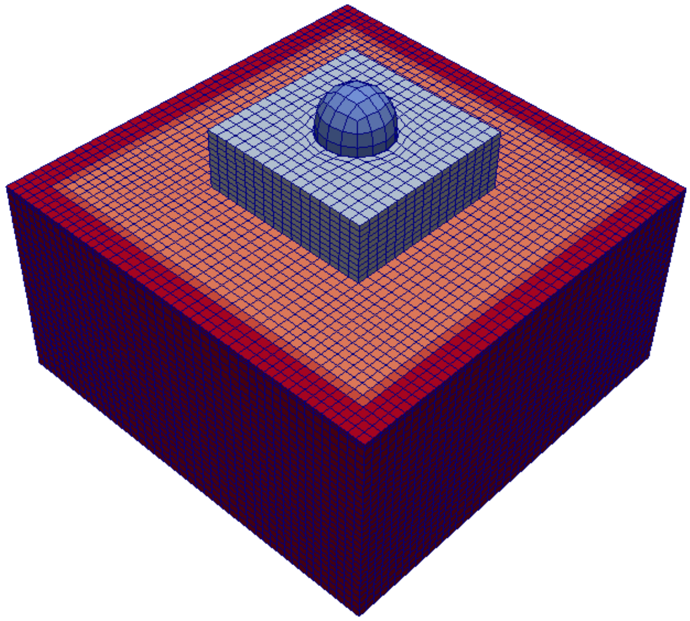


Figure 4.25: Simulation Model

SIMULATION TIME: With 32 cores on AWS EC2 c4.8xlarge instance, the running time for this example is 30 hours.

Chapter 5

Nonlinear Analysis Steps

5.1 Free Field 1D

Elastic Material The Real-ESSI input files for elastic example are available HERE. The compressed package of input files is HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass Density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

Elastoplastic Material The Real-ESSI input files for elastoplastic material example are available HERE. The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises nonlinear hardening material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - von Mises radius, k, 60 kPa
  - nonlinear kinematic hardening rate, H_a, 30 MPa
  - nonlinear kinematic hardening rate, C_r, 25
  - isotropic hardening rate, K_{iso}, 0 Pa

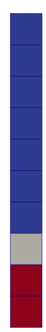


Figure 5.1: Simulation Model

The illustration results of the simulation is shown in Fig. 5.1. As shown in the results, outside the DRM layer, there is no outgoing waves.

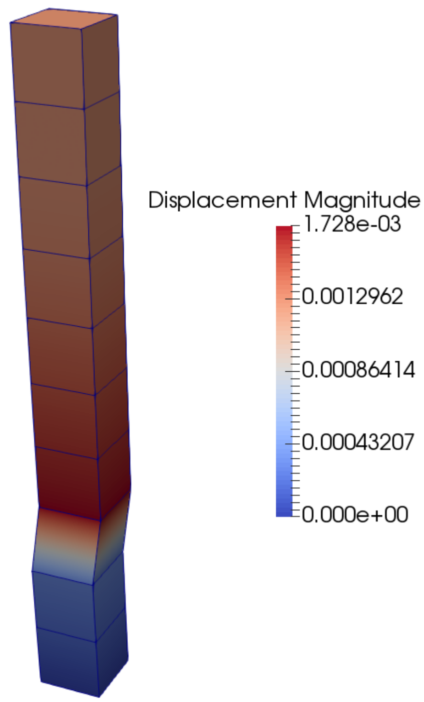


Figure 5.2: Simulation Model

The time series of simulation results is shown in Fig. 5.3.

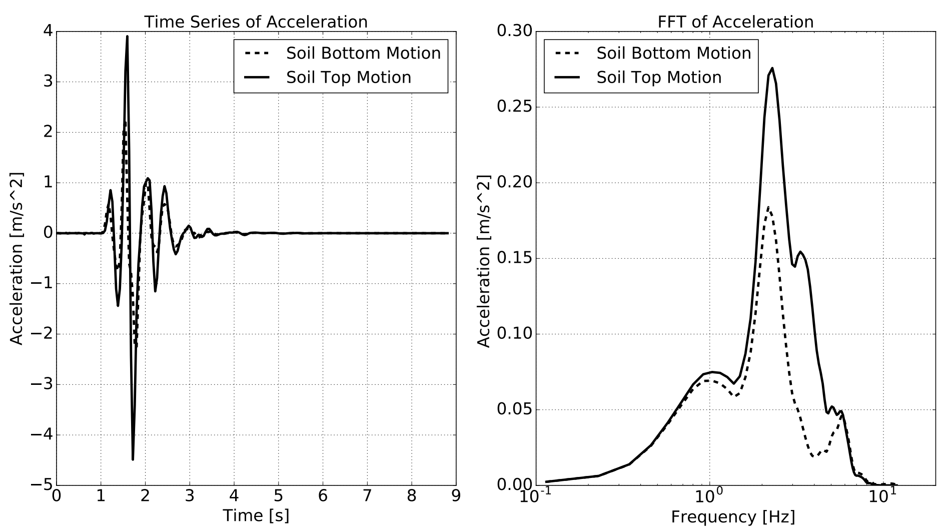


Figure 5.3: Simulation Results: Acceleration Time Series

The response spectrum of motion is shown in Fig. 5.4.

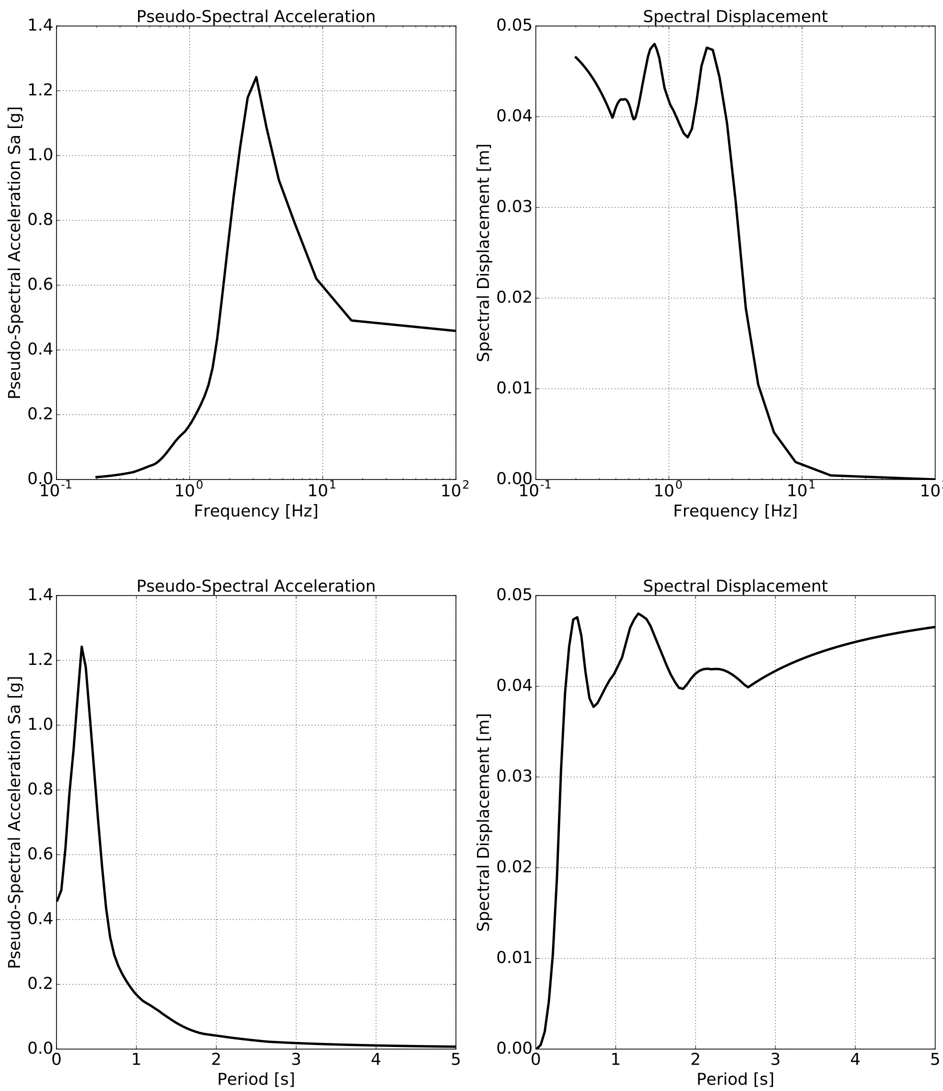


Figure 5.4: Simulation Results: Response Spectrum at Soil Top

5.2 Free Field 3D

Elastic Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 5 minutes.

von-Mises Armstrong-Frederick Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises nonlinear hardening material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - von Mises radius, k, 60 kPa
  - nonlinear kinematic hardening rate, H_a, 30 MPa
  - nonlinear kinematic hardening rate, C_r, 25
  - isotropic hardening rate, K_{iso}, 0 Pa

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 17 minutes.

von-Mises G/Gmax Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Total number of shear modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 565 minutes.

Drucker-Prager G/Gmax Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- Drucker-Prager G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Initial confining stress, p_0, 100 kPa
  - Reference pressure, p_{refer}, 100 kPa
  - Pressure exponential, n, 0.5
  - Cohesion, n, 1 kPa
  - Total number of Shear Modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 565 minutes.

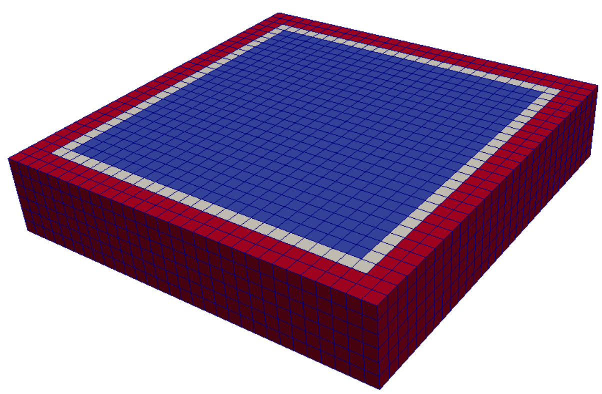


Figure 5.5: Simulation Model

The illustration results of the simulation is shown in Fig. 3.12. As shown in the results, outside the DRM layer, there is no outgoing waves.

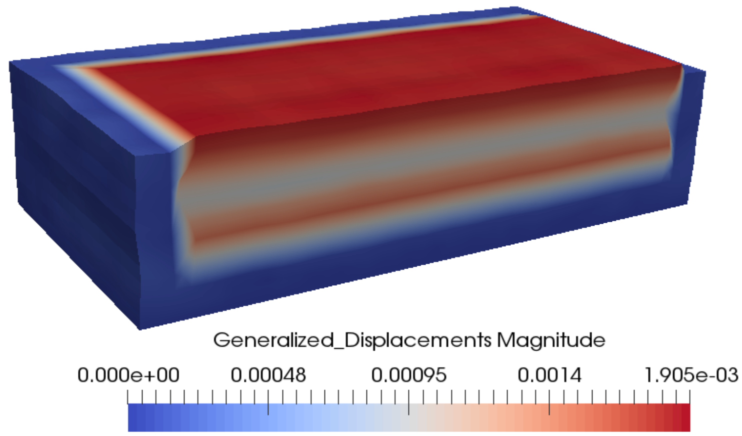


Figure 5.6: Simulation Model

The node tags of critical points for postprocessing are shown in Fig.5.12.

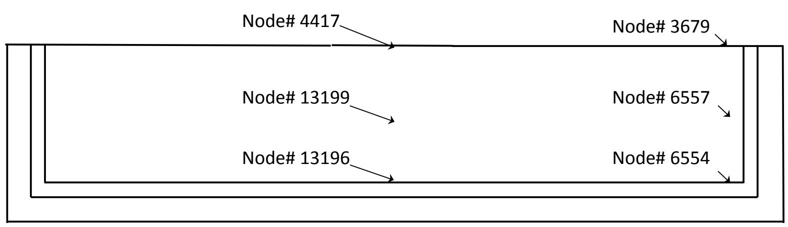


Figure 5.7: Critical Points of Simulation Model

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 871 minutes.

The time series of simulation results is shown in Fig. 5.8.

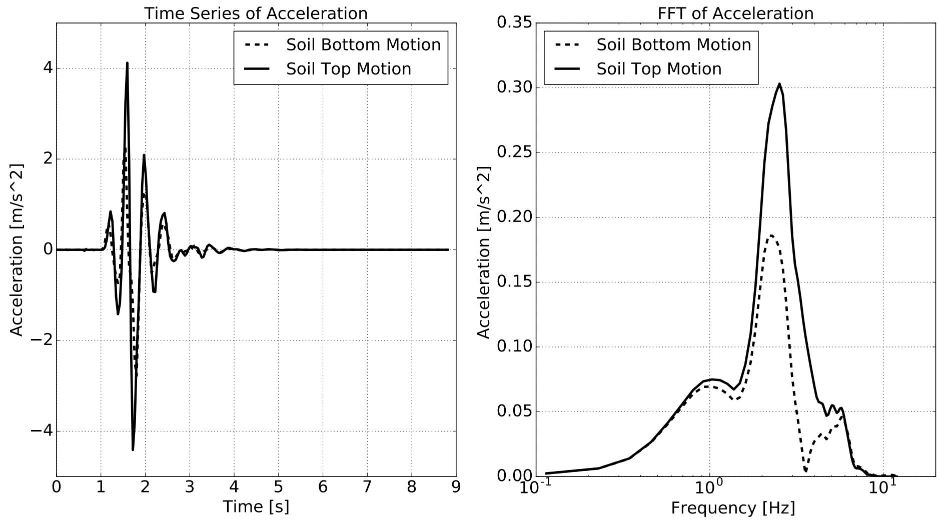


Figure 5.8: Simulation Results: Acceleration Time Series

The response spectrum of motion is shown in Fig. 5.9.

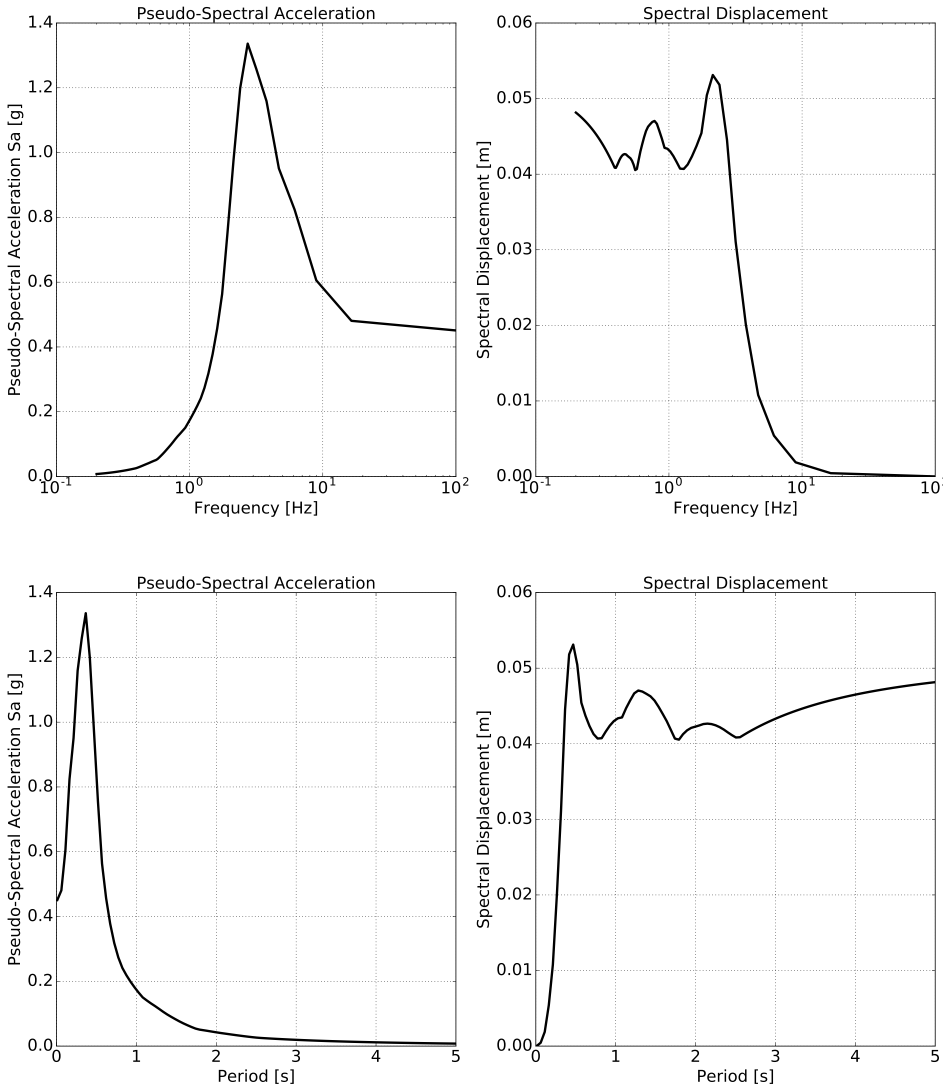


Figure 5.9: Simulation Results: Response Spectrum at Soil Top

5.3 Soil-Foundation Interaction 3D

Elastic Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 13 minutes.

von-Mises Armstrong-Frederick Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises nonlinear hardening material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - von Mises radius, k, 60 kPa
  - nonlinear kinematic hardening rate, H_a, 30 MPa
  - nonlinear kinematic hardening rate, C_r, 25
  - isotropic hardening rate, K_{iso}, 0 Pa

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 36 minutes.

von-Mises G/Gmax Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Total number of shear modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 726 minutes.

Drucker-Prager G/Gmax Material The compressed package of input files is HERE.
The Modeling parameters are listed.

- Drucker-Prager G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Initial confining stress, p_0, 100 kPa
  - Reference pressure, p_{refer}, 100 kPa
  - Pressure exponential, n, 0.5
  - Cohesion, n, 1 kPa
  - Total number of Shear Modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 1252 minutes.

Contact Elements The compressed package of input files is HERE.
The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 24 minutes.

Both Elastoplastic Material and Contact Elements The compressed package of input files is HERE.
SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 41 minutes.

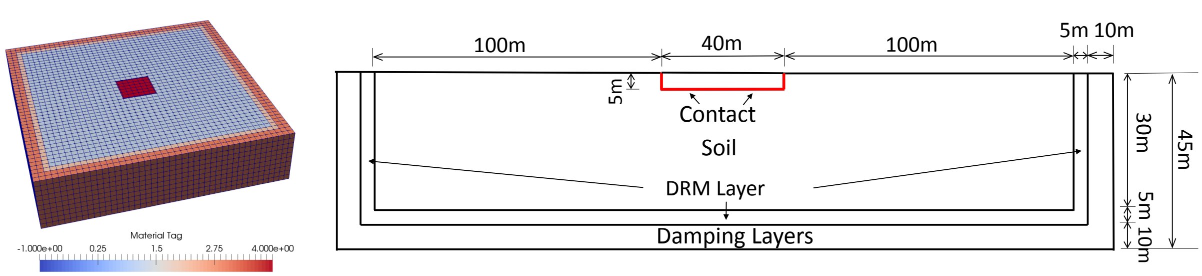


Figure 5.10: Simulation Model

The illustration results of the simulation is shown in Fig. 5.14. As shown in the results, outside the DRM layer, there is no outgoing waves.

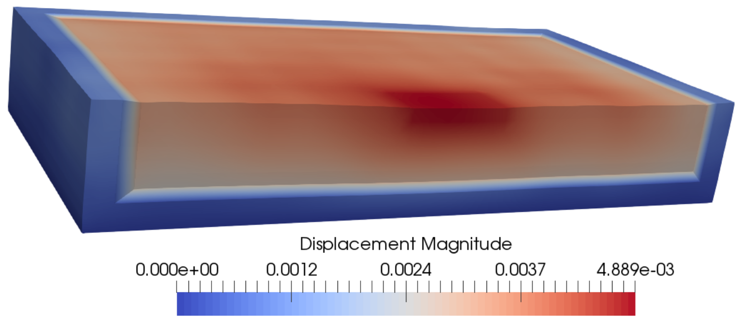


Figure 5.11: Soil Foundation Interaction Results

The node tags of critical points for postprocessing are shown in Fig.5.12.

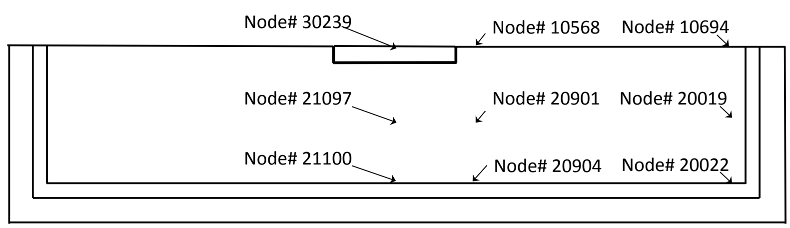


Figure 5.12: Critical Points of Simulation Model

5.4 Soil-Structure Interaction 3D

Elastic Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 10 minutes.

von-Mises Armstrong-Frederick Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises nonlinear hardening material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - von Mises radius, k, 60 kPa
  - nonlinear kinematic hardening rate, H_a, 30 MPa
  - nonlinear kinematic hardening rate, C_r, 25
  - isotropic hardening rate, K_{iso}, 0 Pa

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 46 minutes.

von-Mises G/Gmax Material The compressed package of input files is HERE.

The Modeling parameters are listed.

- von-Mises G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Total number of shear modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 755 minutes.

Drucker-Prager G/Gmax Material The compressed package of input files is HERE.

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 1178 minutes.

The Modeling parameters are listed.

- Drucker-Prager G/Gmax material model
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1
  - Initial confining stress, p_0, 100 kPa
  - Reference pressure, p_{refer}, 100 kPa
  - Pressure exponential, n, 0.5
  - Cohesion, n, 1 kPa
  - Total number of Shear Modulus 9
  - G over Gmax, 1,0.995,0.966,0.873,0.787,0.467,0.320,0.109,0.063
  - Shear strain gamma, 0,1E-6,1E-5,5E-5,1E-4, 0.0005, 0.001, 0.005, 0.01

Contact Elements The compressed package of input files is HERE.

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 15 minutes.

Both Elastoplastic Material and Contact Elements The compressed package of input files is HERE.

The thickness of the shell structure is 2 meters.

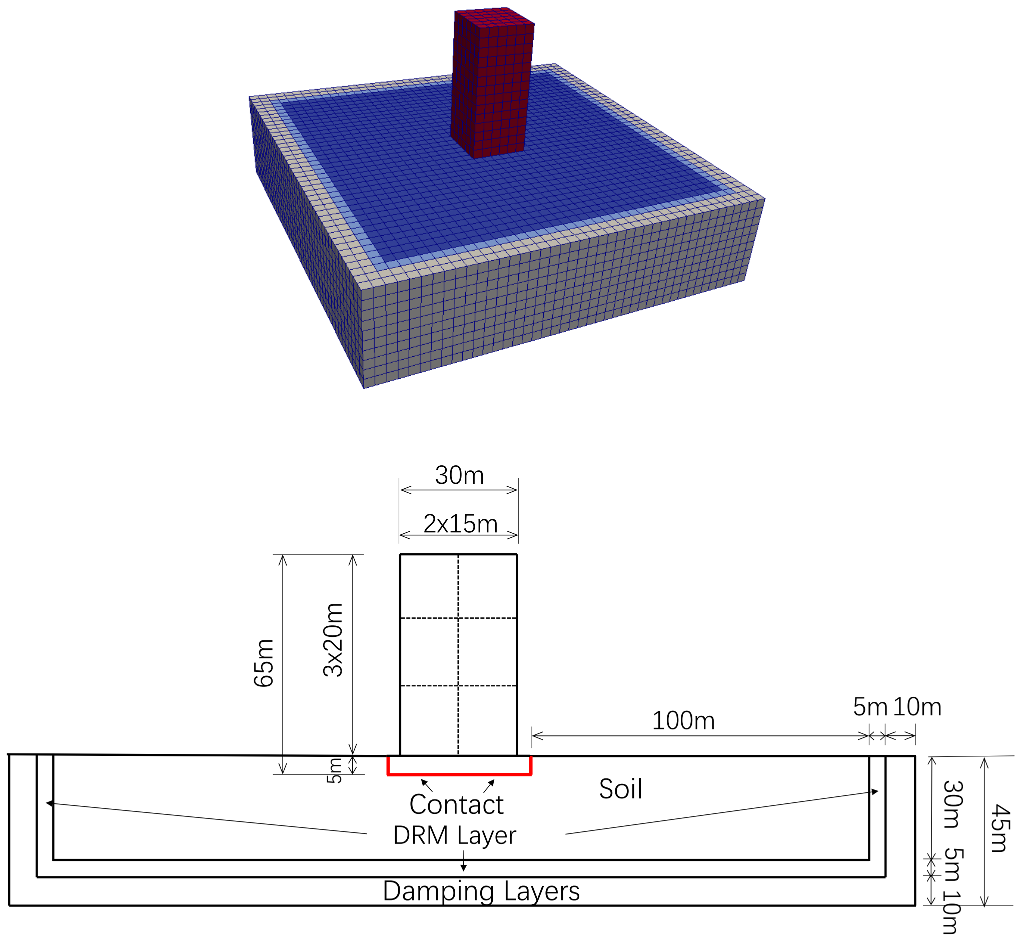


Figure 5.13: Simulation Model

The illustration results of the simulation is shown in Fig. 5.14. As shown in the results, outside the DRM layer, there is no outgoing waves.

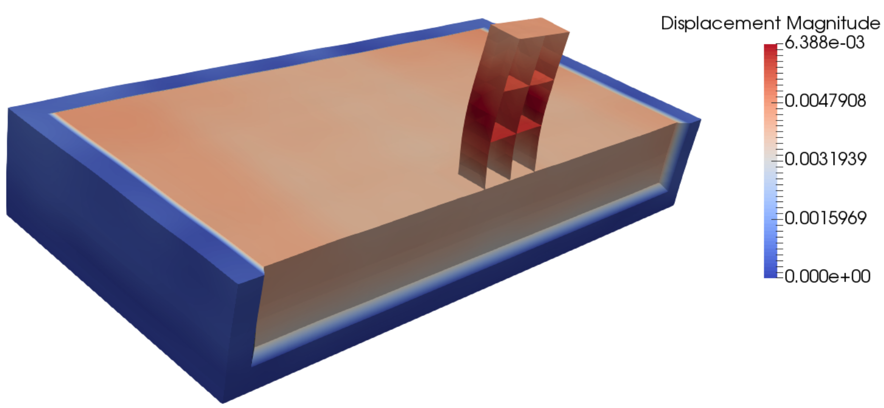


Figure 5.14: Simulation Model

The node tags of critical points for postprocessing are shown in Fig.5.15.

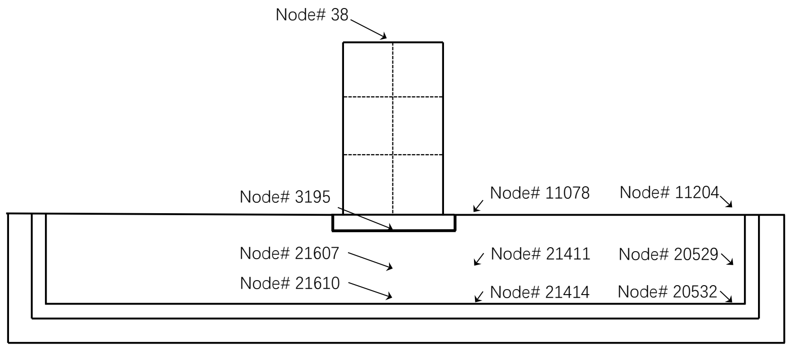


Figure 5.15: Critical Points of Simulation Model

SIMULATION TIME: With 8 cores on AWS EC2 c4.2xlarge instance, the running time for this example is 47 minutes.

Simulation with 1D motion The time series of simulation results is shown in Fig. 5.16.

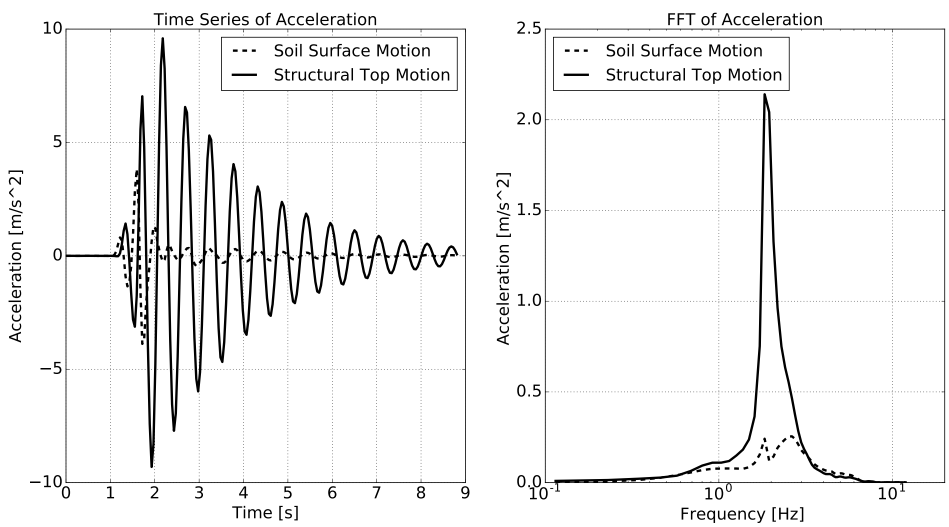


Figure 5.16: Simulation Results: Acceleration Time Series with 1D motion

The response spectrum of motion is shown in Fig. 5.17.

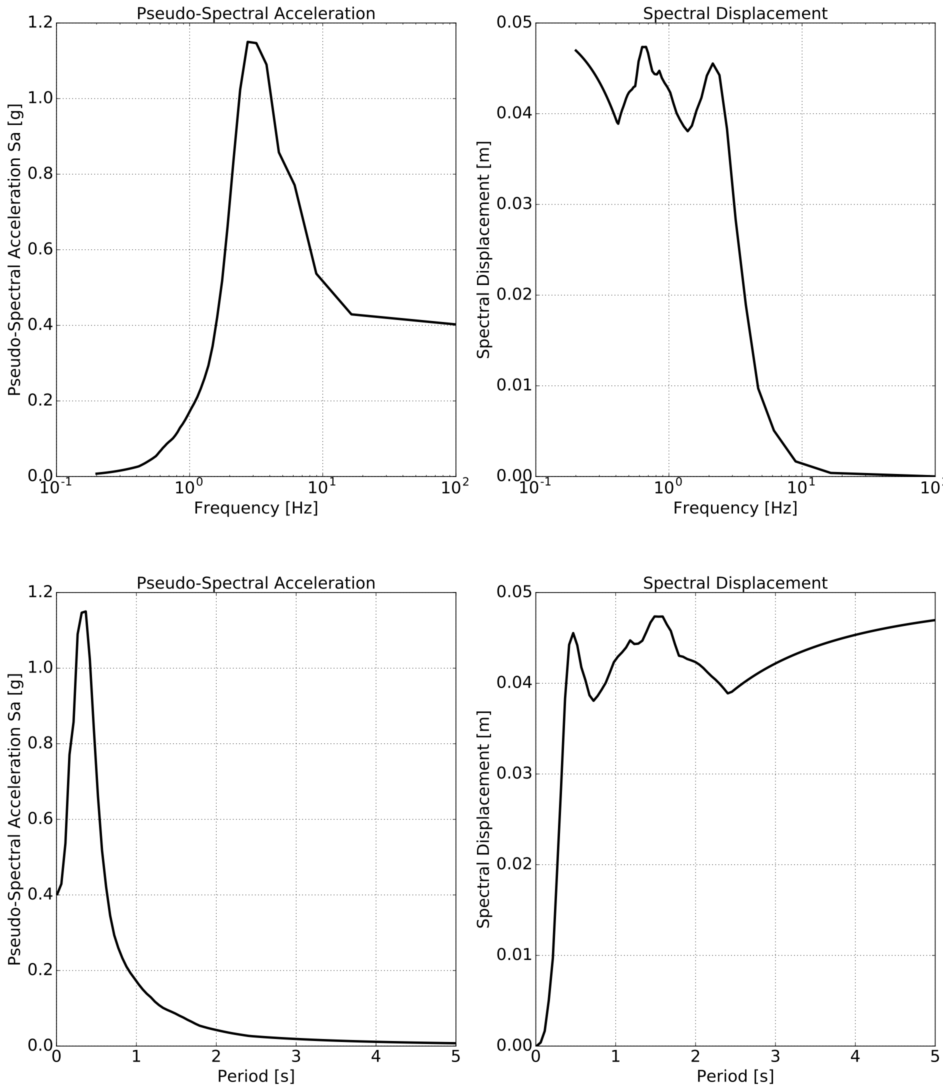


Figure 5.17: Simulation Results: Response Spectrum of Structure Top with 1D motion

Simulation with 3 $\times$ 1D motion The time series of simulation results is shown in Fig. 5.18.

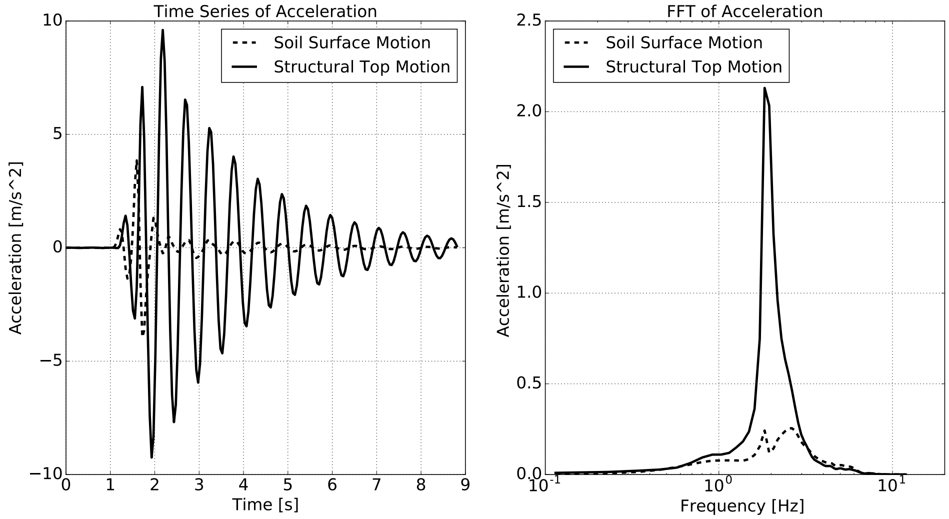


Figure 5.18: Simulation Results: Acceleration Time Series with 3D motion

The response spectrum of motion is shown in Fig. 5.19.

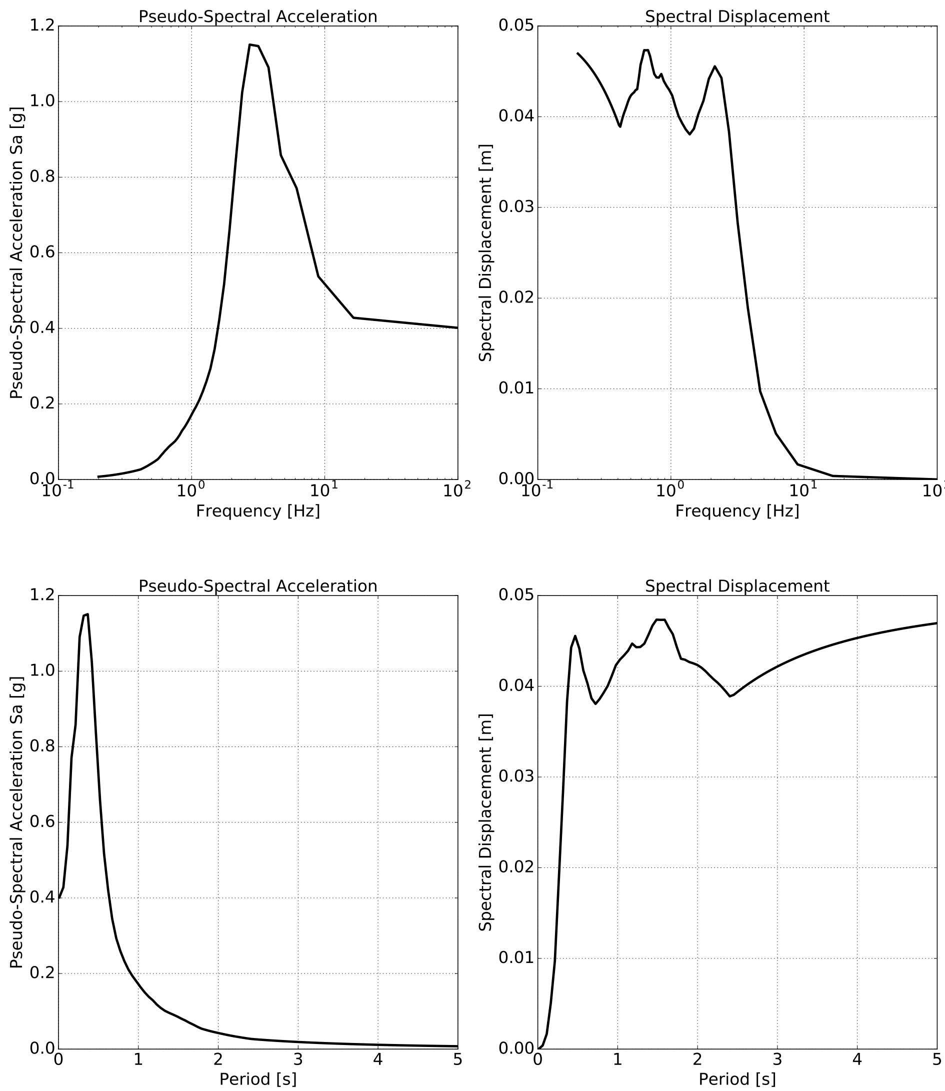


Figure 5.19: Simulation Results: Response Spectrum of Structure Top with 3D motion

5.5 Structure Analysis without Soil

5.5.1 Eigen Analysis

The Real-ESSI input files for this example are available HERE. The compressed package of input files is HERE.

The thickness of the shell structure is 2 meters. The simulation model is shown below.

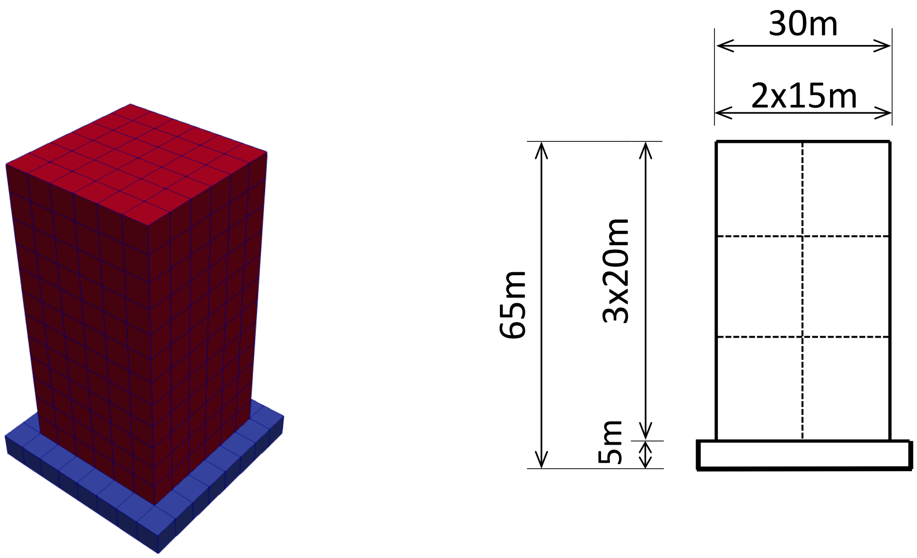


Figure 5.20: Simulation Model

The eigen results:

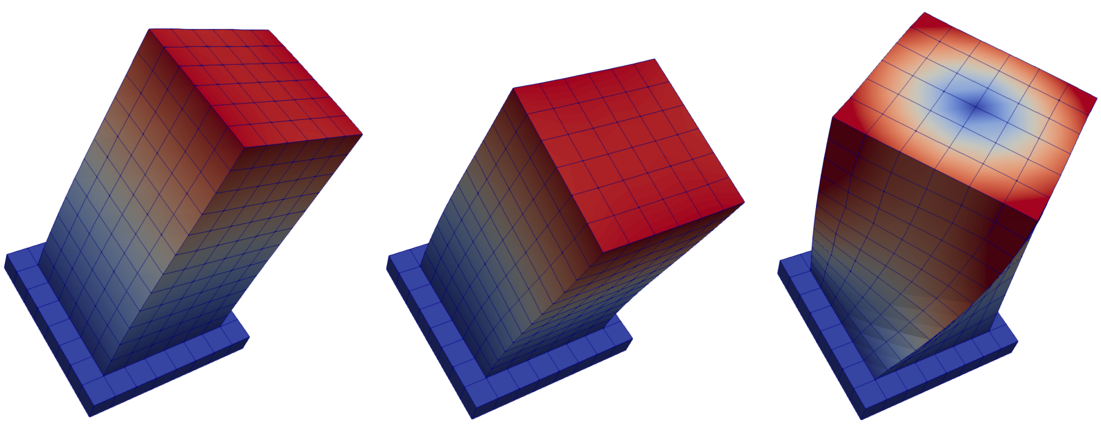


Figure 5.21: Eigen Results (Eigen Mode 1 to 3 from left to right)

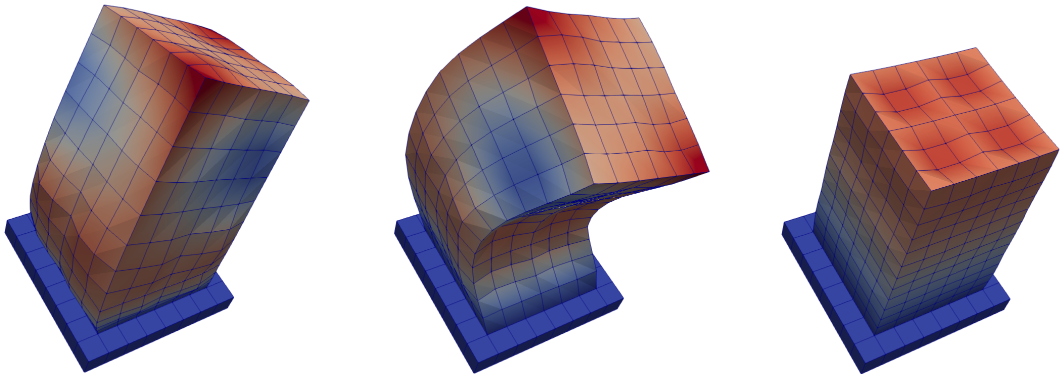


Figure 5.22: Eigen Results (Eigen Mode 4 to 6 from left to right)

5.5.2 Imposed Motion

The Real-ESSI input files for this example are available HERE. The compressed package of input files is HERE.

The Modeling parameters are listed.

- Elastic Material Properties
  - Mass density, ρ, 2000 kg/m^3
  - Young's modulus, E, 1.1 GPa
  - Poisson's ratio, ν, 0.1

The thickness of the shell structure is 2 meters. The simulation model is shown below.

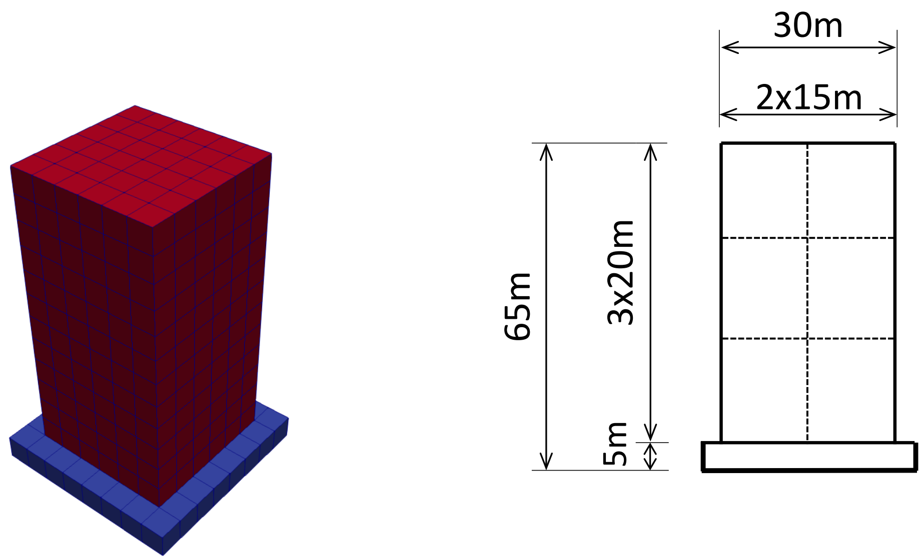


Figure 5.23: Simulation Model

The simulation results:

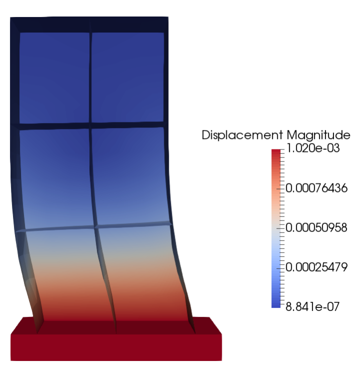


Figure 5.24: Simulation Results

The time series of simulation results is shown in Fig. 5.25.

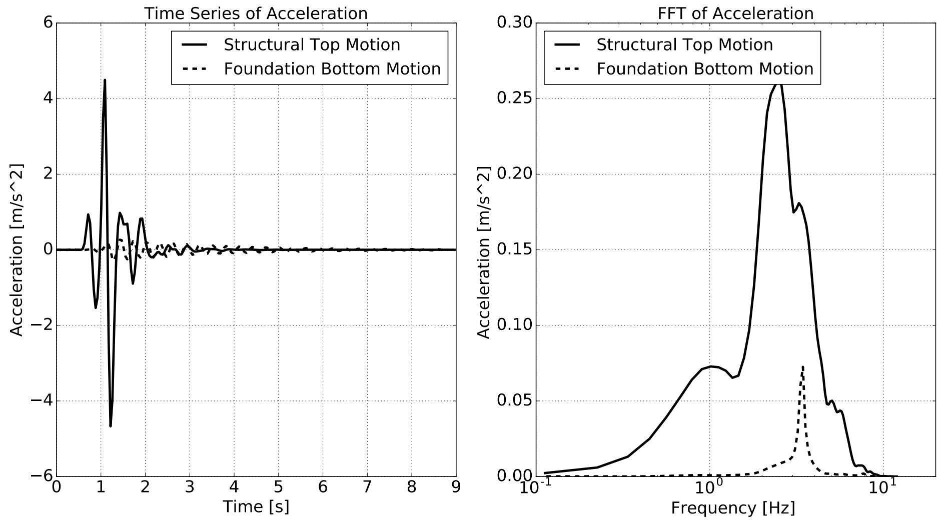


Figure 5.25: Simulation Results: Acceleration Time Series with 1D imposed motion

The response spectrum of motion is shown in Fig. 5.26.

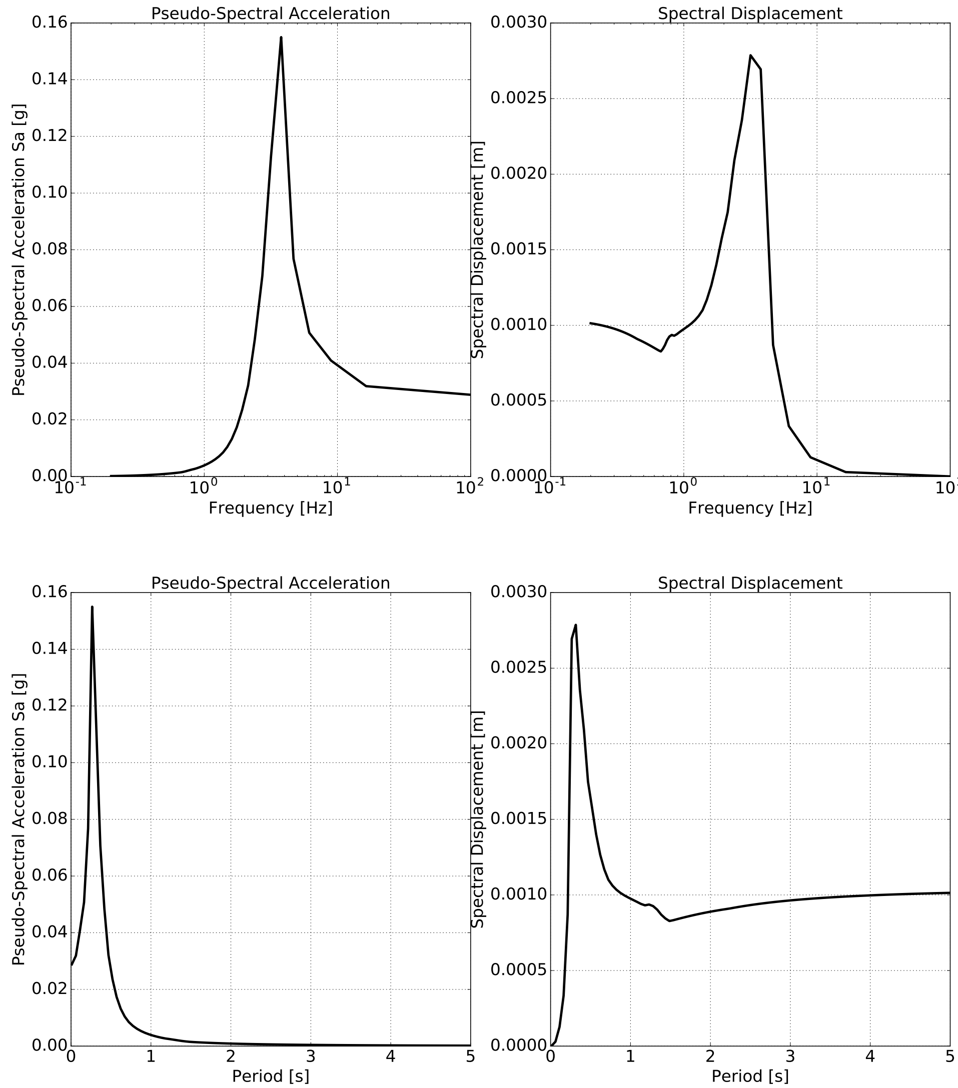


Figure 5.26: Simulation Results: Response Spectrum of Structure Top with 1D imposed motion

Chapter 6

Postprocessing Examples with Python

6.1 Basic Operations on Output

Real-ESSI output are stored in HDF5 file format. HDF5 file a binary file format, which has the internal directories of dataset. To open a dataset in HDF5 output, one can open the HDF5 file with the python interface *h5py*. Then, the dataset can be extracted by following the internal path in the HDF5 format.

```
import h5py
h5file = h5py.File(filename,'r')
time=h5file['/time'][()]
Element_Outputs = h5file['/Model/Elements/Element_Outputs'][:,:]
Gauss_Outputs = h5file['/Model/Elements/Gauss_Outputs'][:,:]
Index_to_Coordinates = h5file['/Model/Nodes/Index_to_Coordinates'][:,:]
Coordinates = h5file['/Model/Nodes/Coordinates'][:,:]
Index_to_Generalized_Displacements = \
h5file['/Model/Nodes/Index_to_Generalized_Displacements'][:,:]
Generalized_Displacements = \
h5file['/Model/Nodes/Generalized_Displacements'][:,:]
```

6.2 Time Series Plotting

Following the basic options on HDF5 outptu, suppose one already extracted the dataset in the HDF5 output, then, the plot of the time series is illustrated below.

```
target_displacement = Generalized_Displacements[15]
plt.plot(time, target_displacement)
plt.xlabel("Time␣[s]")
plt.ylabel("Displacement␣[m]")
plt.grid()
plt.savefig("target_displacement_time_series.pdf")
plt.show()
```

Note that the output of Real-ESSI is always in the standard unit.

6.3 Spectrum Analysis

Furthermore, one can also extract the results and do spectrum analysis of the output.

```
import numpy as np
import matplotlib.pyplot as plt
import scipy.fftpack
import math
def FFT(x,dt,maxf,plot=True):
        # Number of samplepoints
        N = x.size;
        # Total Time
        T = N*dt;
        # sample dpacing is dt
        # sampling frequency
        Fs = 1/dt;
        xfft  = scipy.fftpack.fft(x);
        xfreq = np.linspace(0.0, Fs/2, N/2);
        xfftHalf = 2.0/N * np.abs(xfft[:N//2]);
        xfftHalf[0] = xfftHalf[0]/2;
        if(plot):
                fig, ax = plt.subplots()
                ax.plot(xfreq, xfftHalf,'-k')
                if(maxf is not None):
                        plt.xlim(0, maxf)
                plt.ylabel('Fourier transform |FFT(x)|')
                plt.xlabel('Frequency |Hz|')
                plt.show()
        return xfreq, xfftHalf
```

For advanced python scripts with Real-ESSI, please visit `https://github.com/SumeetSinha/Python-Scripts`.

Chapter 7

Summary