Bridge PBEE Numerical Simulation Framework

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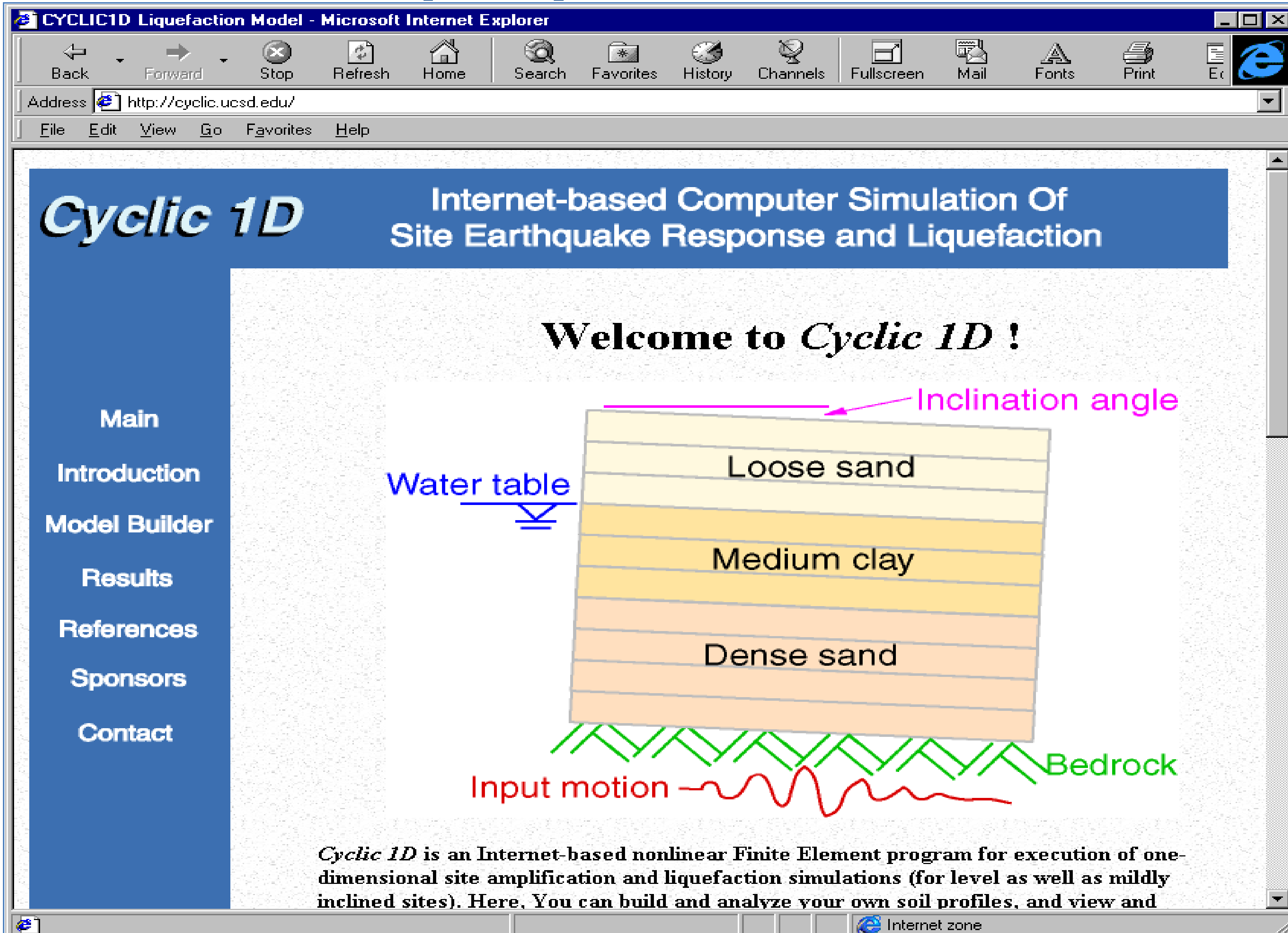
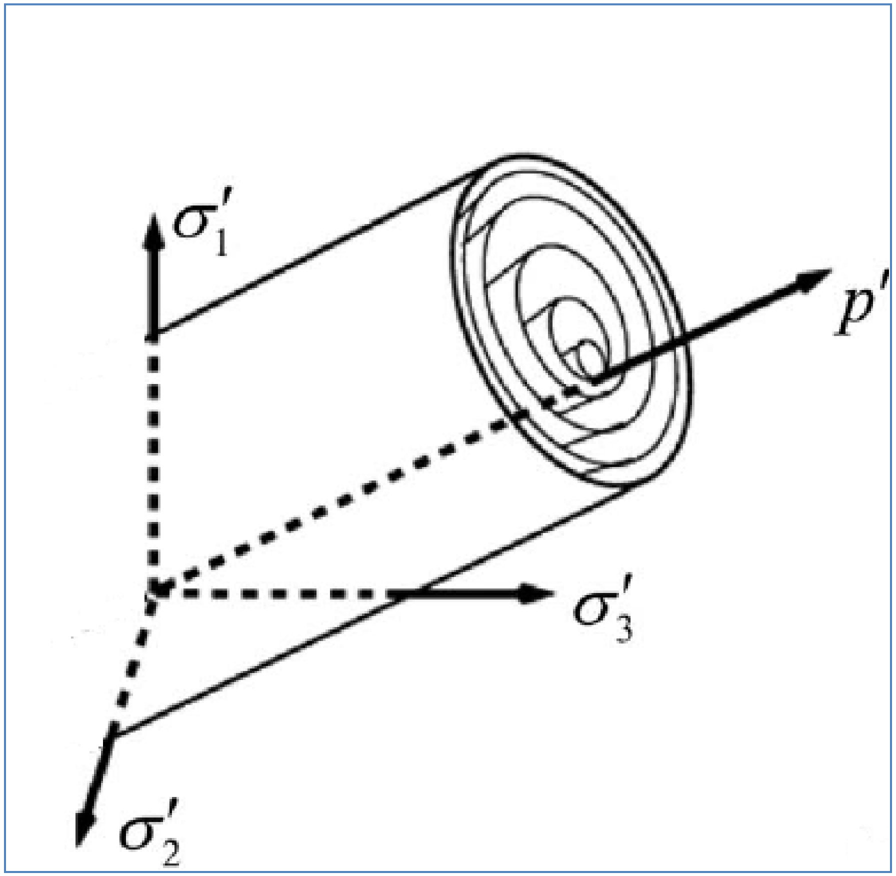
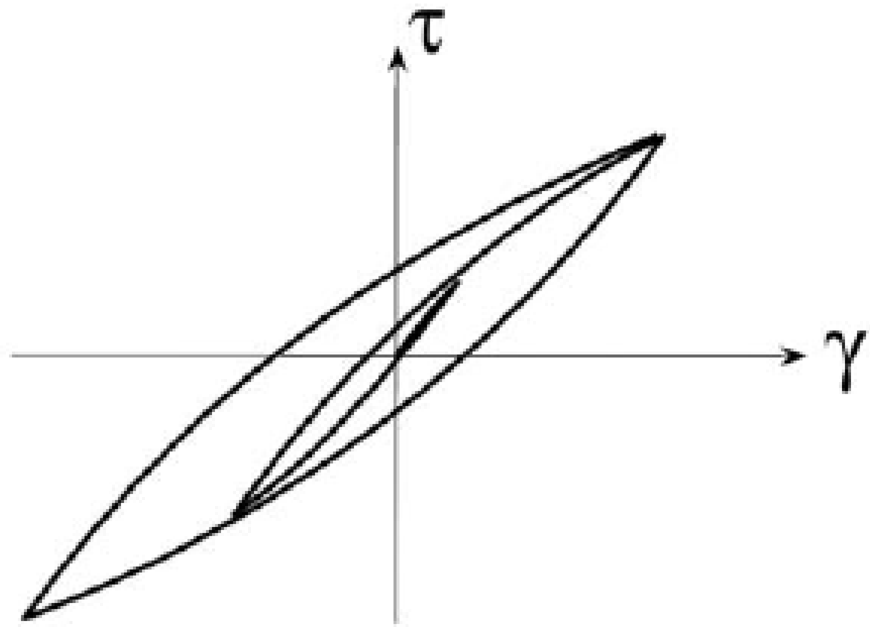
University of California, San Diego
Kevin Mackie
University of Central Florida

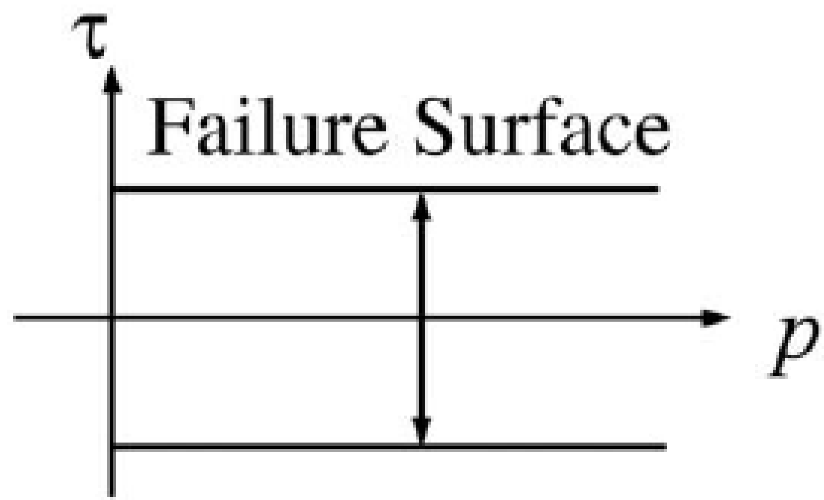
http://cyclic.ucsd.edu



Nonlinear hysteretic Model



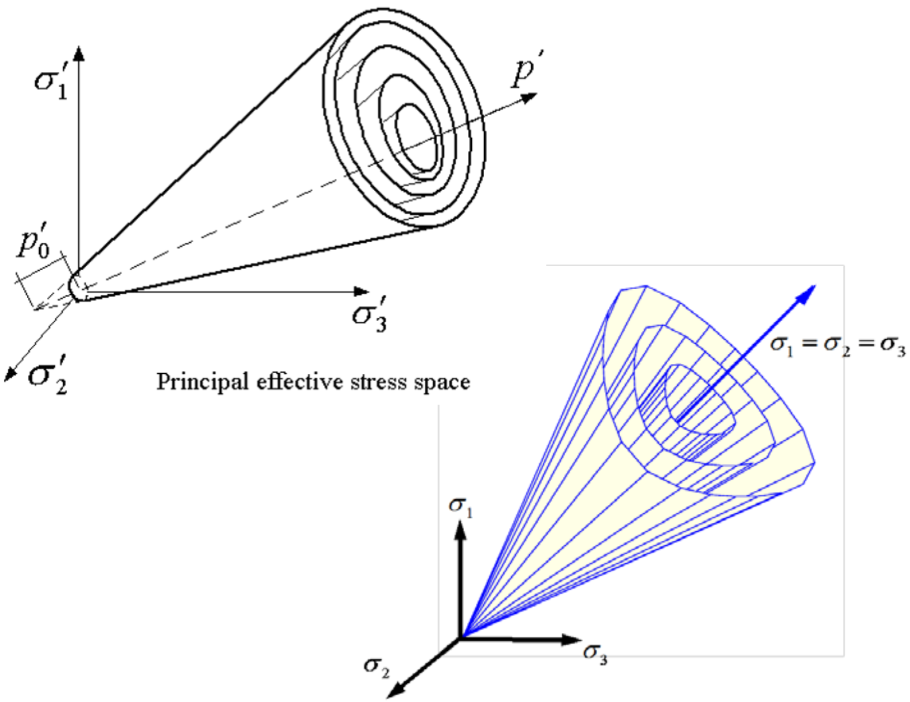




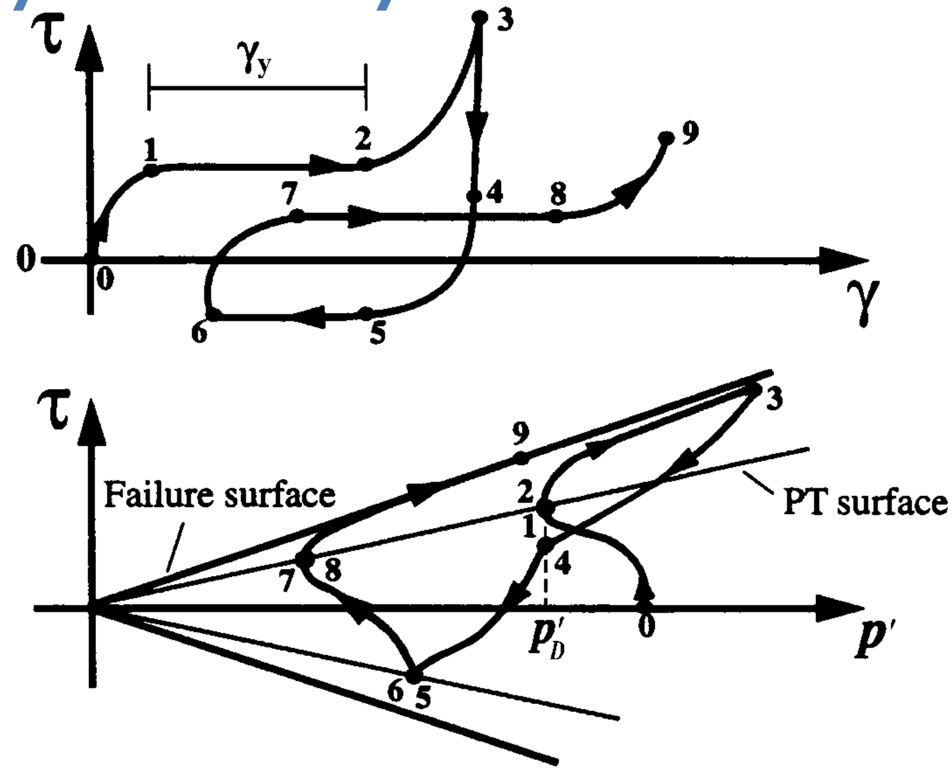
Note: Also available with Tension Cut-off for interface between structure and soil

Soil Constitutive Model

- **Multi-yield surface plasticity model (based on Prevost 1985)**
- **Incorporating dilatancy and cyclic mobility effects**

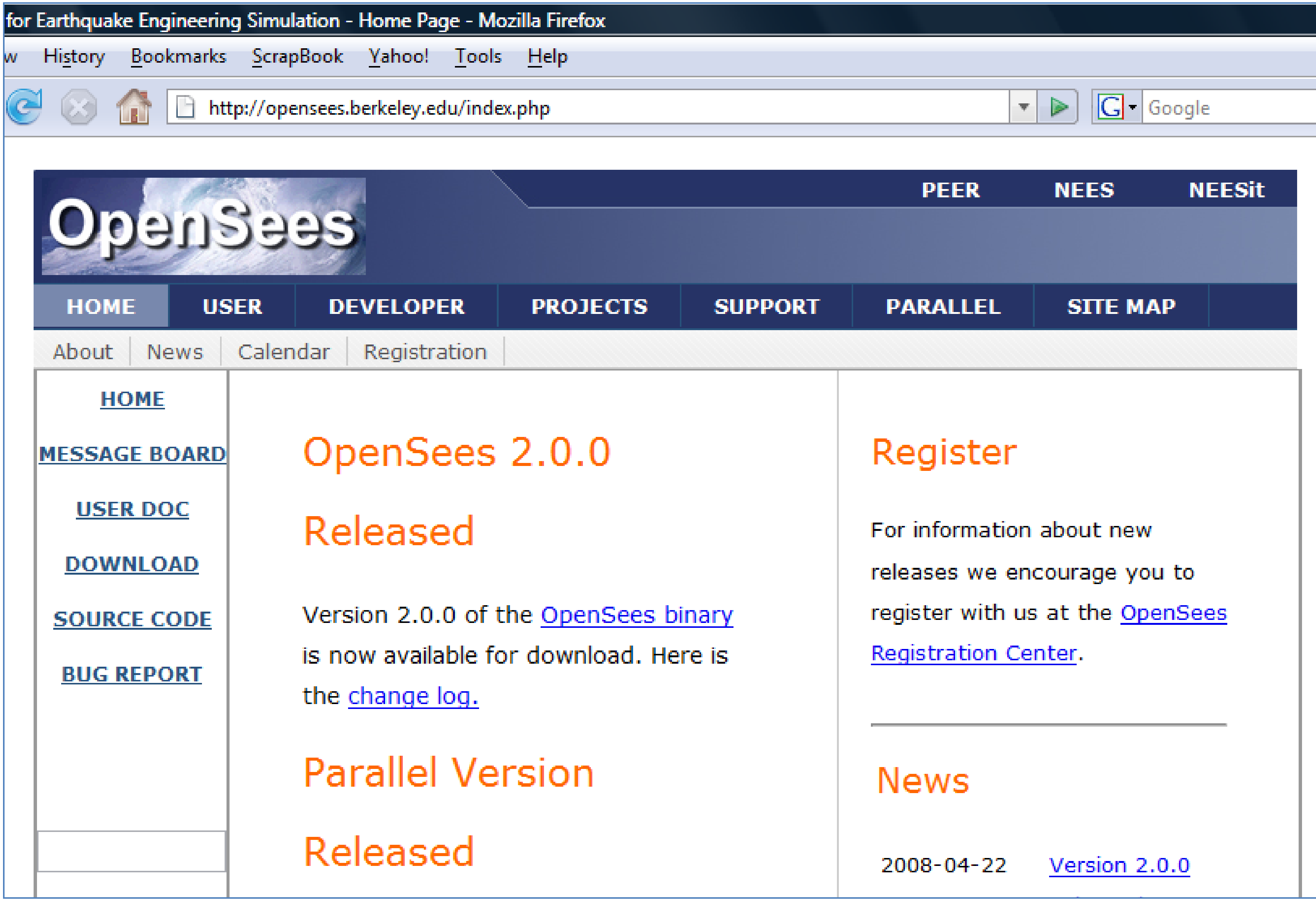


Conical yield surfaces for granular soils (Prevost 1985; Elgamal et al. 2003; Yang and Elgamal 2008)



Shear stress-strain and effective stress path under undrained shear loading condition (Parra 1996, Yang 2000, Yang and Elgamal 2002)

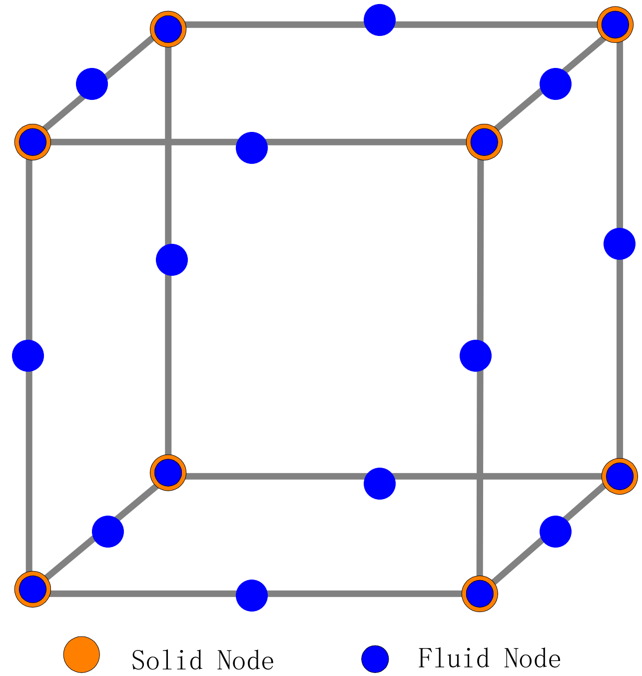
OpenSees at UC Berkeley



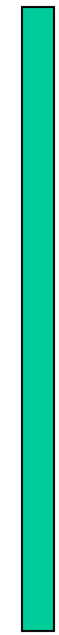
OpenSees http://opensees.berkeley.edu/

PEER Center, UC Berkeley, Prof. Gregory Fenves

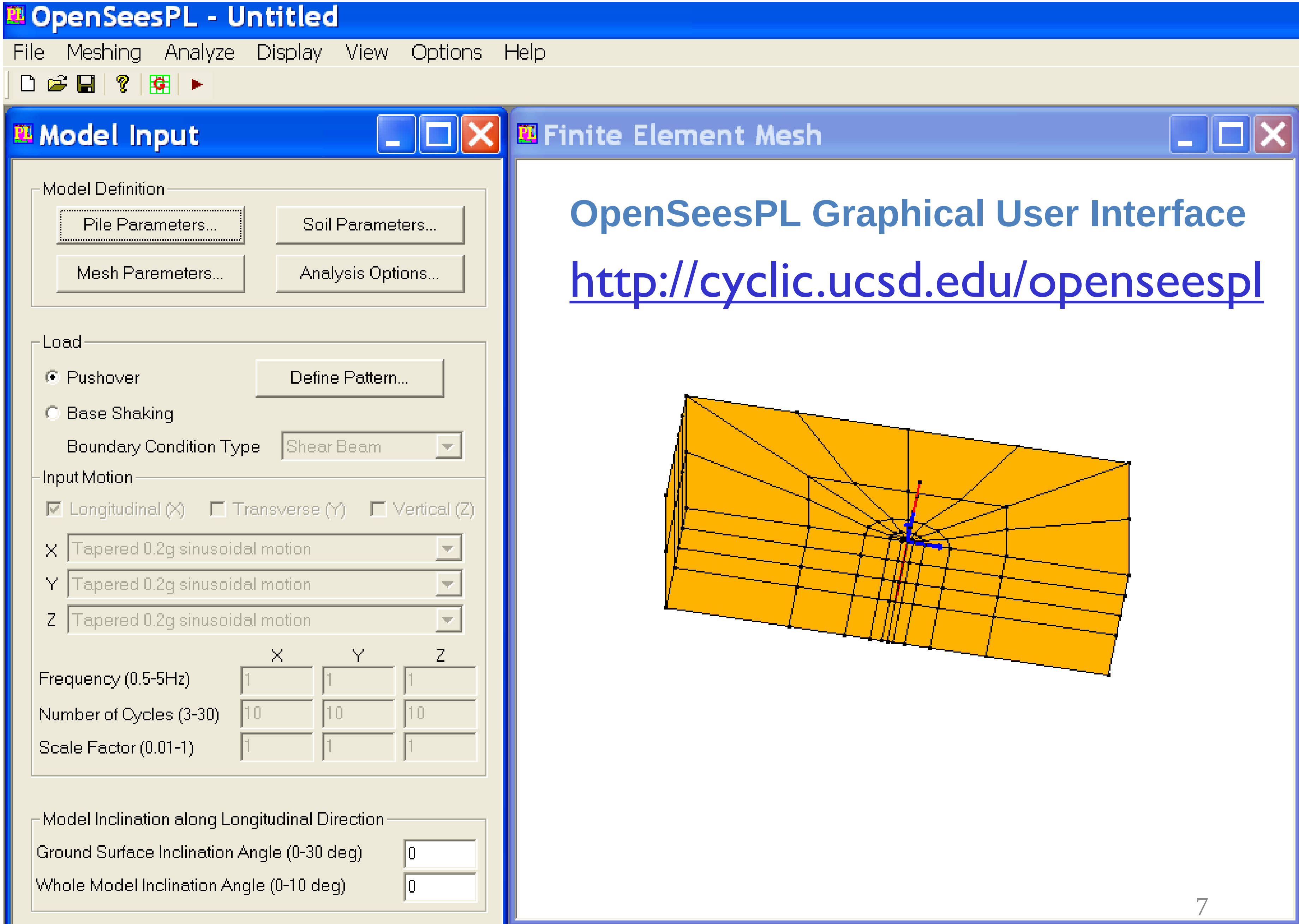
Open-source platform



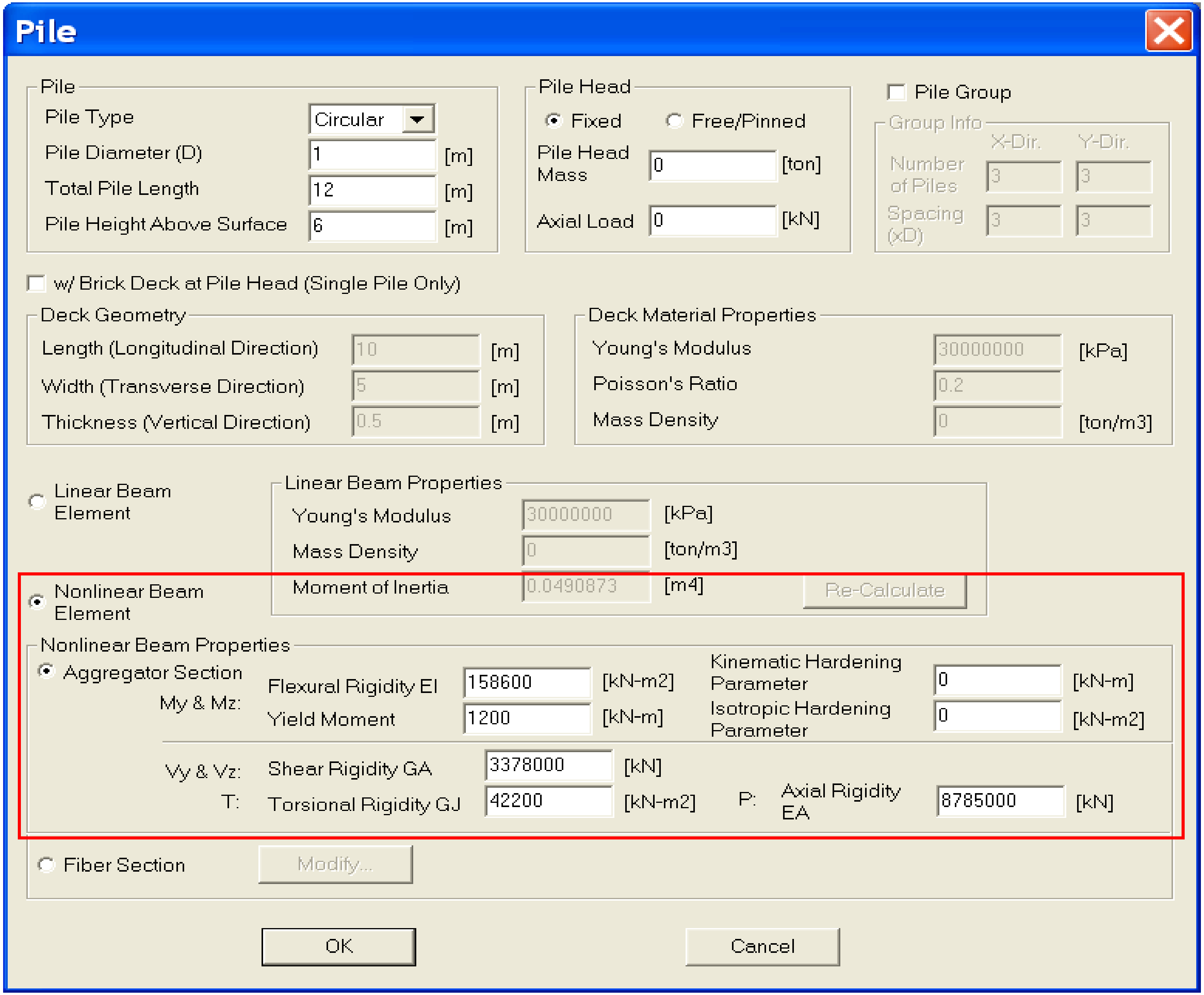
Solid-Fluid Fully Coupled Element for Saturated Soil



Beam Element for Pile


OpenSeesPL - Untitled
File
Meshing
Analyze
Display
View
Options
Help
Model Input
Model Definition
Pile Parameters...
Soil Parameters...
Mesh Paremeters...
Analysis Options...
Load
Pushover
Define Pattern...
Base Shaking
Boundary Condition Type
Shear Beam
Input Motion
Longitudinal (X)
Transverse (Y)
Vertical (Z)
X Tapered 0.2g sinusoidal motion
Y Tapered 0.2g sinusoidal motion
Z Tapered 0.2g sinusoidal motion
X Y Z
Frequency (0.5-5Hz) 1 1 1
Number of Cycles (3-30) 10 10 10
Scale Factor (0.01-1) 1 1 1
Model Inclination along Longitudinal Direction
Ground Surface Inclination Angle (0-30 deg) 0
Whole Model Inclination Angle (0-10 deg) 0
Finite Element Mesh
OpenSeesPL Graphical User Interface
http://cyclic.ucsd.edu/openseespl

OpenSeesPL: http://cyclic.ucsd.edu/openseespl



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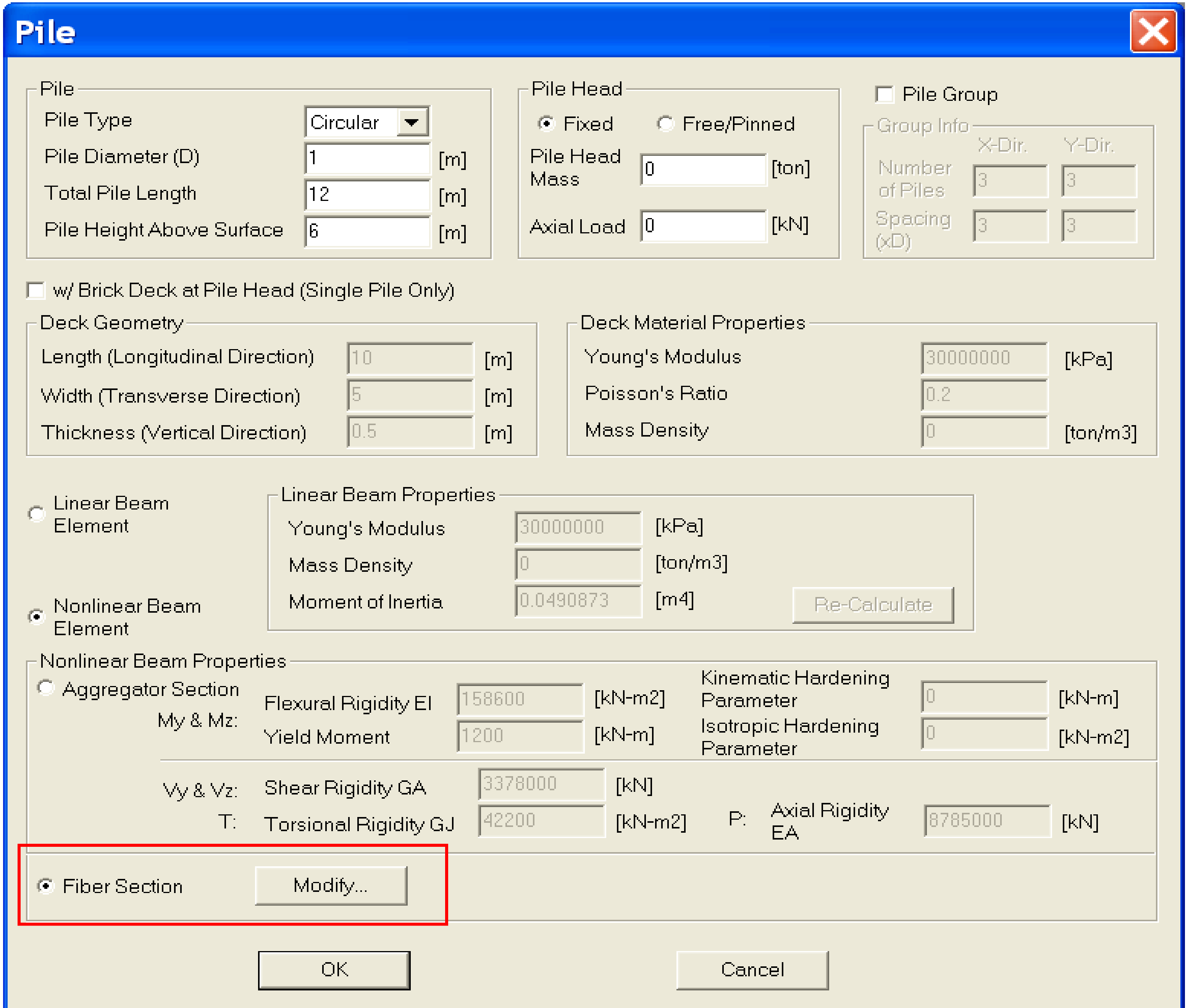
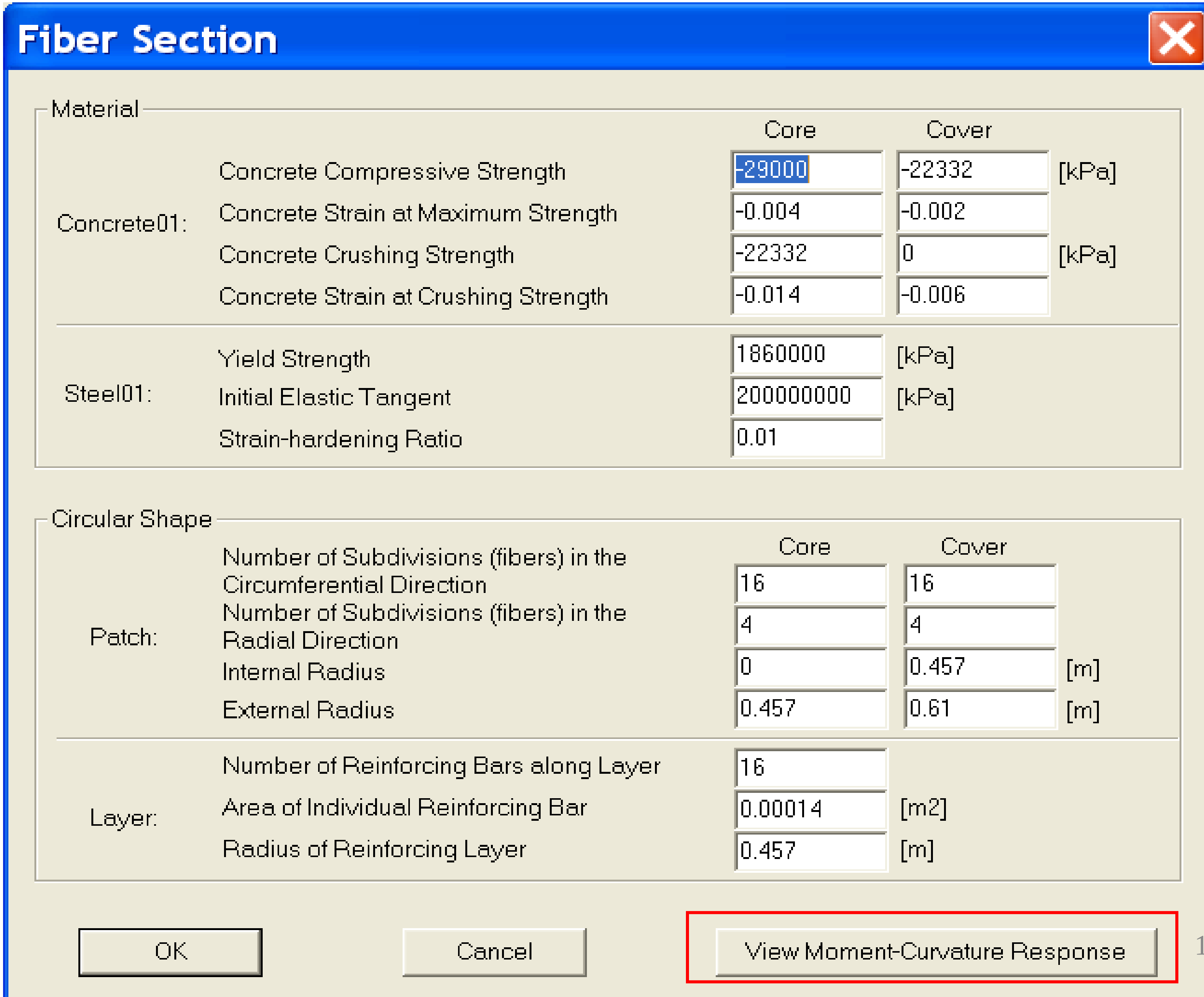
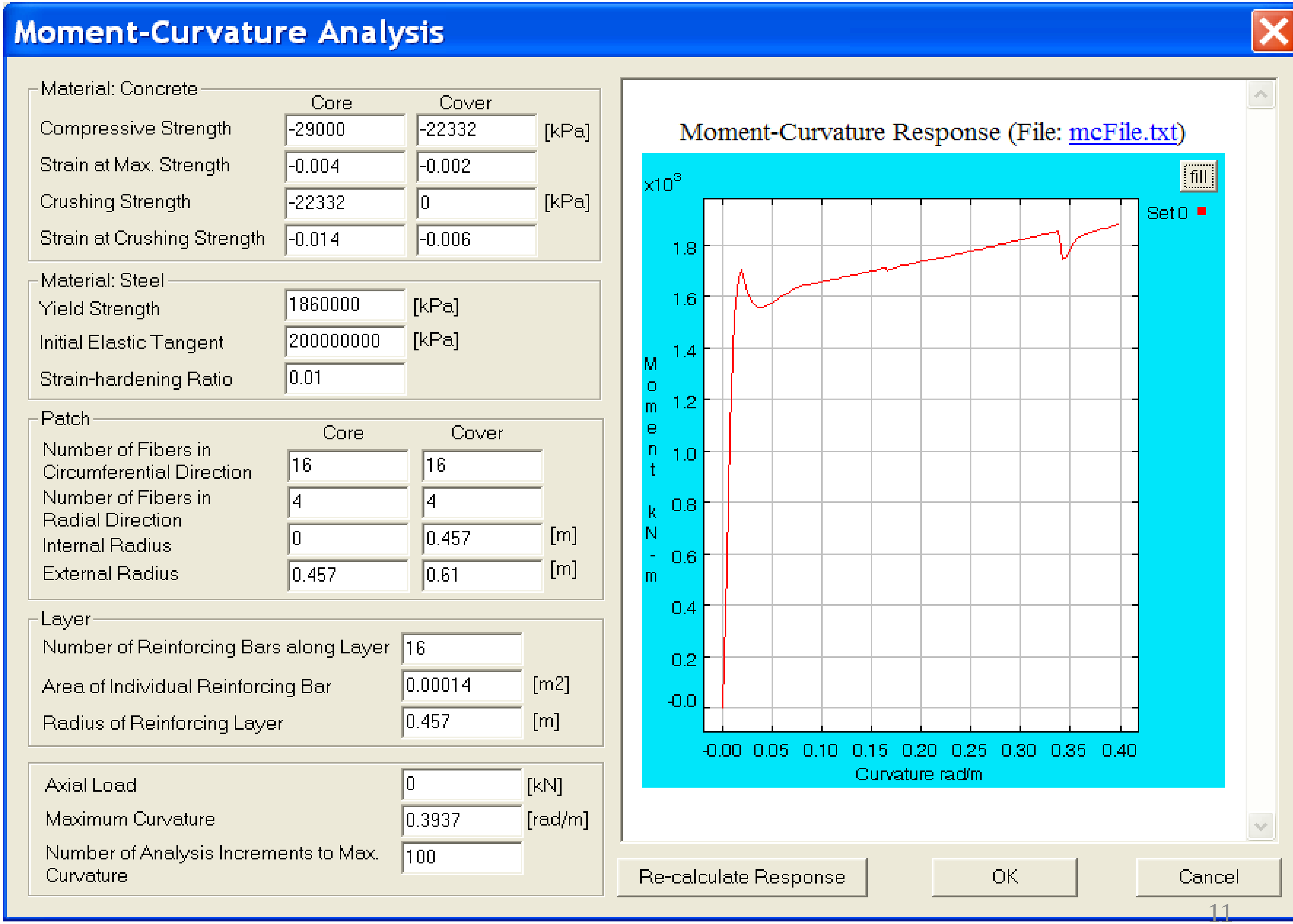


OpenSeesPL: http://cyclic.ucsd.edu/openseespl



OpenSeesPL: http://cyclic.ucsd.edu/openseespl



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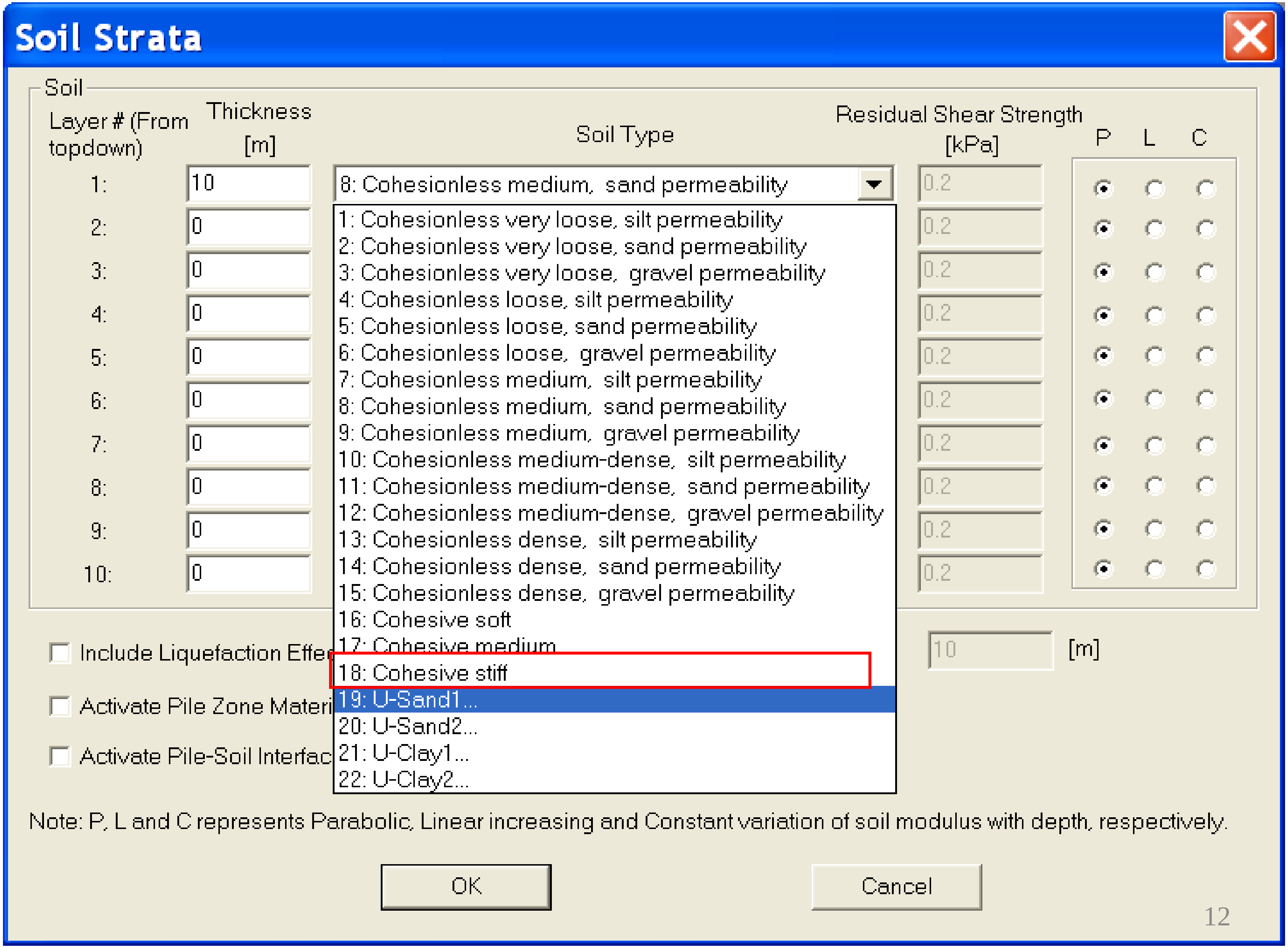
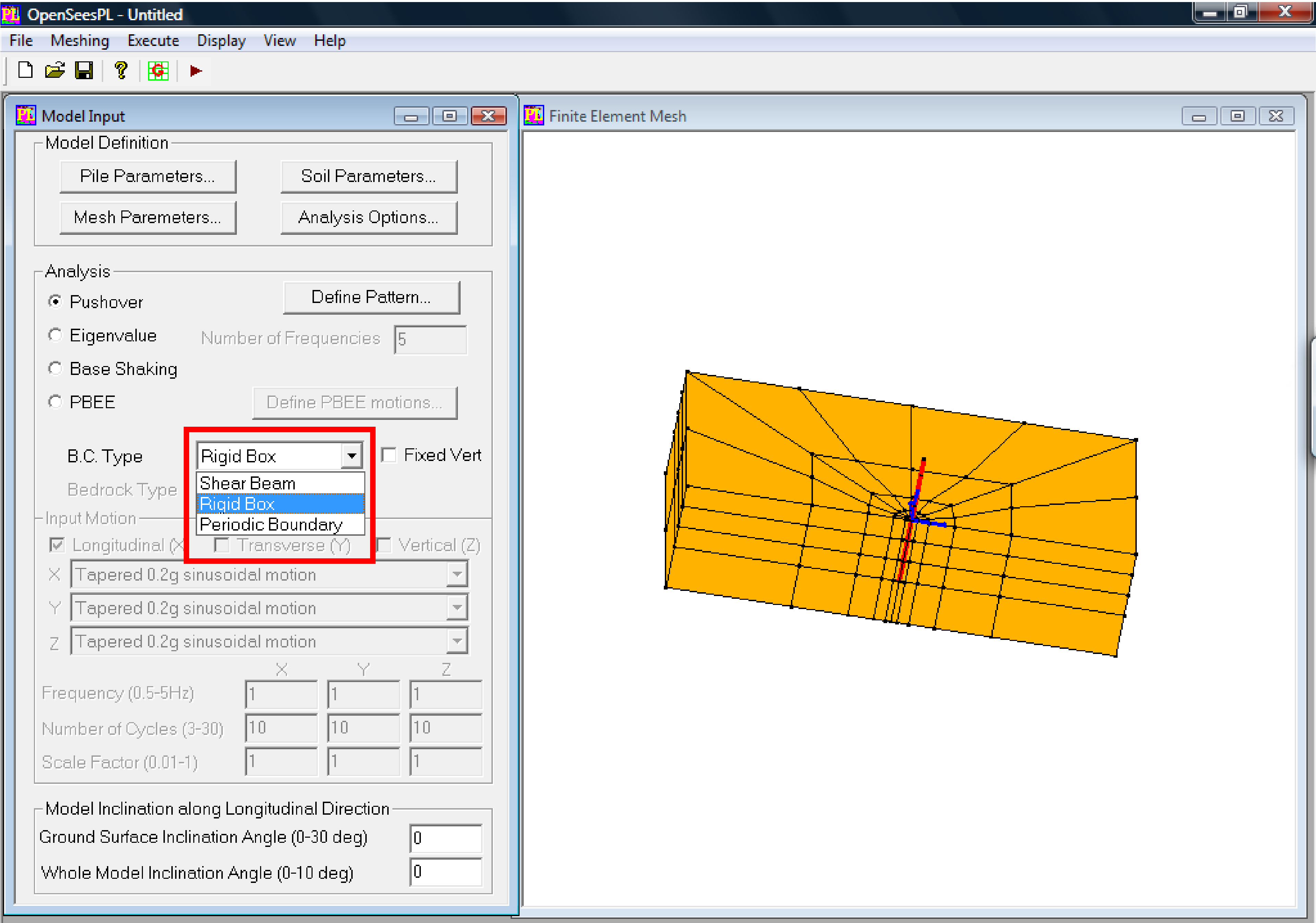
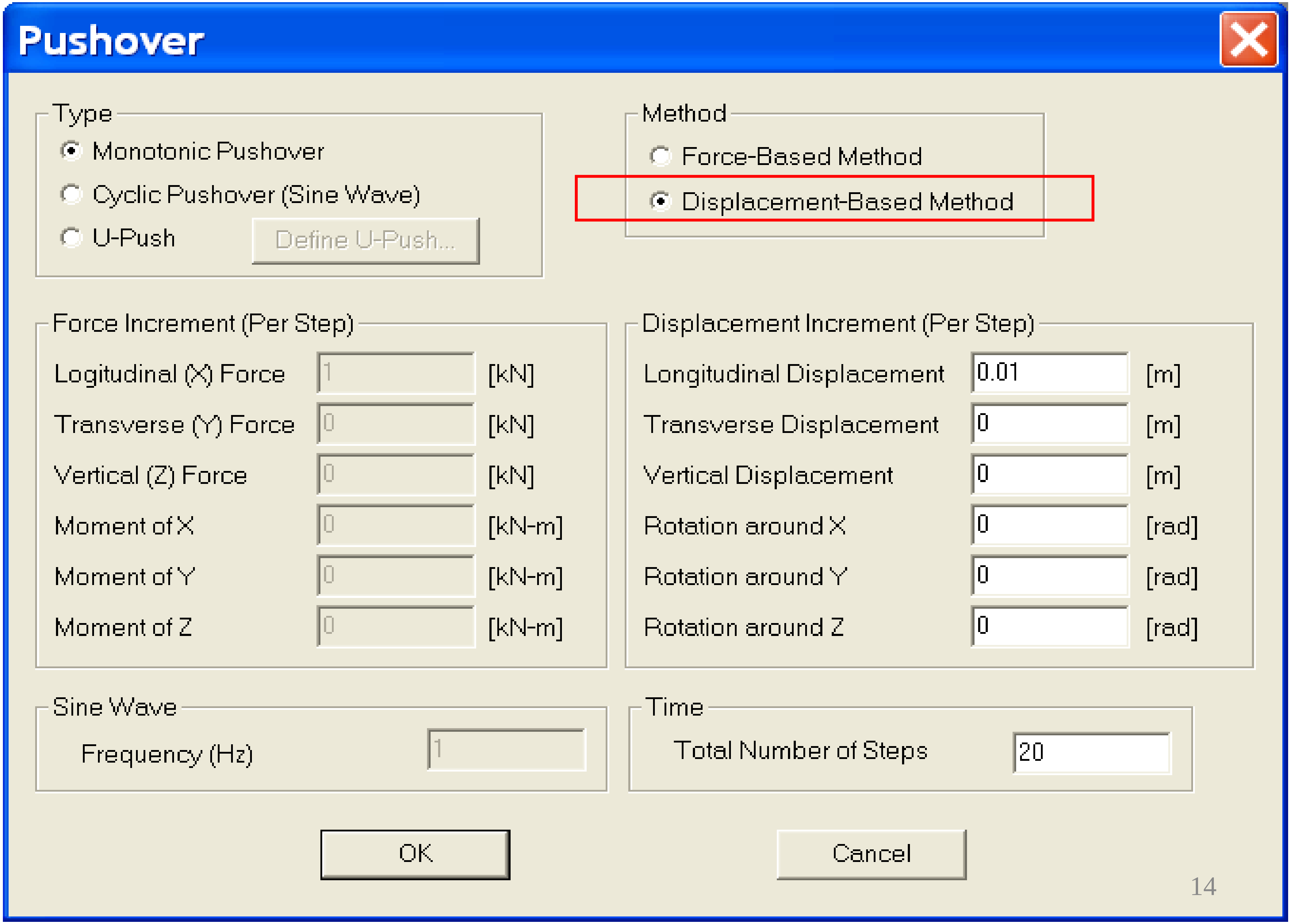


OpenSeesPL: http://cyclic.ucsd.edu/openseespl



OpenSeesPL: http://cyclic.ucsd.edu/openseespl



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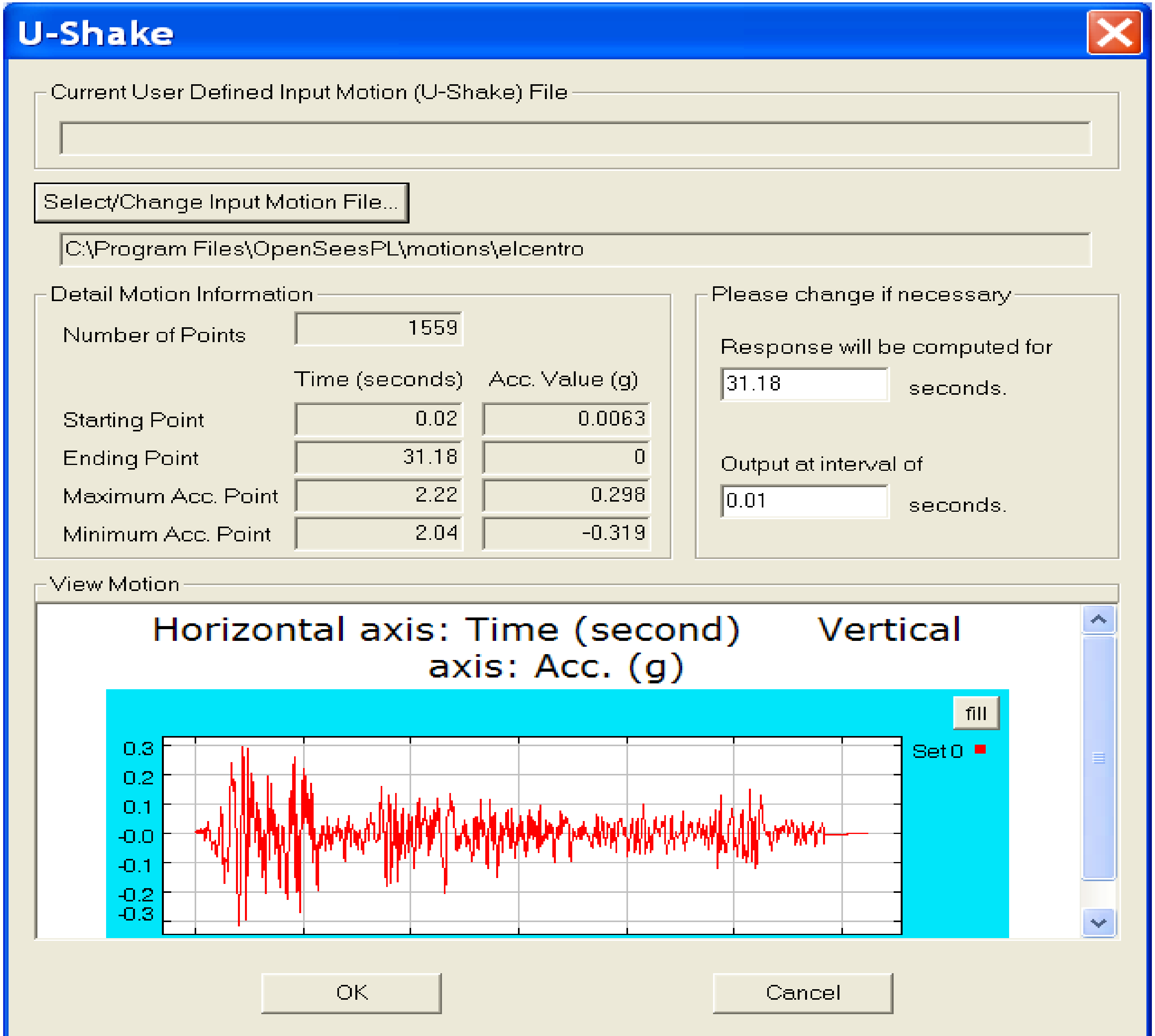

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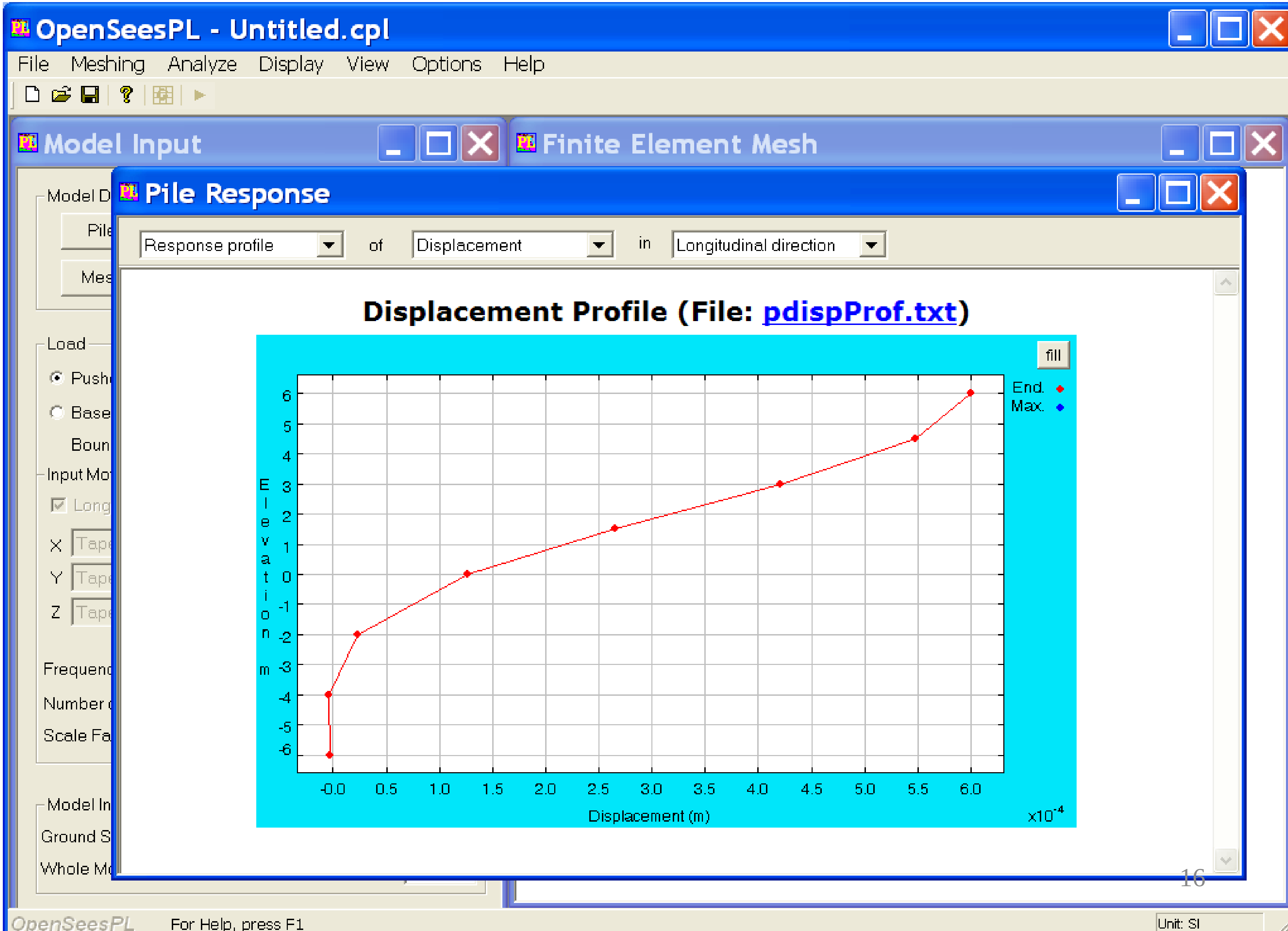
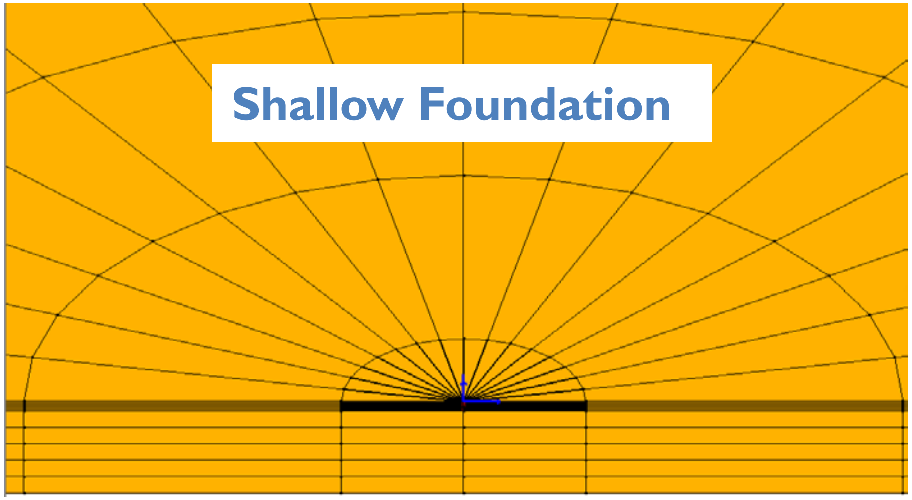
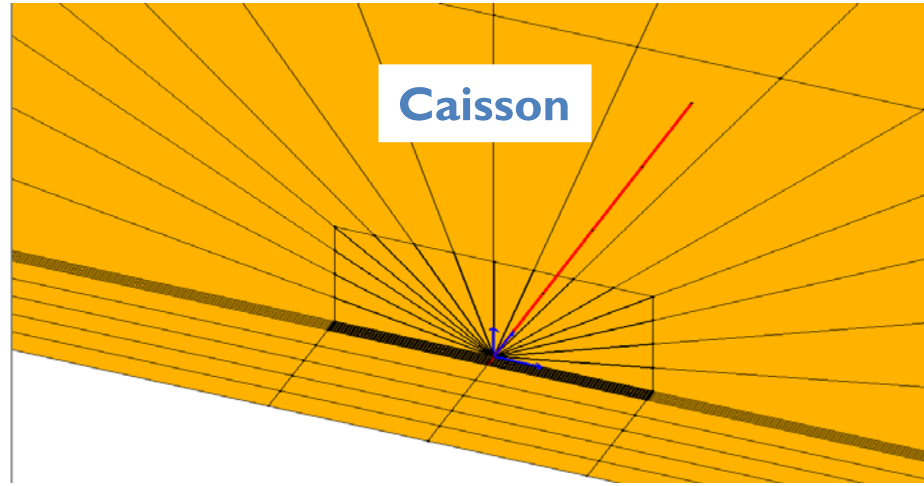
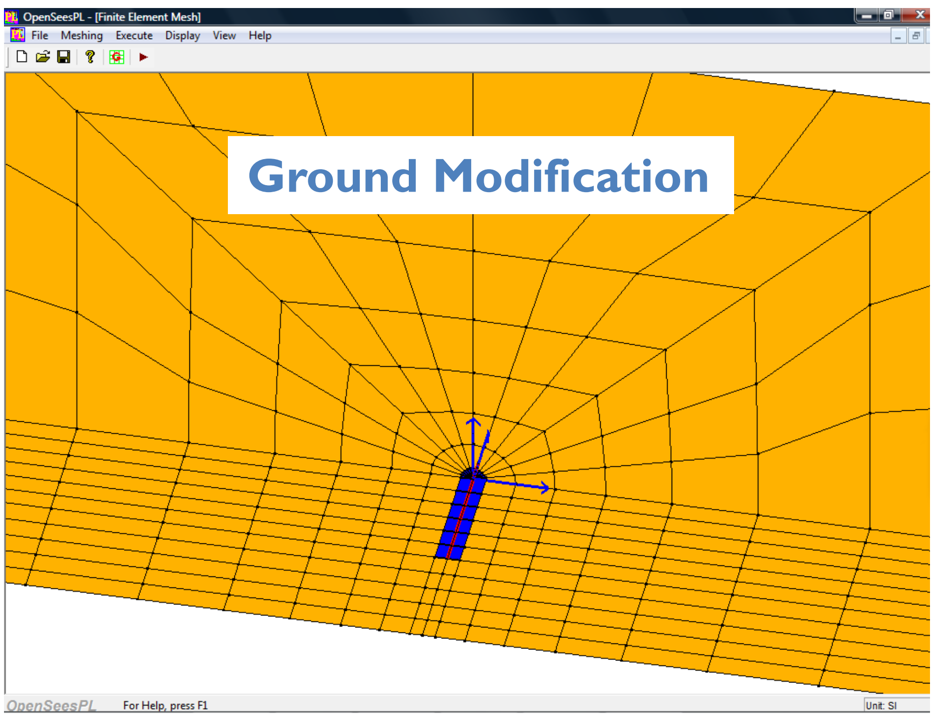
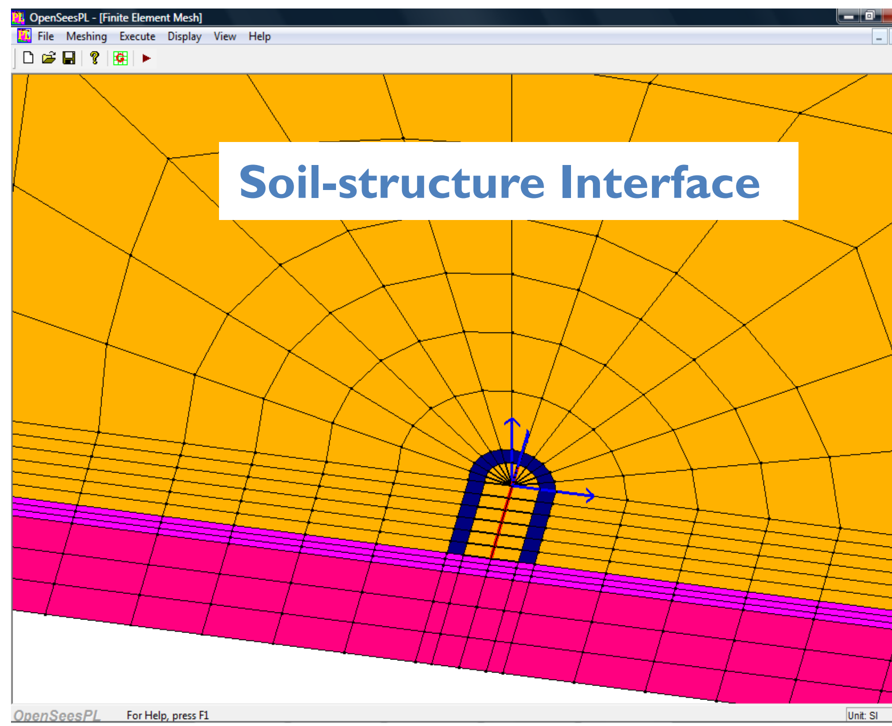
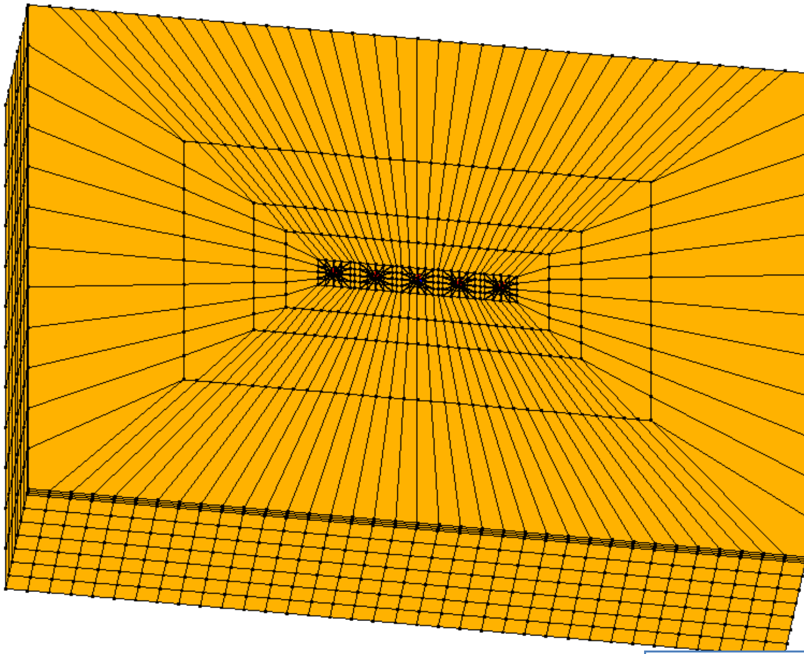


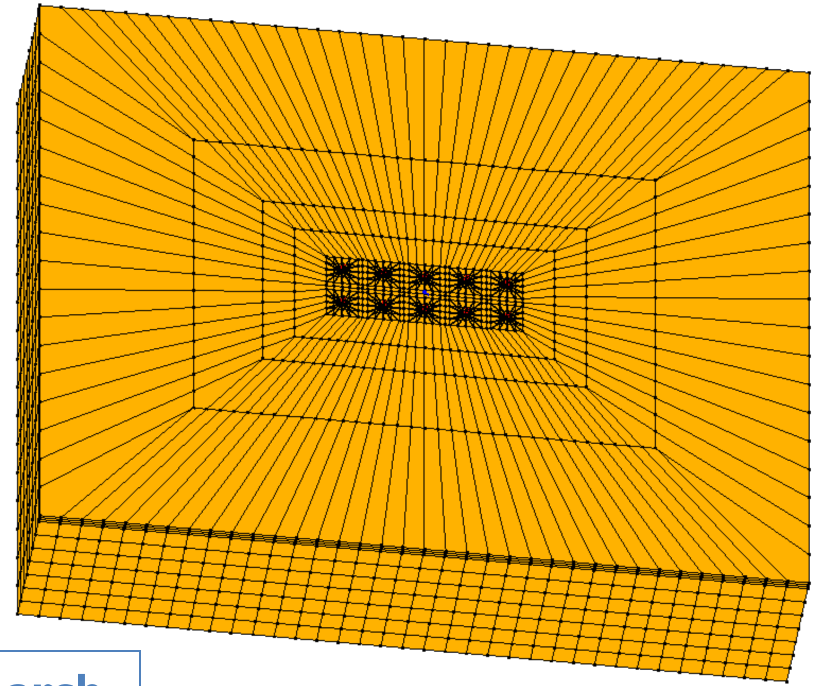

Shallow Foundation


Caisson

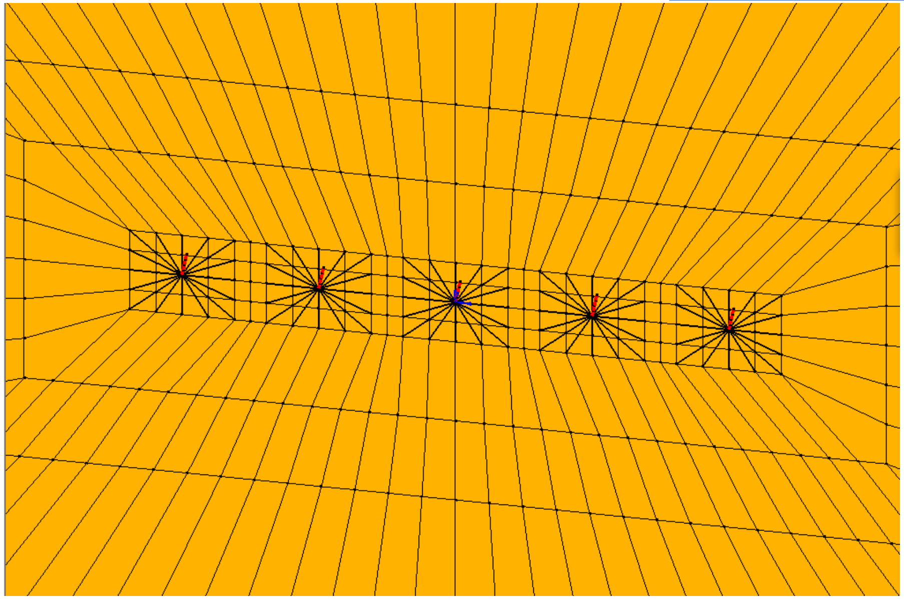

OpenSeesPL - [Finite Element Mesh]
File Meshing Execute Display View Help
Ground Modification
OpenSeesPL
For Help, press F1
Unit: SI

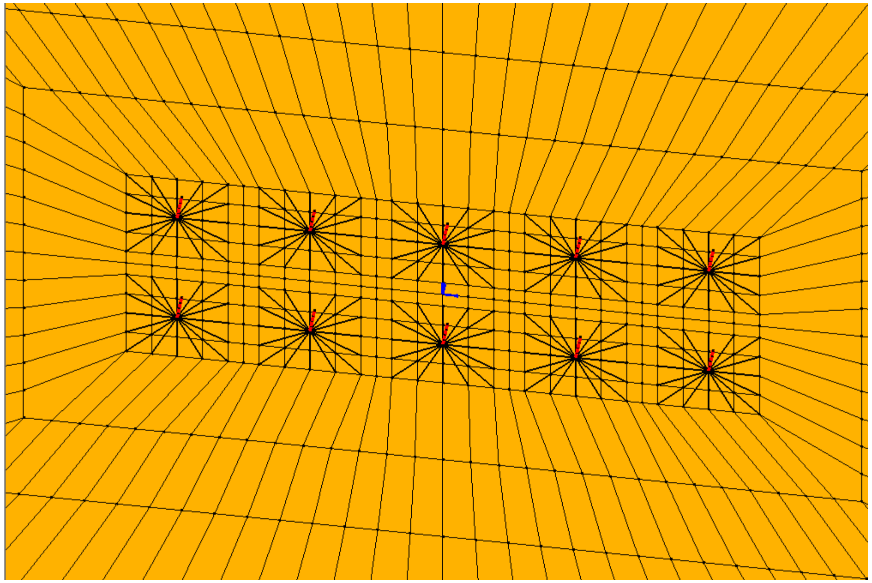

OpenSeesPL - [Finite Element Mesh]
File Meshing Execute Display View Help
Soil-structure Interface
OpenSeesPL
For Help, press F1
Unit: SI





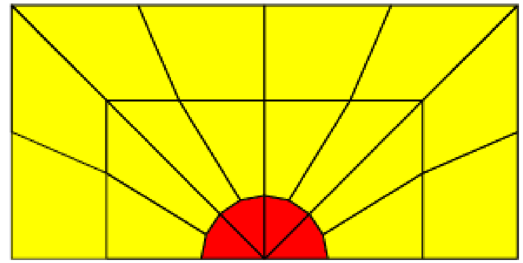
Ongoing Research

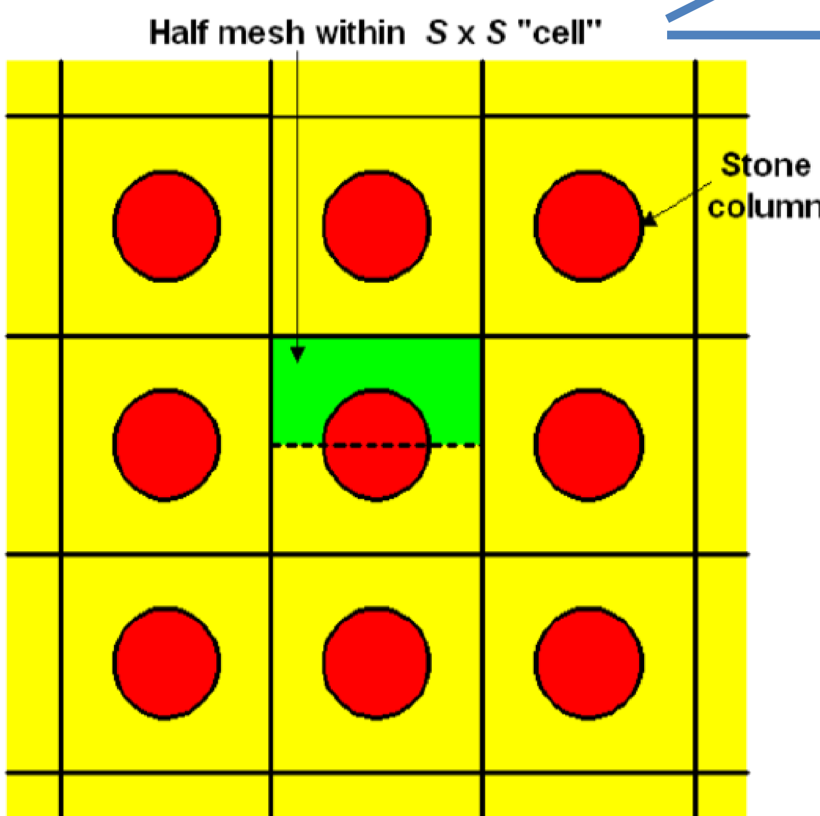


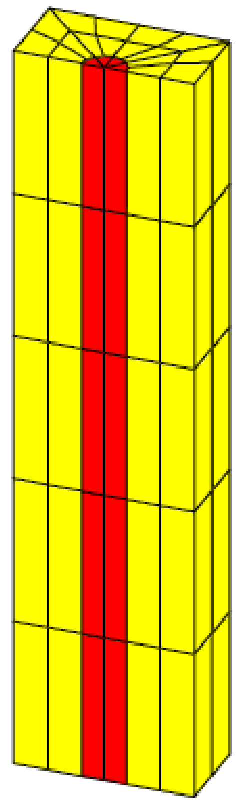


Ground Modification

- Gravel Drain/Stone column
- Pile Pinning





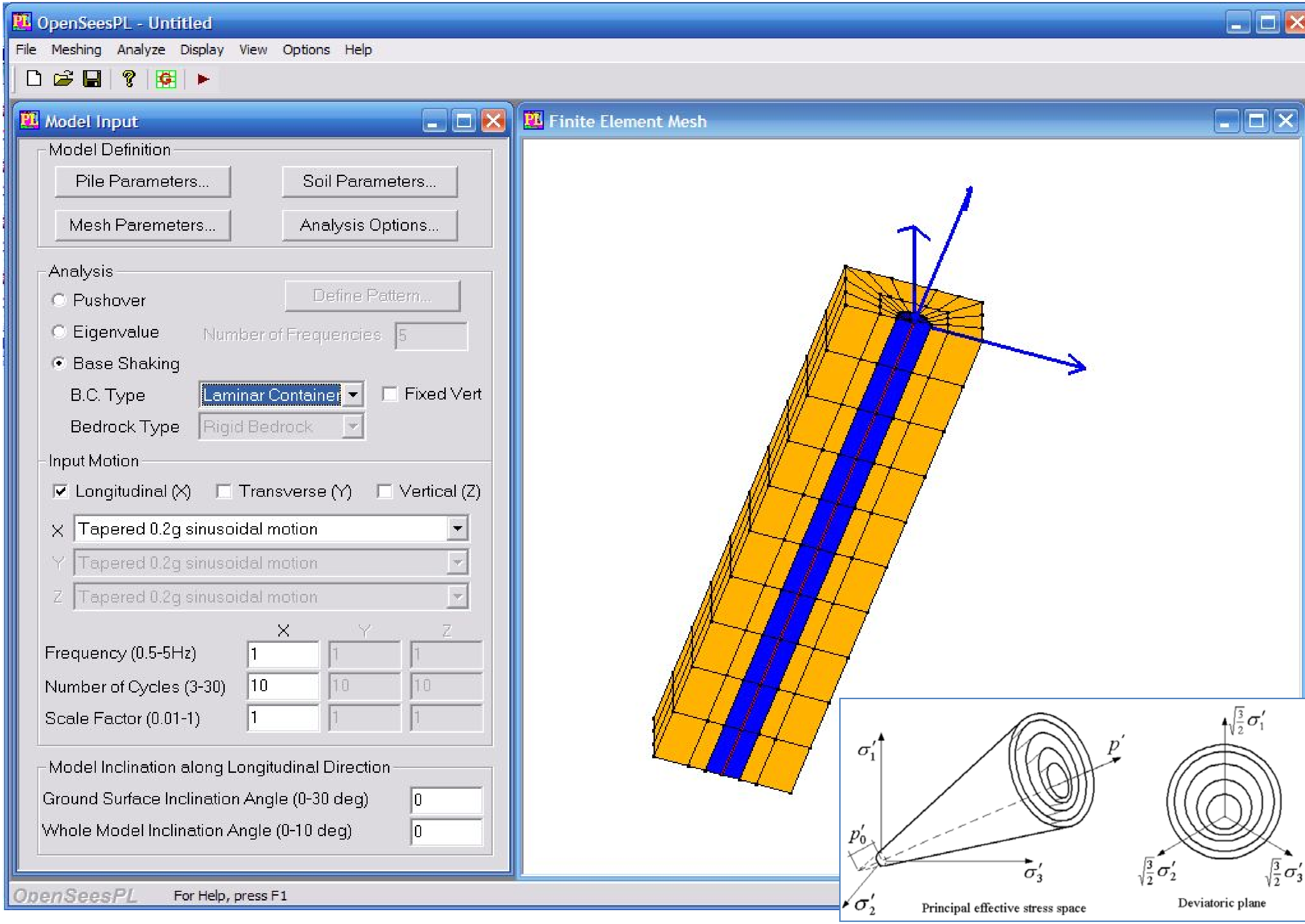


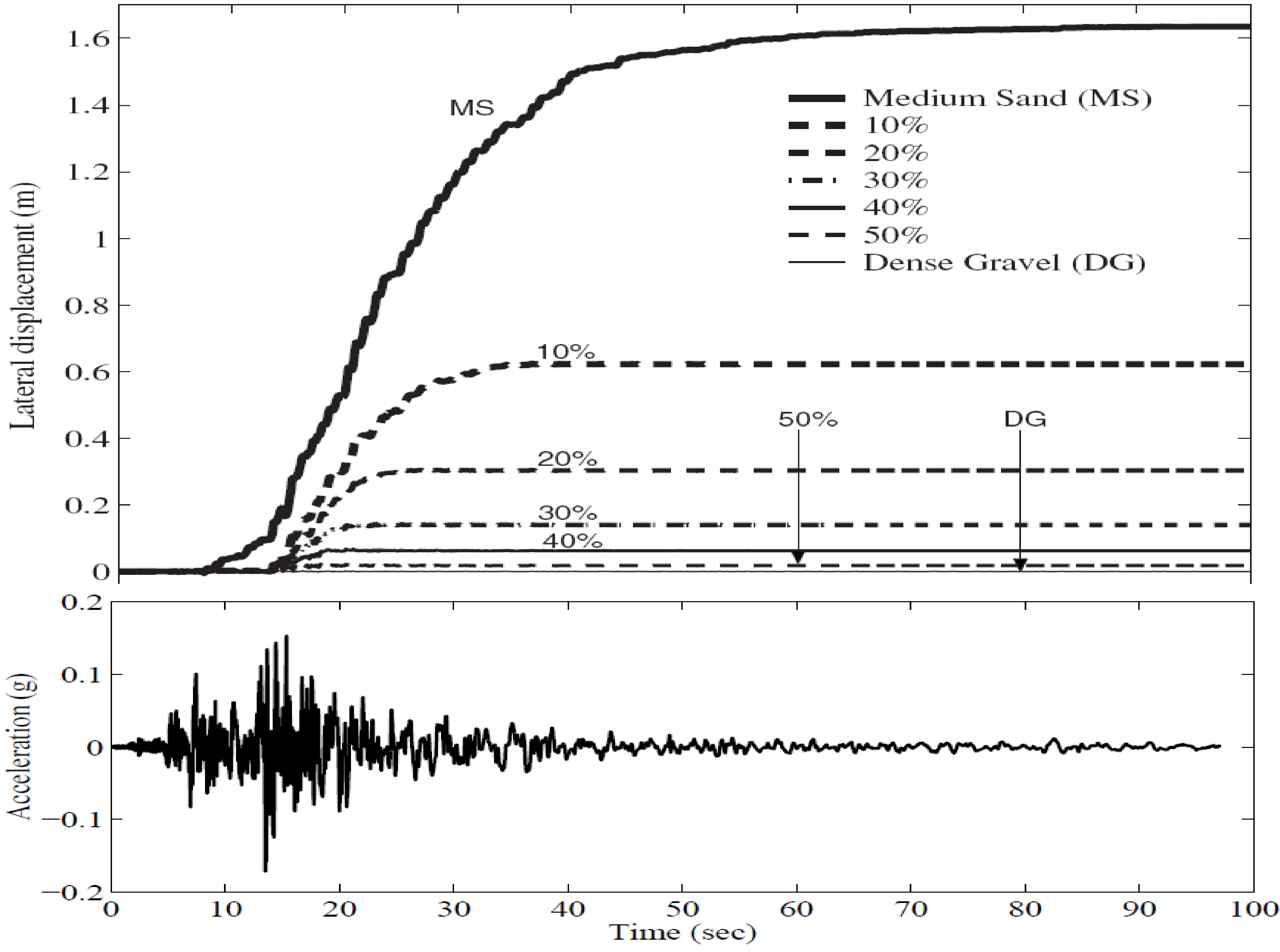
Schematic view of stone column or pile-pinning layout

10 m depth Sand Layer (or Silt Layer)

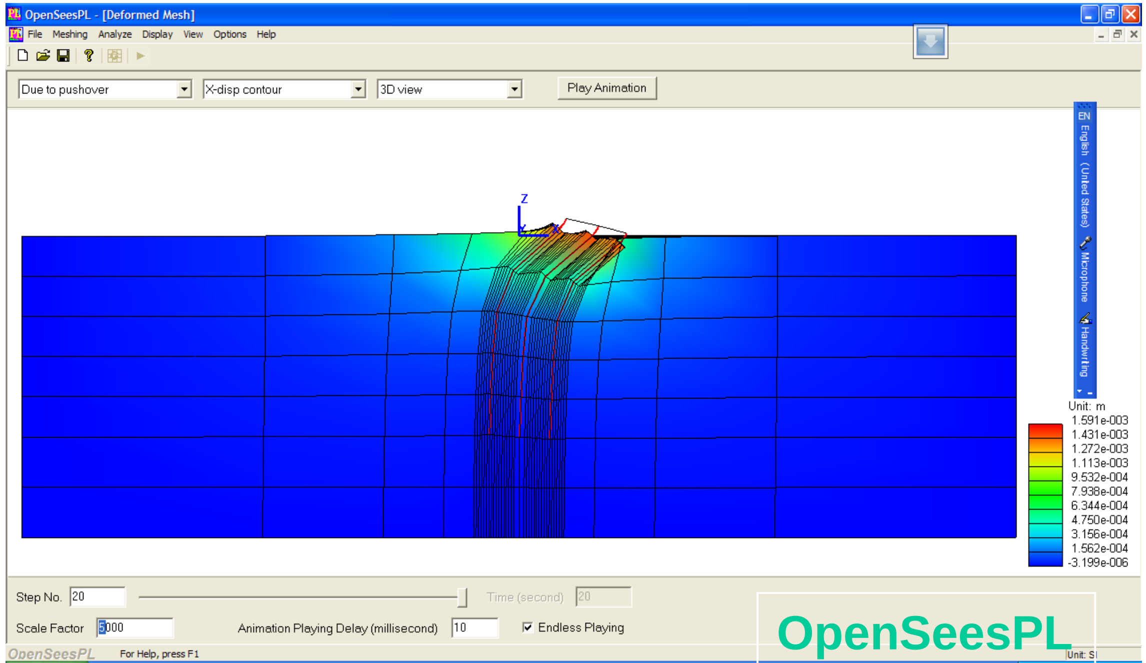
Mild Infinite Slope (4 degrees)

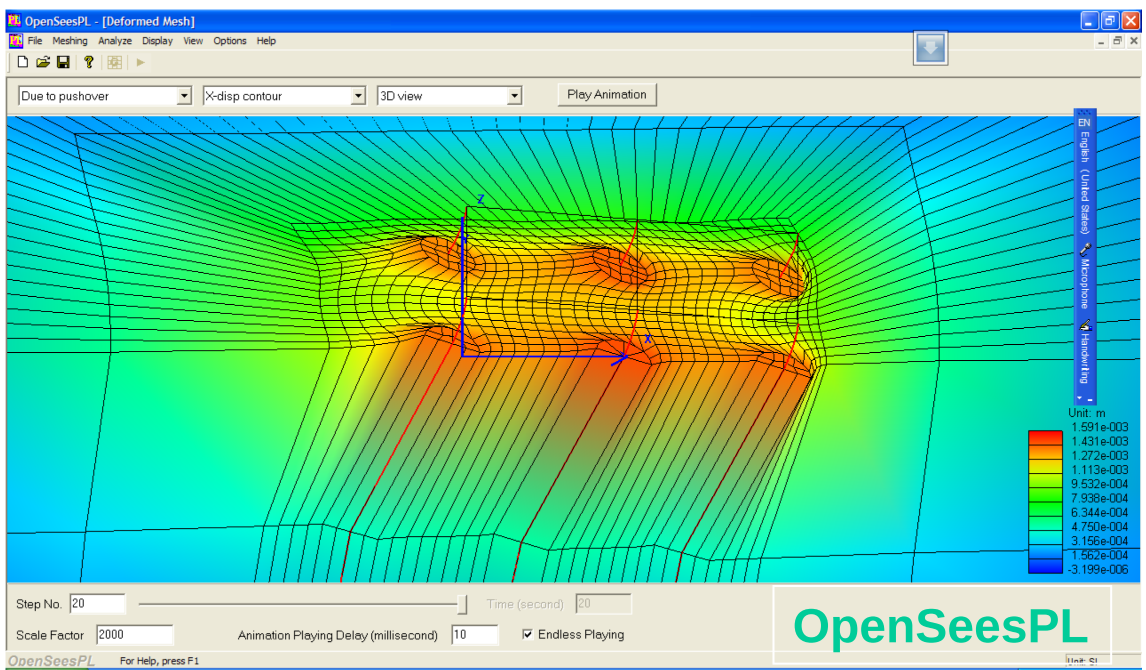
http://cyclic.ucsd.edu/openseespl



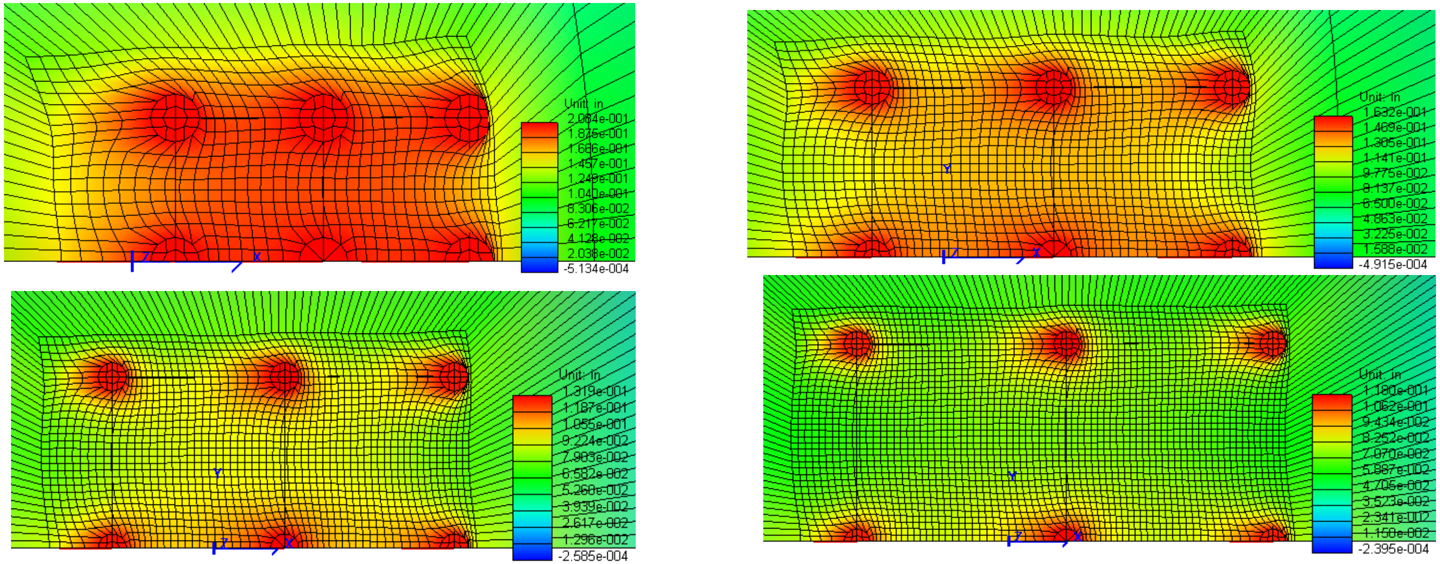


Lateral displacement (m)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
MS
Medium Sand (MS)
10%
20%
30%
40%
50%
Dense Gravel (DG)
10%
50%
DG
20%
30%
40%
Acceleration (g)
0.2
0.1
0
−0.1
−0.2
0
10
20
30
40
50
60
70
80
90
100
Time (sec)


OpenSeesPL - [Deformed Mesh]
File Meshing Analyze Display View Options Help
Due to pushover
X-disp contour
3D view
Play Animation
Unit: m
1.591e-003
1.431e-003
1.272e-003
1.113e-003
9.532e-004
7.938e-004
6.344e-004
4.750e-004
3.156e-004
1.562e-004
-3.199e-006
Step No. 20
Time (second) 20
Scale Factor 5000
Animation Playing Delay (millisecond) 10
Endless Playing
OpenSeesPL
For Help, press F1

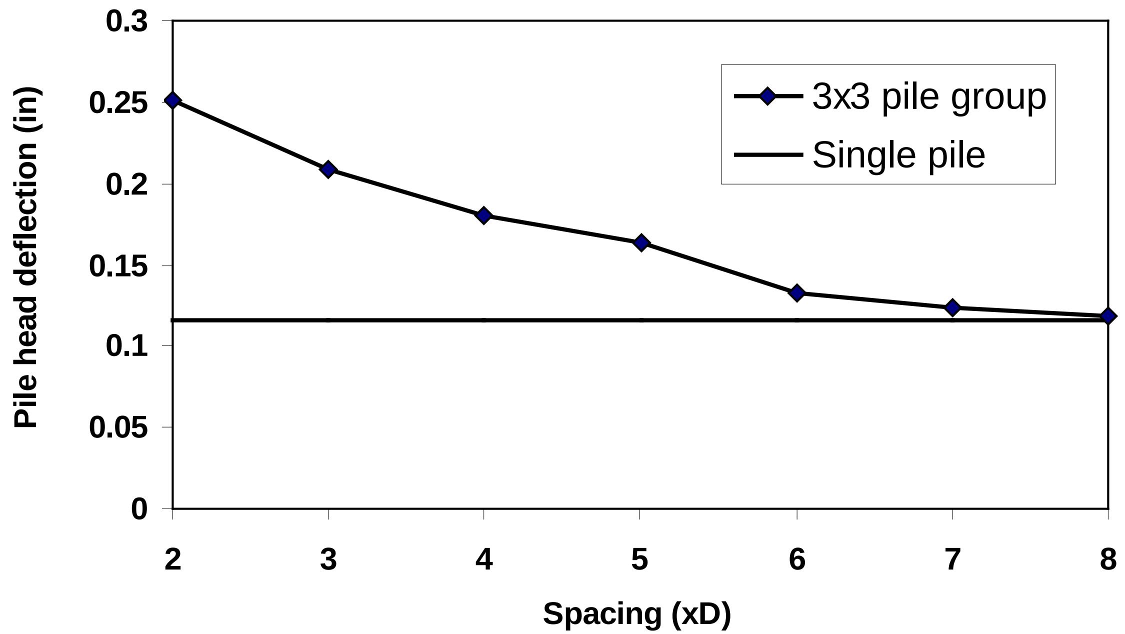

OpenSeesPL - [Deformed Mesh]
File Meshing Analyze Display View Options Help
Due to pushover
X-disp contour
3D view
Play Animation
Unit: m
1.591e-003
1.431e-003
1.272e-003
1.113e-003
9.532e-004
7.938e-004
6.344e-004
4.750e-004
3.156e-004
1.562e-004
-3.199e-006
Step No. 20
Time (second) 20
Scale Factor 2000
Animation Playing Delay (millisecond) 10
Endless Playing
OpenSeesPL
For Help, press F1

Elgamal, A. and Lu, J. (2009). "A Framework for 3D Finite Element Analysis of Lateral Pile System Response," Proceedings of the 2009 International Foundation Congress, ASCE GSP 186, M. Iskander, D. F. Laefer, and M. H. Hussein, Editors, Orlando, Florida, pp. 616-623.



OpenSees Computations through Graphical Interface OpenSeesPL

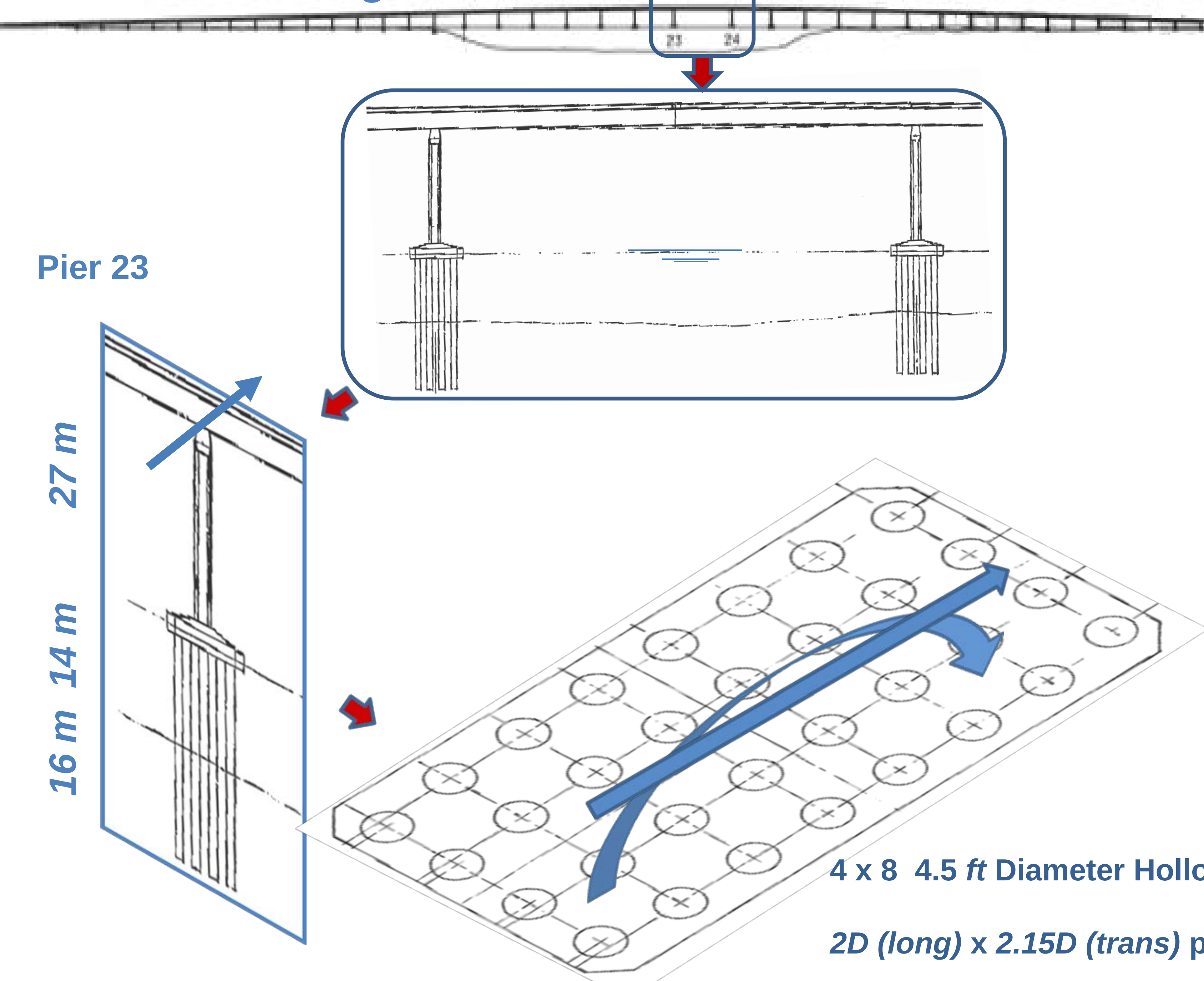
Pile group displacement of the 3x3 pile group (for different spacing) and the single pile under lateral loading.



http://en.wikipedia.org/wiki/File:DumbartonBridgeCA_and_Towers.jpg

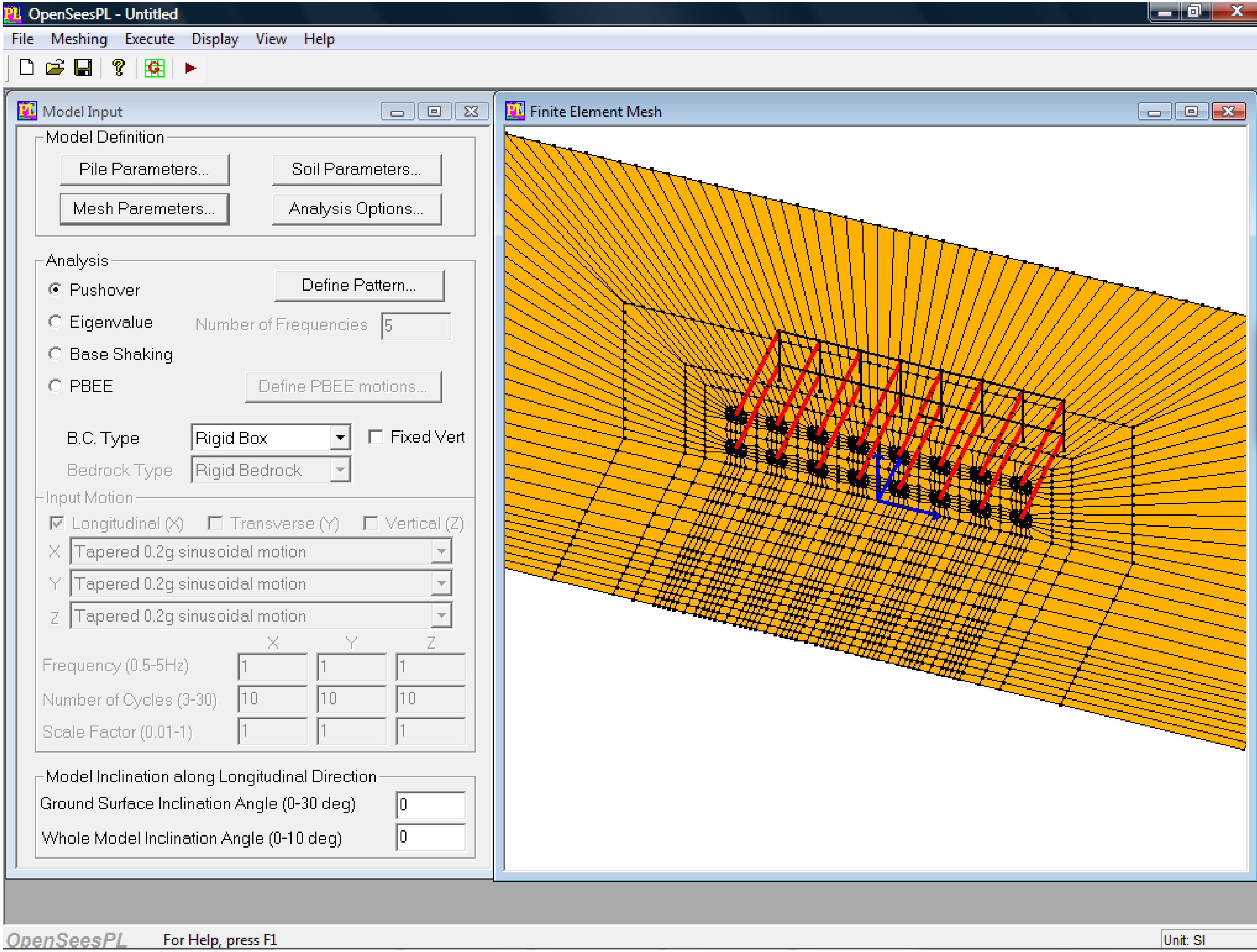
Sunset Under The Dumbarton by Vincent® /

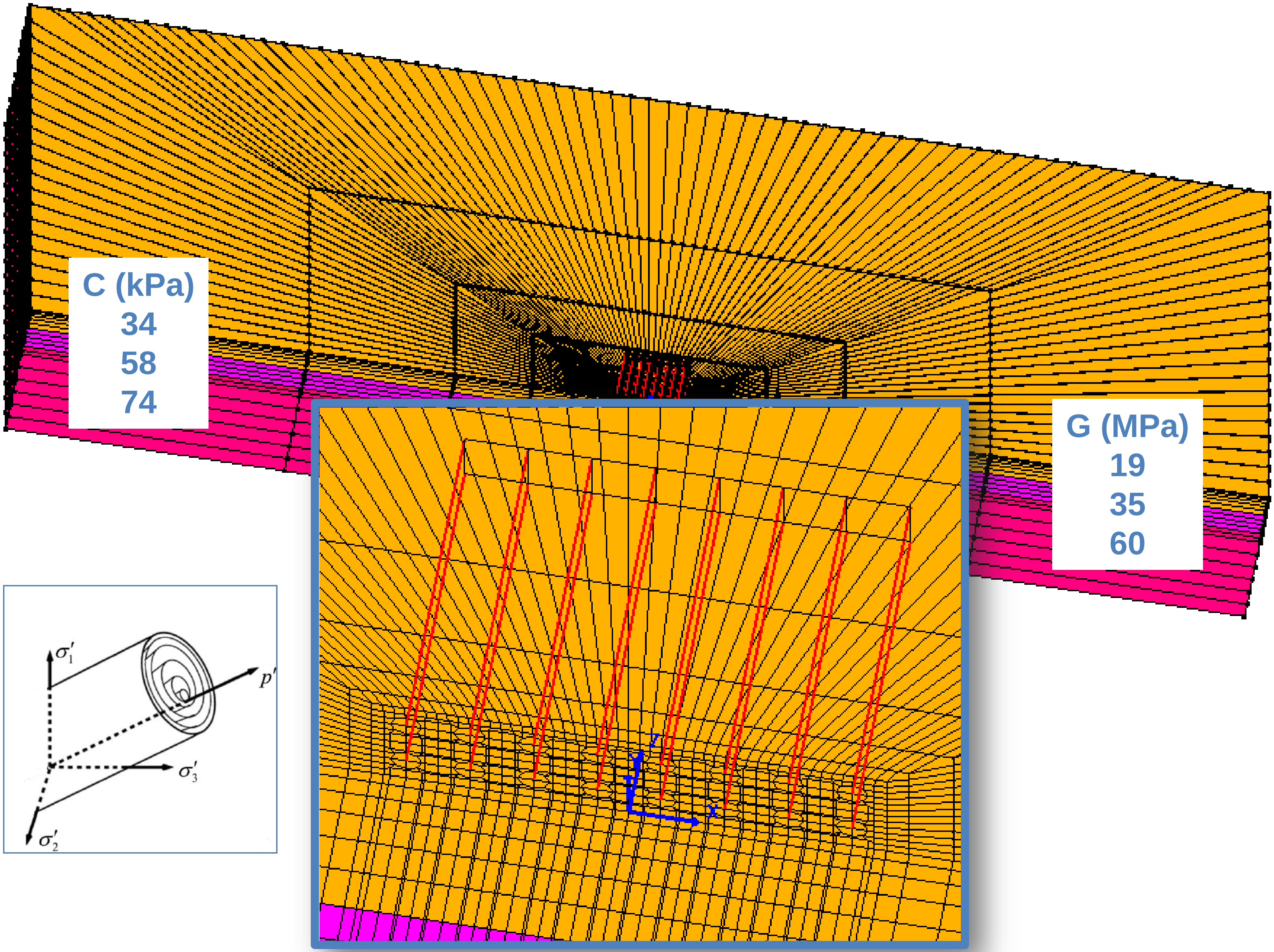
Dumbarton Bridge



4 x 8 4.5 *ft* Diameter Hollow RC Piles

***2D (long)* x *2.15D (trans)* pile spacing**


OpenSeesPL - Untitled
File
Meshing
Execute
Display
View
Help
Model Input
Model Definition
Pile Parameters...
Soil Parameters...
Mesh Paremeters...
Analysis Options...
Analysis
Pushover
Define Pattern...
Eigenvalue
Number of Frequencies
5
Base Shaking
PBEE
Define PBEE motions...
B.C. Type
Rigid Box
Fixed Vert
Bedrock Type
Rigid Bedrock
Input Motion
Longitudinal (X)
Transverse (Y)
Vertical (Z)
X
Tapered 0.2g sinusoidal motion
Y
Tapered 0.2g sinusoidal motion
Z
Tapered 0.2g sinusoidal motion
X
Y
Z
Frequency (0.5-5Hz)
1
1
1
Number of Cycles (3-30)
10
10
10
Scale Factor (0.01-1)
1
1
1
Model Inclination along Longitudinal Direction
Ground Surface Inclination Angle (0-30 deg)
0
Whole Model Inclination Angle (0-10 deg)
0
Finite Element Mesh
OpenSeesPL
For Help, press F1
Unit: SI

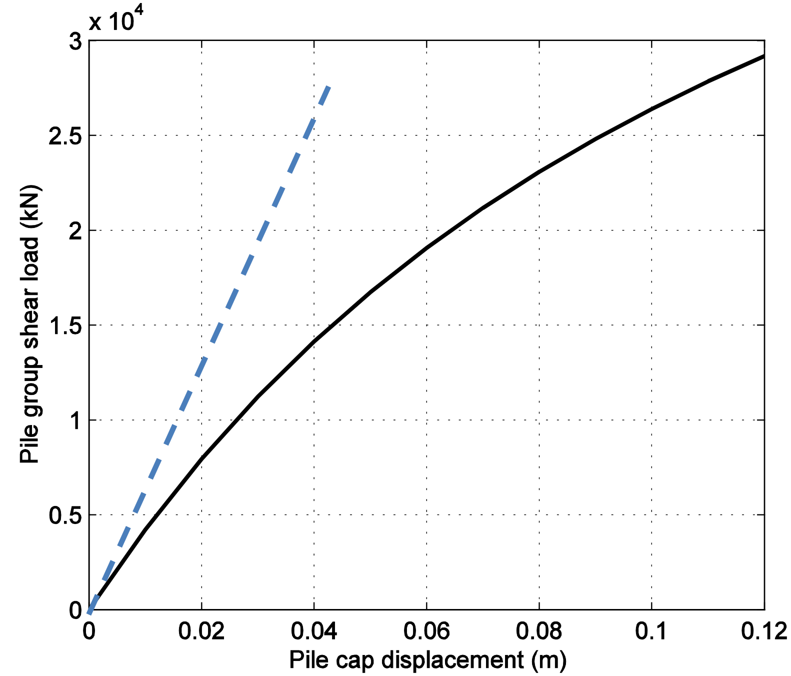


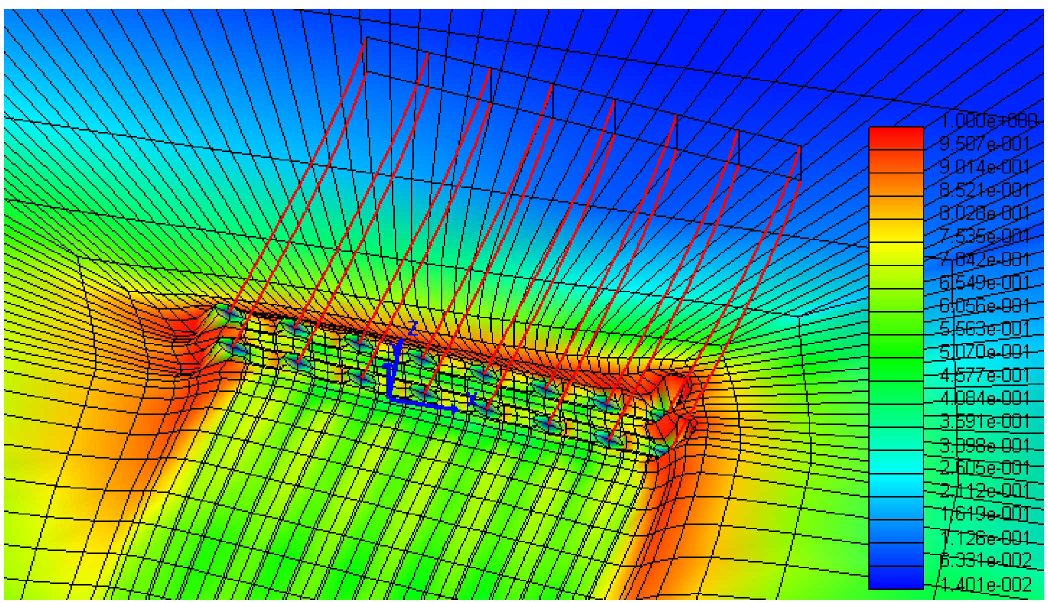
C (kPa)
34
58
74
G (MPa)
19
35
60
σ_1'
p'
σ_3'
σ_2'
Z
X

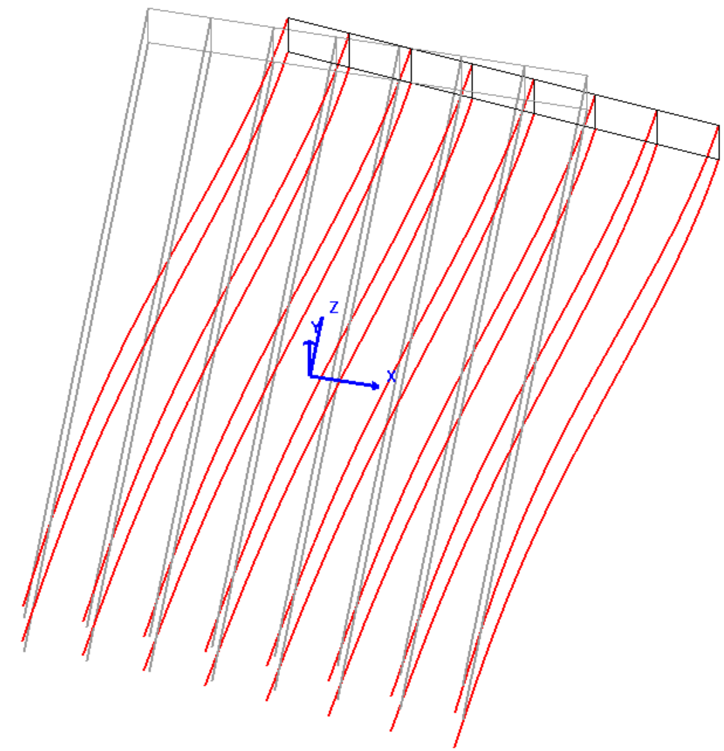
Applied Loads

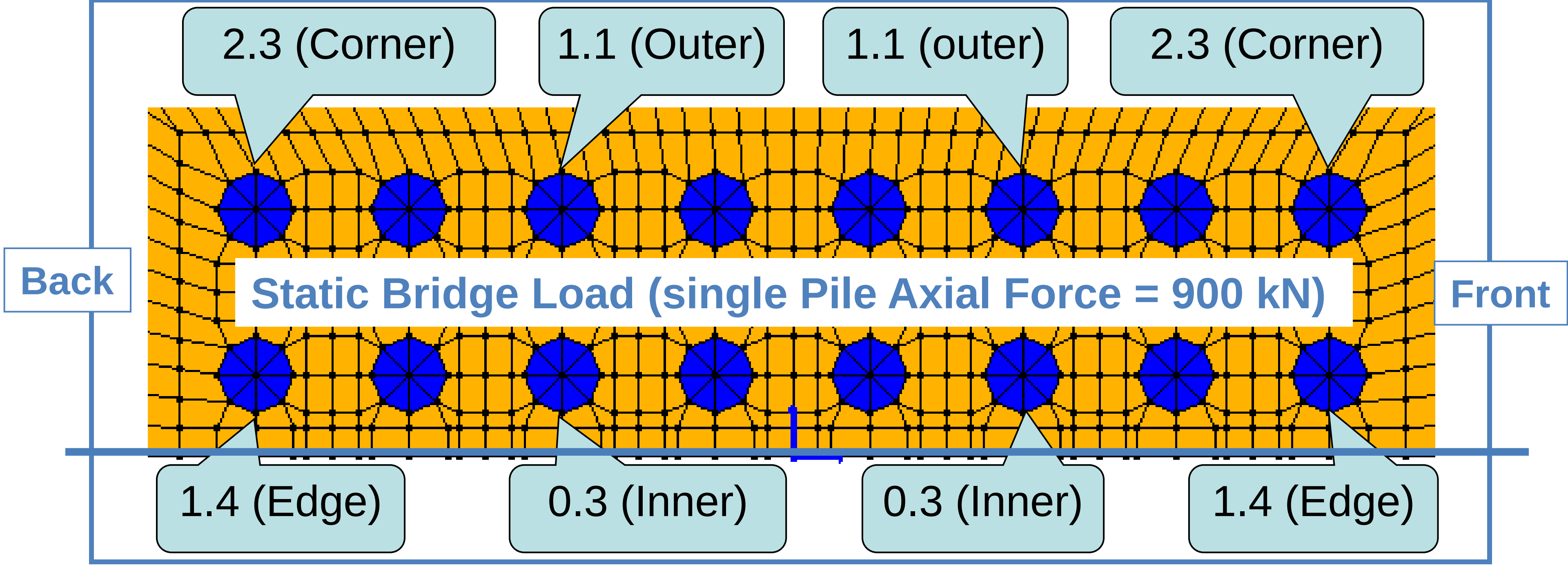
1. Bridge Own weight

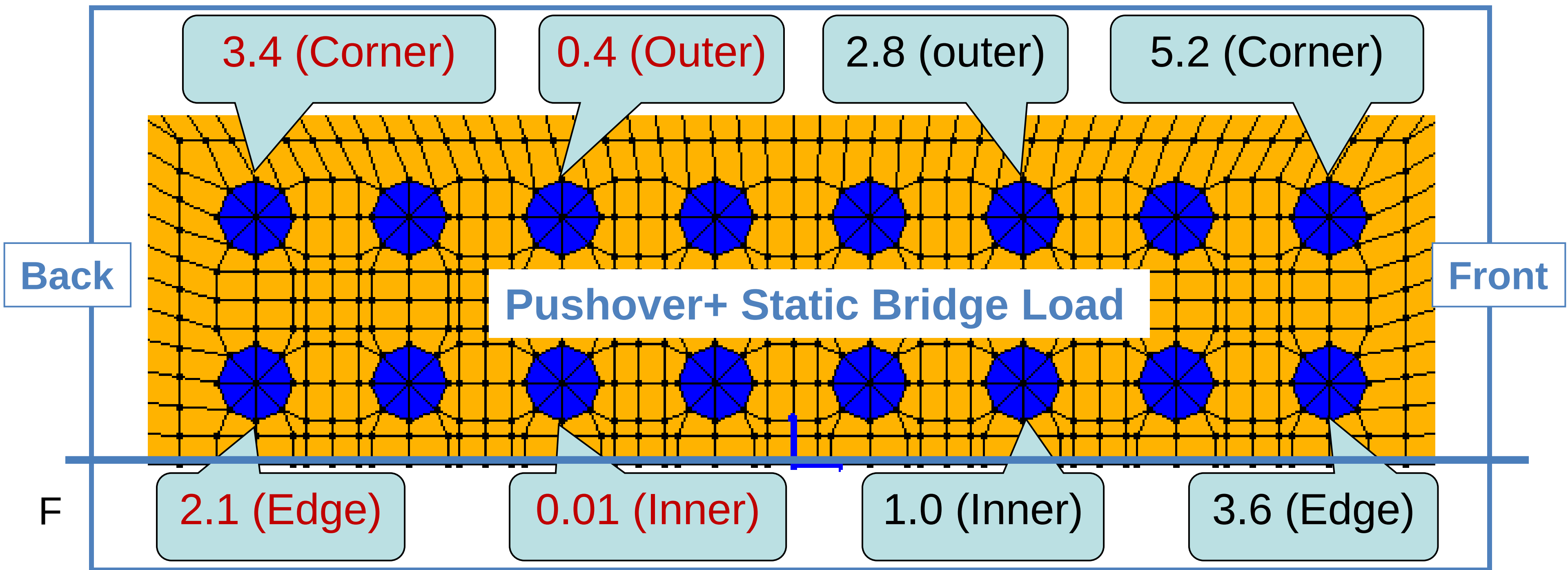
2. Pushover analysis (1 g)



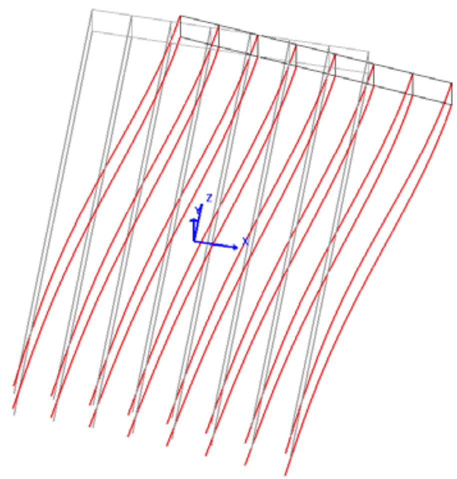


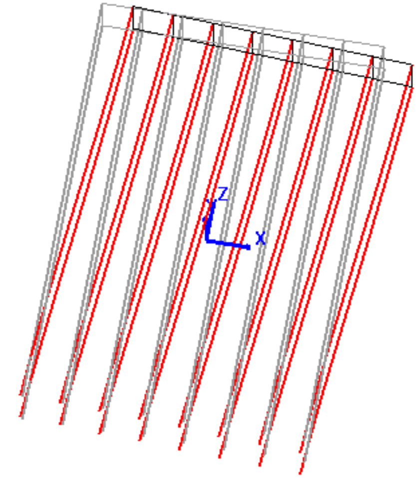


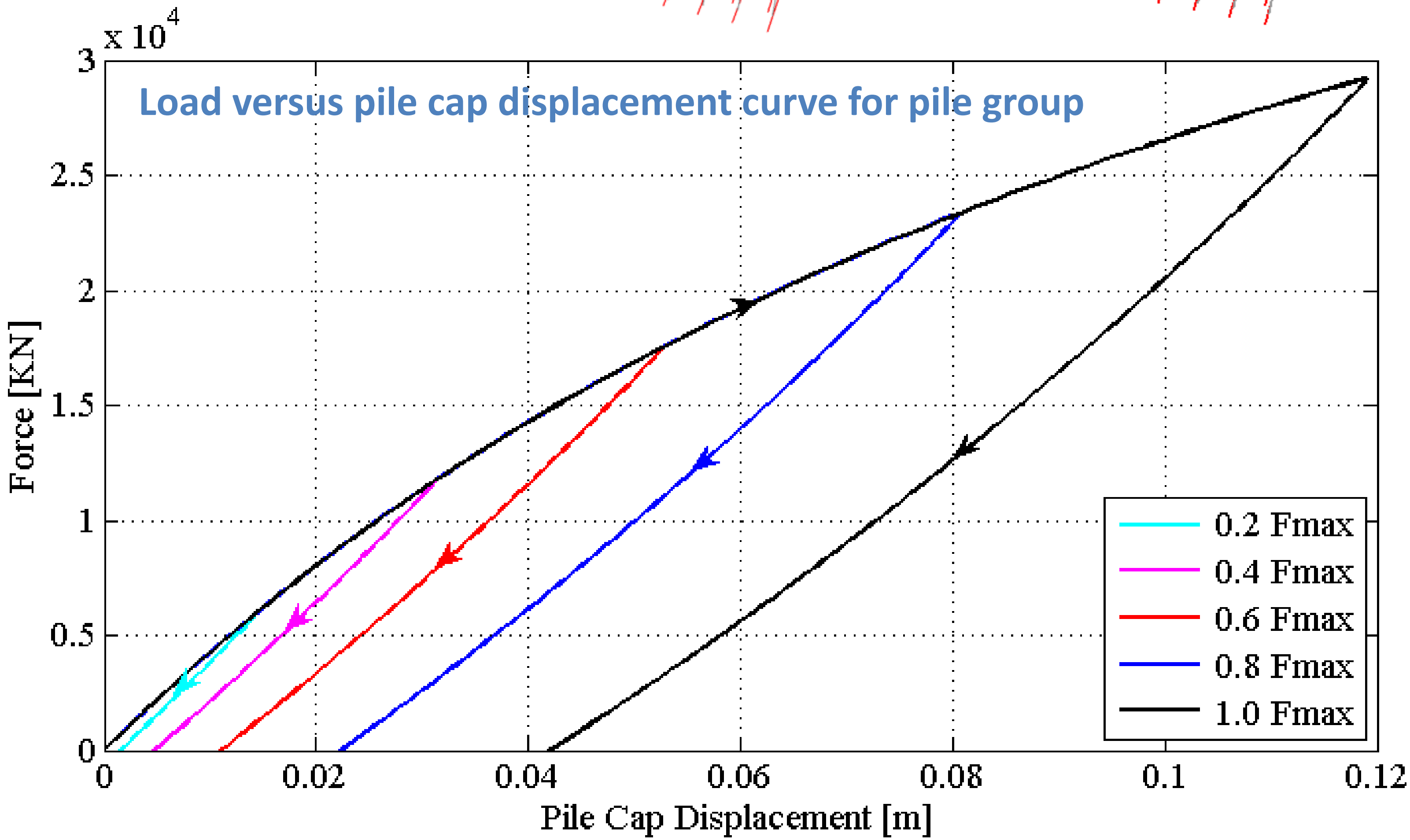

2.3 (Corner)
1.1 (Outer)
1.1 (outer)
2.3 (Corner)
Back
Static Bridge Load (single Pile Axial Force = 900 kN)
Front
1.4 (Edge)
0.3 (Inner)
0.3 (Inner)
1.4 (Edge)


3.4 (Corner)
0.4 (Outer)
2.8 (outer)
5.2 (Corner)
Back
Pushover+ Static Bridge Load
Front
F
2.1 (Edge)
0.01 (Inner)
1.0 (Inner)
3.6 (Edge)

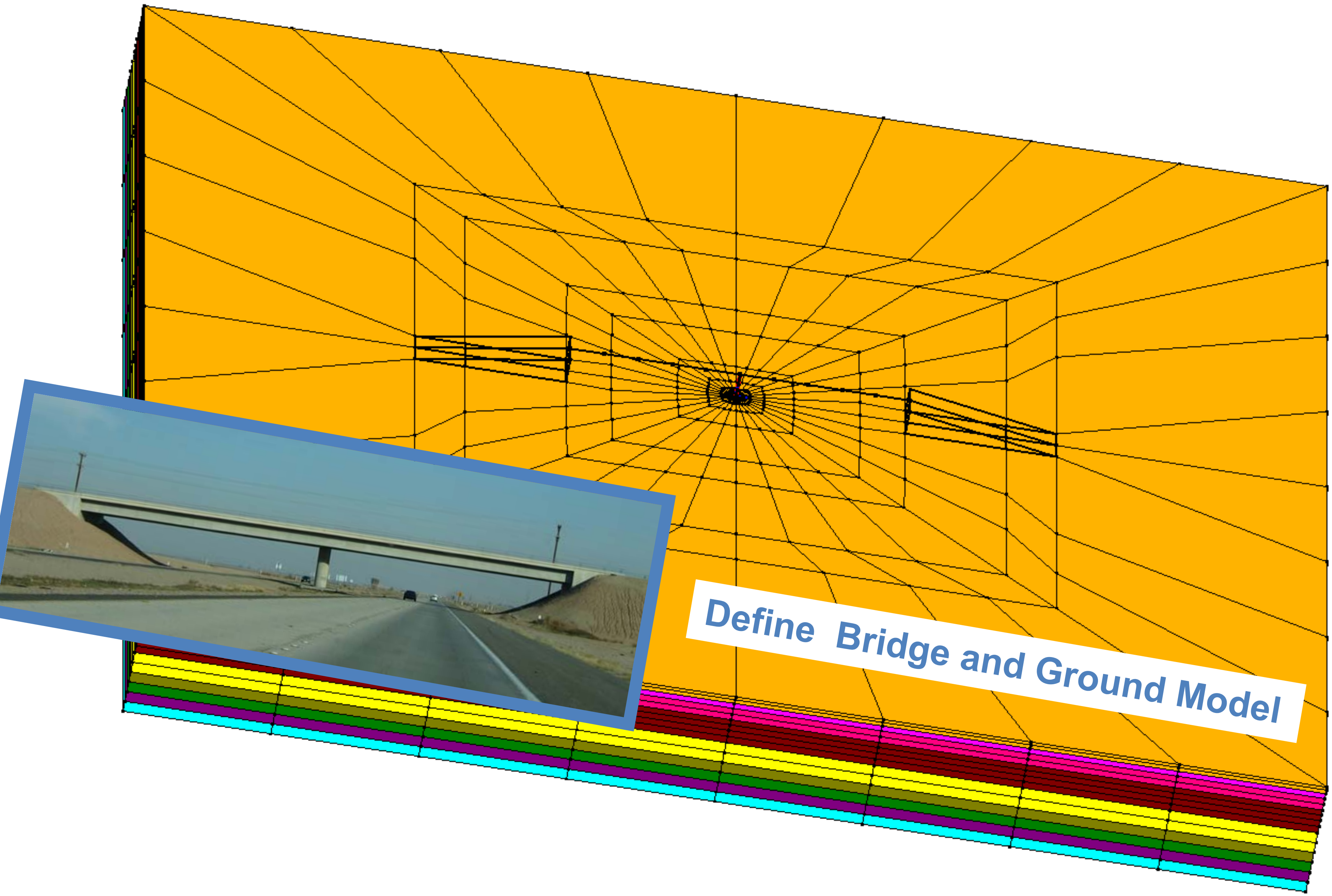
Permanent Deformation

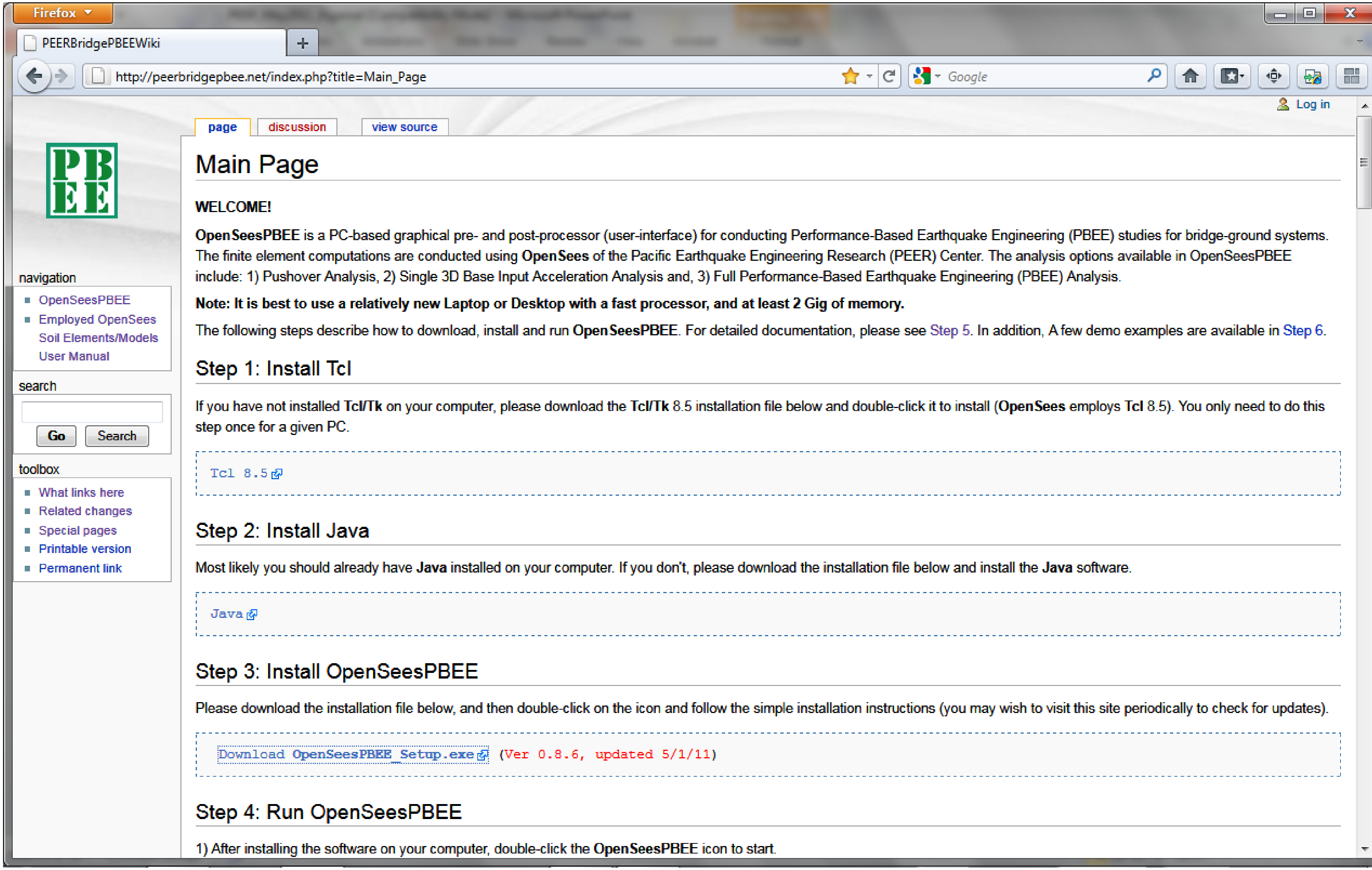






OpenSeesPL Bridge-Ground Model for Performance-Based Earthquake Engng- with Prof Kevin Mackie





Main Page

WELCOME!

OpenSeesPBEE is a PC-based graphical pre- and post-processor (user-interface) for conducting Performance-Based Earthquake Engineering (PBEE) studies for bridge-ground systems. The finite element computations are conducted using **OpenSees** of the Pacific Earthquake Engineering Research (PEER) Center. The analysis options available in OpenSeesPBEE include: 1) Pushover Analysis, 2) Single 3D Base Input Acceleration Analysis and, 3) Full Performance-Based Earthquake Engineering (PBEE) Analysis.

Note: It is best to use a relatively new Laptop or Desktop with a fast processor, and at least 2 Gig of memory.

The following steps describe how to download, install and run **OpenSeesPBEE**. For detailed documentation, please see Step 5. In addition, A few demo examples are available in Step 6.

Step 1: Install Tcl

If you have not installed **Tcl/Tk** on your computer, please download the **Tcl/Tk** 8.5 installation file below and double-click it to install (**OpenSees** employs **Tcl** 8.5). You only need to do this step once for a given PC.

```
Tcl 8.5
```

Step 2: Install Java

Most likely you should already have **Java** installed on your computer. If you don't, please download the installation file below and install the **Java** software.

```
Java
```

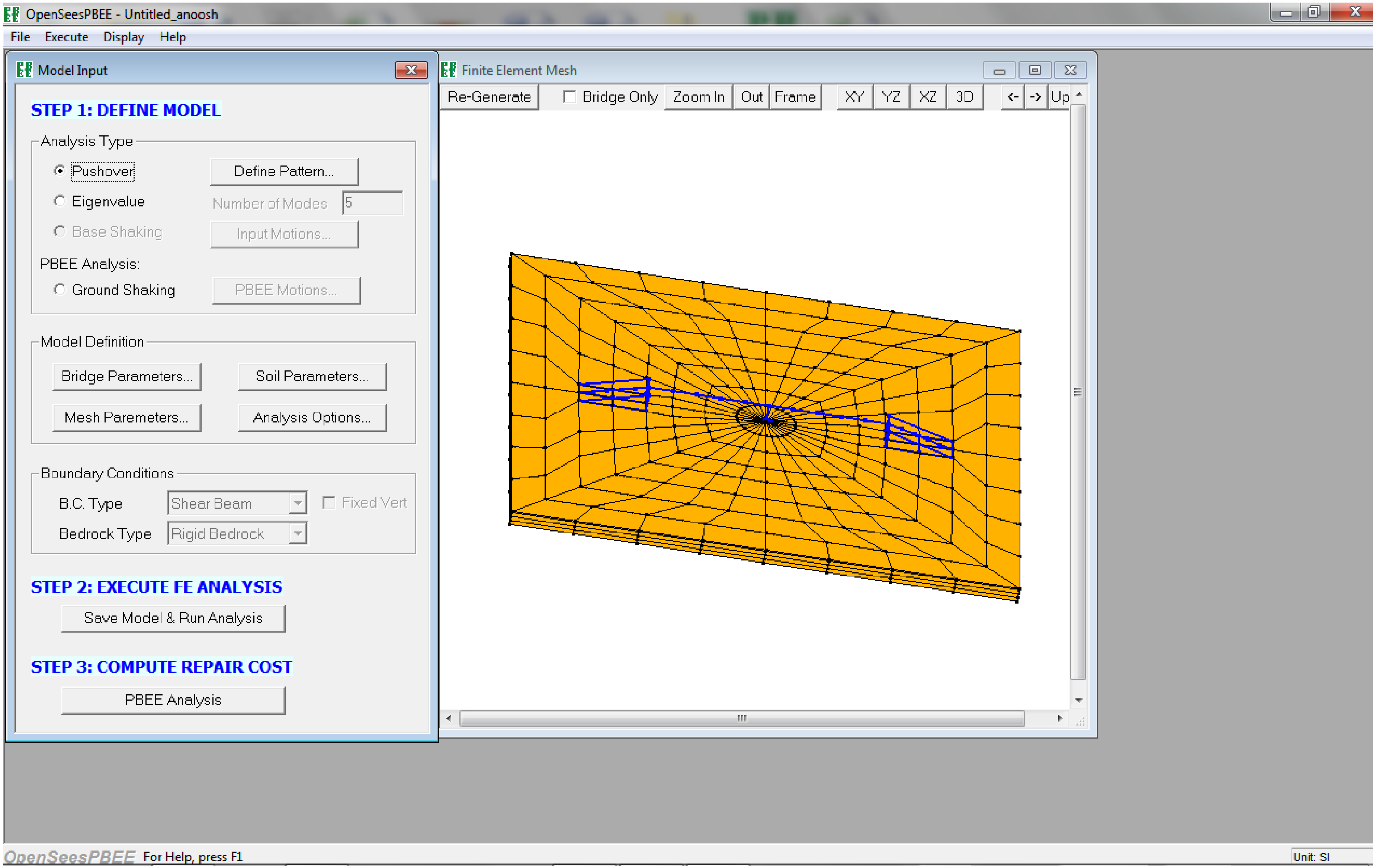
Step 3: Install OpenSeesPBEE

Please download the installation file below, and then double-click on the icon and follow the simple installation instructions (you may wish to visit this site periodically to check for updates).

```
Download OpenSeesPBEE_Setup.exe (Ver 0.8.6, updated 5/1/11)
```

Step 4: Run OpenSeesPBEE

1) After installing the software on your computer, double-click the **OpenSeesPBEE** icon to start.


OpenSeesPBEE - Untitled_anoosh
File
Execute
Display
Help
Model Input
STEP 1: DEFINE MODEL
Analysis Type
Pushover
Define Pattern...
Eigenvalue
Number of Modes
5
Base Shaking
Input Motions...
PBEE Analysis:
Ground Shaking
PBEE Motions...
Model Definition
Bridge Parameters...
Soil Parameters...
Mesh Paremeters...
Analysis Options...
Boundary Conditions
B.C. Type
Shear Beam
Fixed Vert
Bedrock Type
Rigid Bedrock
STEP 2: EXECUTE FE ANALYSIS
Save Model & Run Analysis
STEP 3: COMPUTE REPAIR COST
PBEE Analysis
Finite Element Mesh
Re-Generate
Bridge Only
Zoom In
Out
Frame
XY
YZ
XZ
3D
<-
->
Up
OpenSeesPBEE
For Help, press F1
Unit: SI

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Ground Motions for PEER Transportation Research Program

by Nirmal Jayaram, Shrey Shahi and Jack Baker, 2010

The following files document selected ground motions for use in the PEER transportation systems research program. Documentation

Report on PEER Systems Workshop1.doc

Documentation

The following are presentations given in the process of developing these ground motions:

– January 21st draft report documenting selected ground motions and the methods used to select them. (PDF file - 752 KB)

Set #1a: Broad-band ground motions (M = 7, R = 10 km, soil site)

See the report above for background regarding the selection of these ground motions.

– Spreadsheet documenting selected ground motions. Worksheets are provided to list a summary of the selected ground motions' metadata, their response spectra, and comparisons of the ground motion set's mean, standard deviation to comparable values predicted by ground motion models. (Excel file - 676 KB)

– Zip file containing acceleration time histories for the 40 selected ground motions. Fault-normal, fault-parallel and vertical components are included. (Zip file - 7 MB)

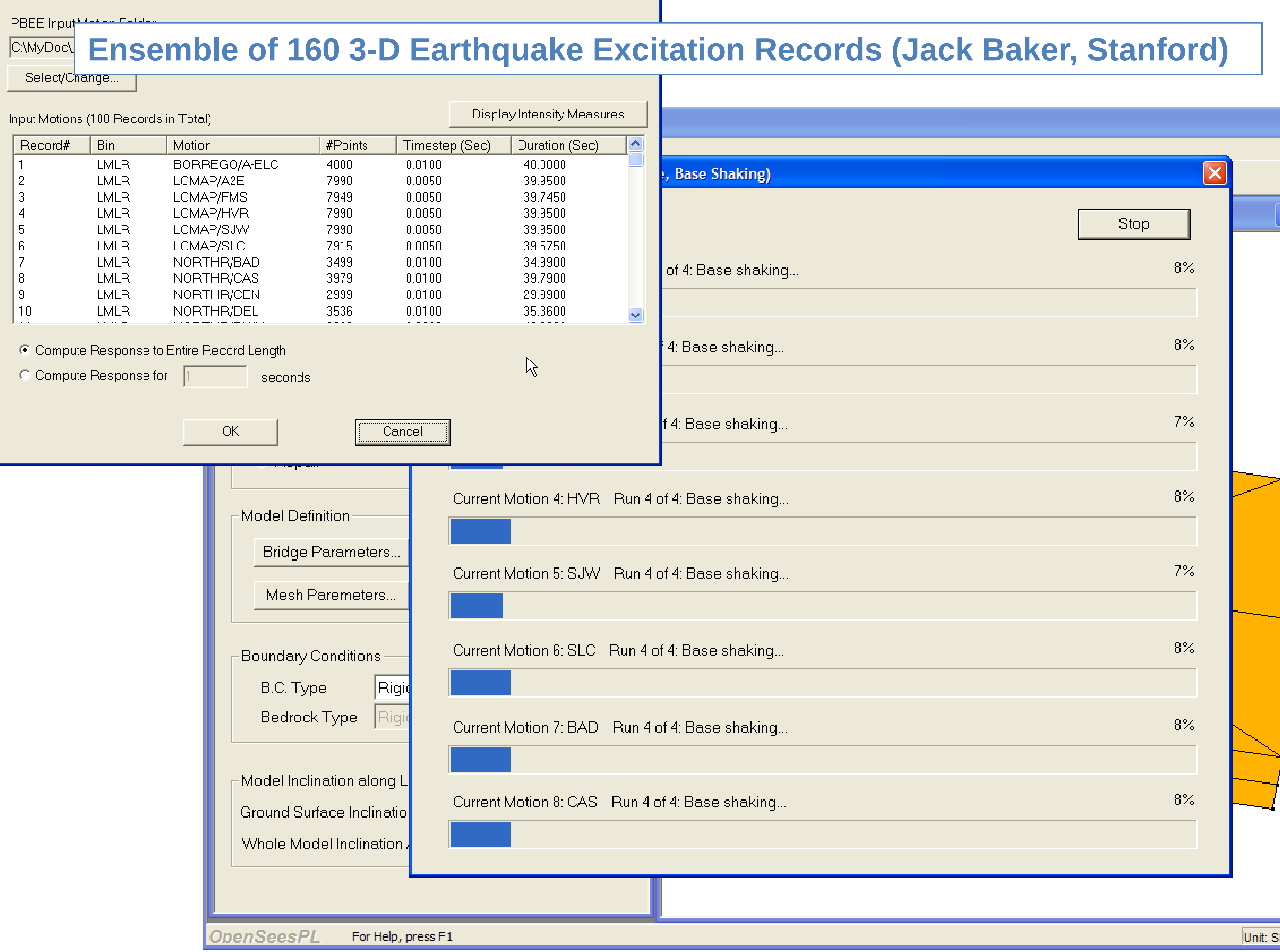
Set #1b: Broad-band ground motions (M = 6, R = 25 km, soil site)

See the report above for background regarding the selection of these ground motions.

– Spreadsheet documenting selected ground motions. Worksheets are provided to list a summary of the selected ground

Done

Ensemble of 160 3-D Earthquake Excitation Records (Jack Baker, Stanford)



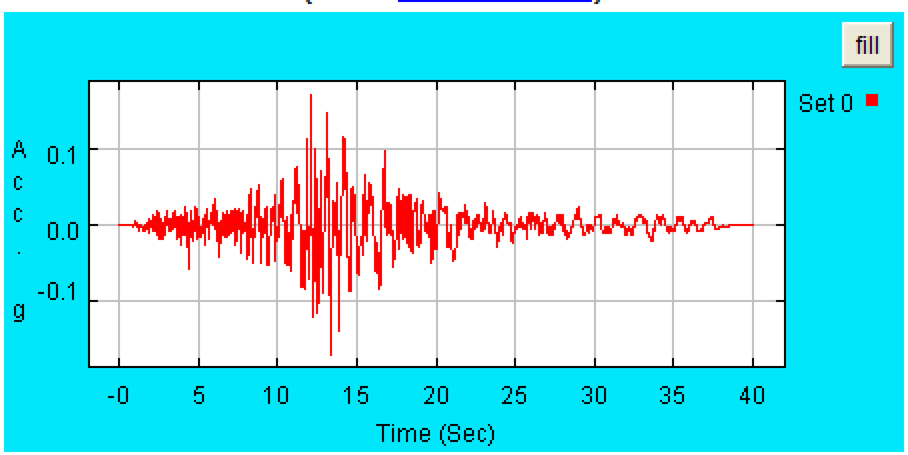
Motion: A2E

Intensity Measures

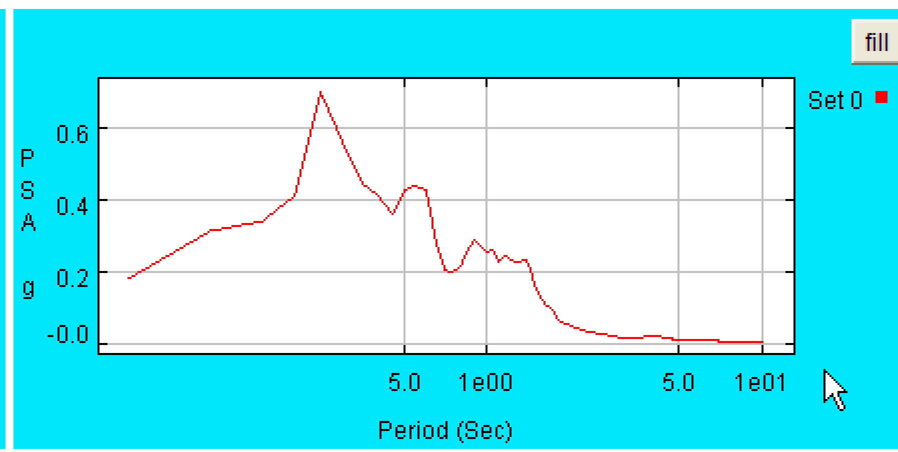
	Horizontal 1	Horizontal 2	Horizontal SRSS	Vertical
PGA (g)	0.170558	0.138501	0.181953	0.095212
PGV (cm/sec)	13.712202	11.527482	17.248343	3.759779
PGD (cm)	3.891637	5.643364	5.753599	2.382868
D(5-95) (sec)	31.530000	30.845000		36.905000
CAV (cm/sec)	616.701389	508.981512		323.320389
Arias Intensity (cm/sec)	40.190139	27.553230		9.283904

Acceleration Time Histories and Pseudo-Spectral Acceleration (PSA)

Horizontal 1 Acceleration (g) (Motion File: A2E000.AT2.data)
(File: motionX.txt)

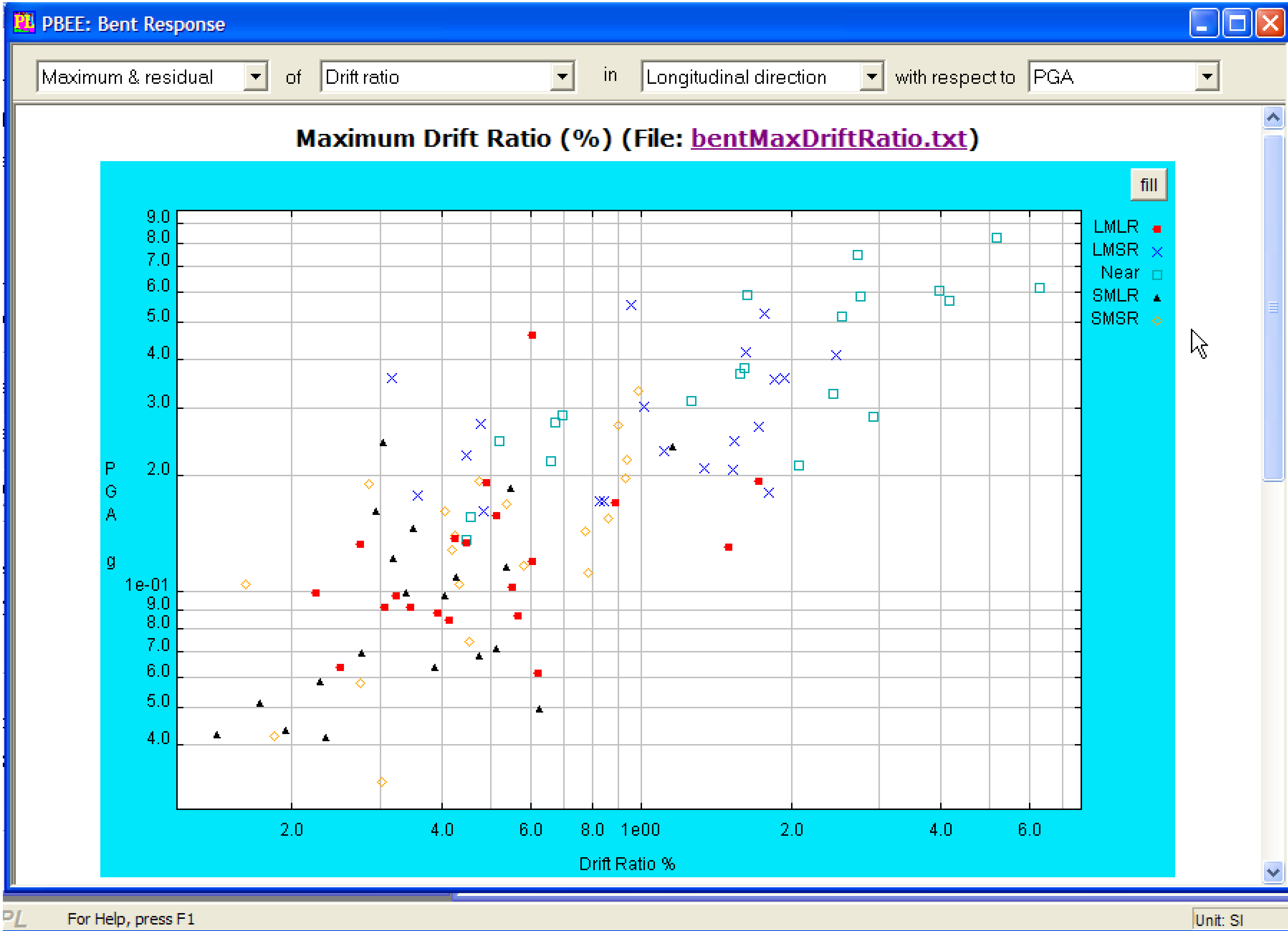


Horizontal 1 Pseudo-Spectral Acceleration (g) (File: spectralAccX.txt)



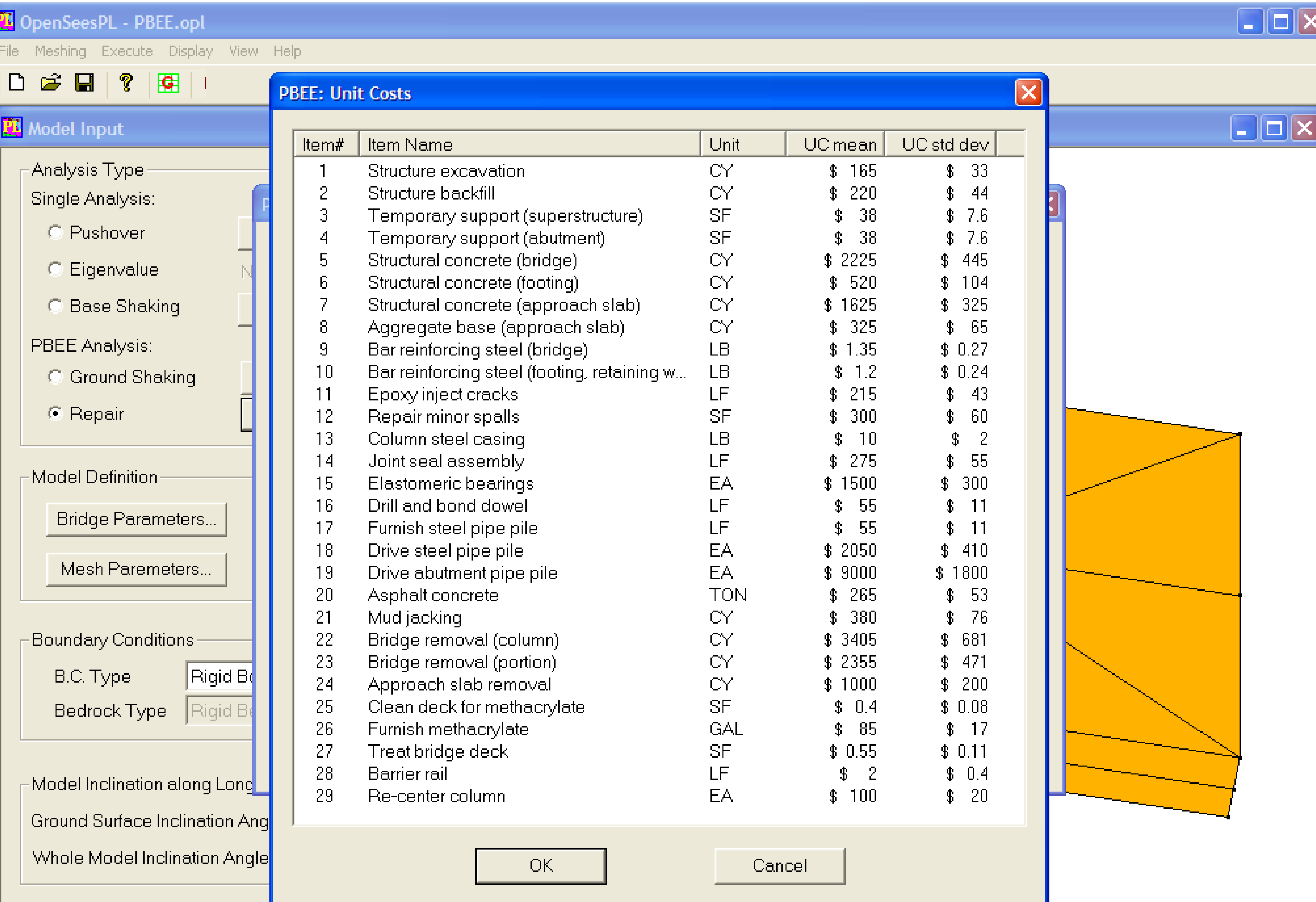
Horizontal 2 Acceleration (g) (Motion File:

Horizontal 2 Pseudo-Spectral Acceleration (g) (File:

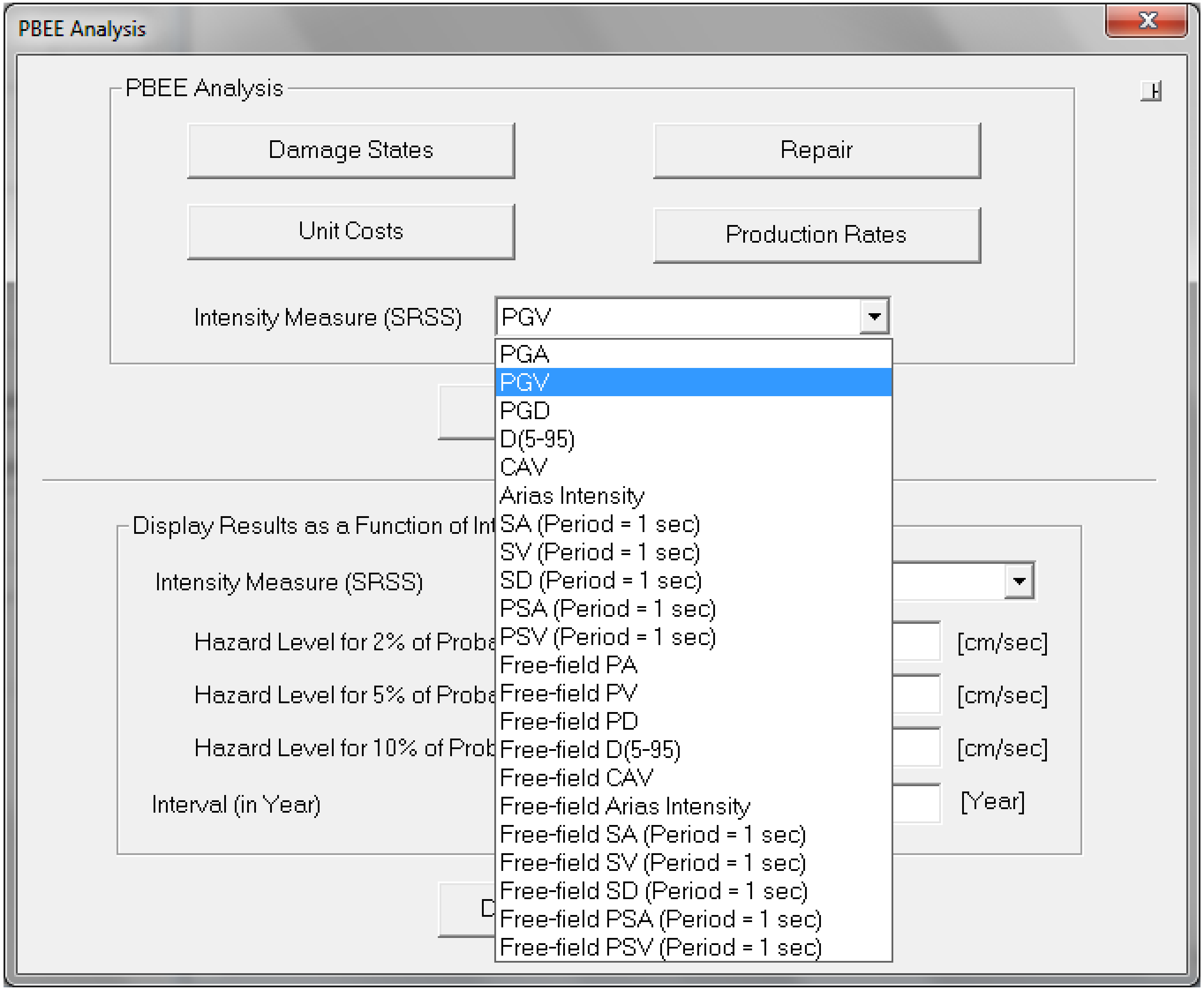


PBEE: Bent Response
Maximum & residual
of
Drift ratio
in
Longitudinal direction
with respect to
PGA
Maximum Drift Ratio (%) (File: bentMaxDriftRatio.txt)
fill
LMLR
LMSR
Near
SMLR
SMSR
P
G
A
g
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1e-01
4.0
2.0
4.0
6.0
8.0
1e00
2.0
4.0
6.0
Drift Ratio %
For Help, press F1
Unit: SI

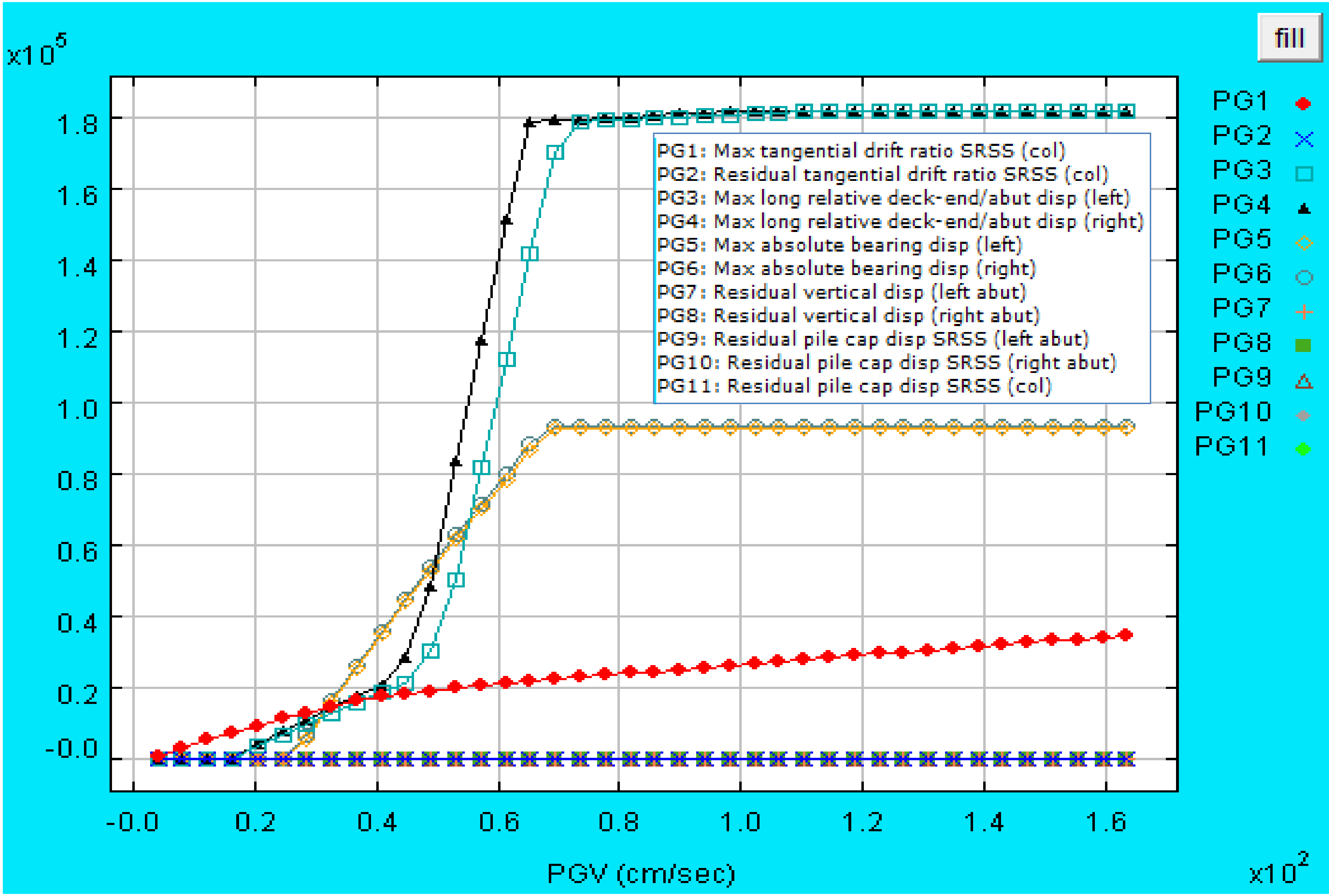
Unit Costs



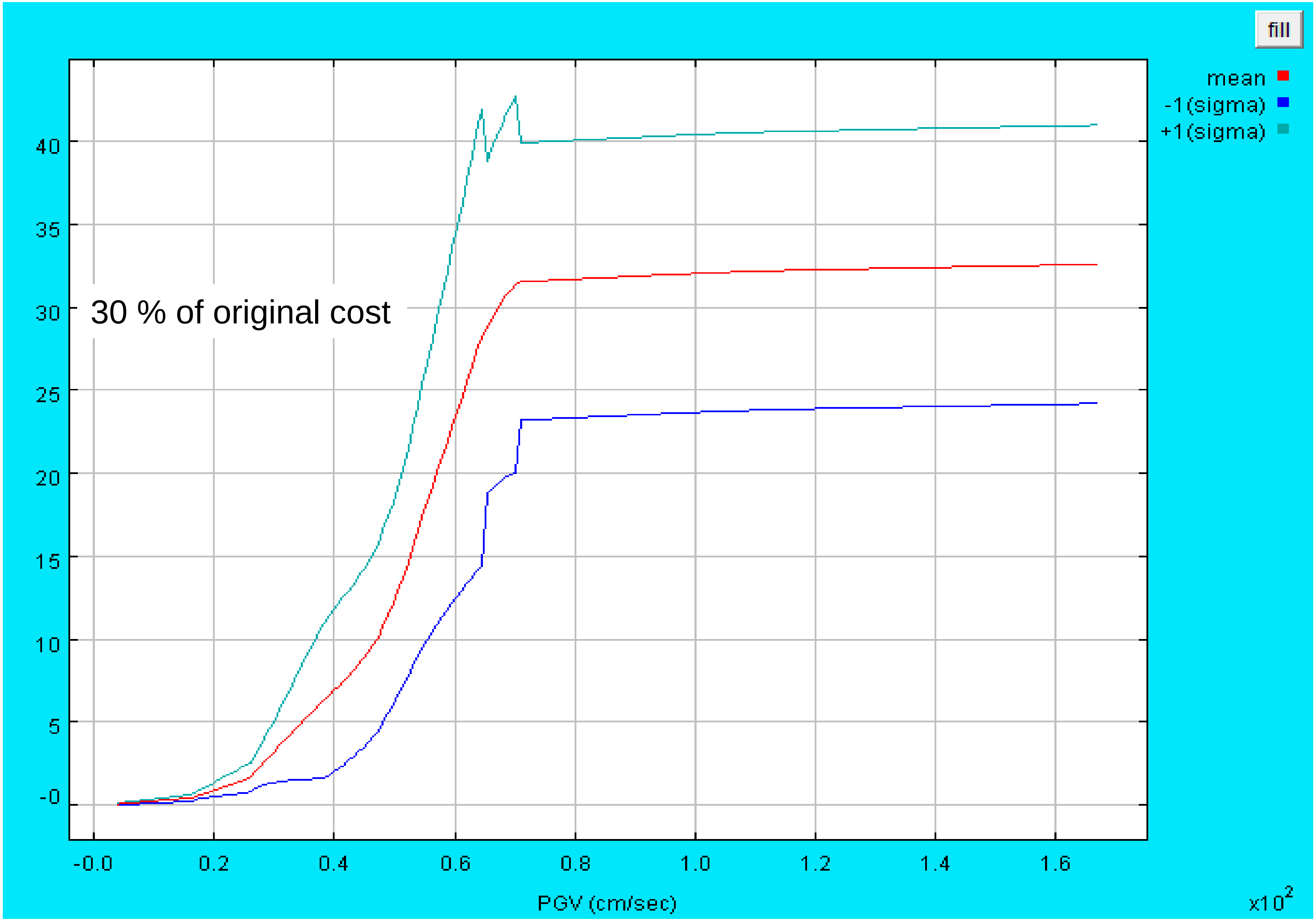
Item#	Item Name	Unit	UC mean	UC std dev
1	Structure excavation	CY	$ 165	$ 33
2	Structure backfill	CY	$ 220	$ 44
3	Temporary support (superstructure)	SF	$ 38	$ 7.6
4	Temporary support (abutment)	SF	$ 38	$ 7.6
5	Structural concrete (bridge)	CY	$ 2225	$ 445
6	Structural concrete (footing)	CY	$ 520	$ 104
7	Structural concrete (approach slab)	CY	$ 1625	$ 325
8	Aggregate base (approach slab)	CY	$ 325	$ 65
9	Bar reinforcing steel (bridge)	LB	$ 1.35	$ 0.27
10	Bar reinforcing steel (footing, retaining w...	LB	$ 1.2	$ 0.24
11	Epoxy inject cracks	LF	$ 215	$ 43
12	Repair minor spalls	SF	$ 300	$ 60
13	Column steel casing	LB	$ 10	$ 2
14	Joint seal assembly	LF	$ 275	$ 55
15	Elastomeric bearings	EA	$ 1500	$ 300
16	Drill and bond dowel	LF	$ 55	$ 11
17	Furnish steel pipe pile	LF	$ 55	$ 11
18	Drive steel pipe pile	EA	$ 2050	$ 410
19	Drive abutment pipe pile	EA	$ 9000	$ 1800
20	Asphalt concrete	TON	$ 265	$ 53
21	Mud jacking	CY	$ 380	$ 76
22	Bridge removal (column)	CY	$ 3405	$ 681
23	Bridge removal (portion)	CY	$ 2355	$ 471
24	Approach slab removal	CY	$ 1000	$ 200
25	Clean deck for methacrylate	SF	$ 0.4	$ 0.08
26	Furnish methacrylate	GAL	$ 85	$ 17
27	Treat bridge deck	SF	$ 0.55	$ 0.11
28	Barrier rail	LF	$ 2	$ 0.4
29	Re-center column	EA	$ 100	$ 20

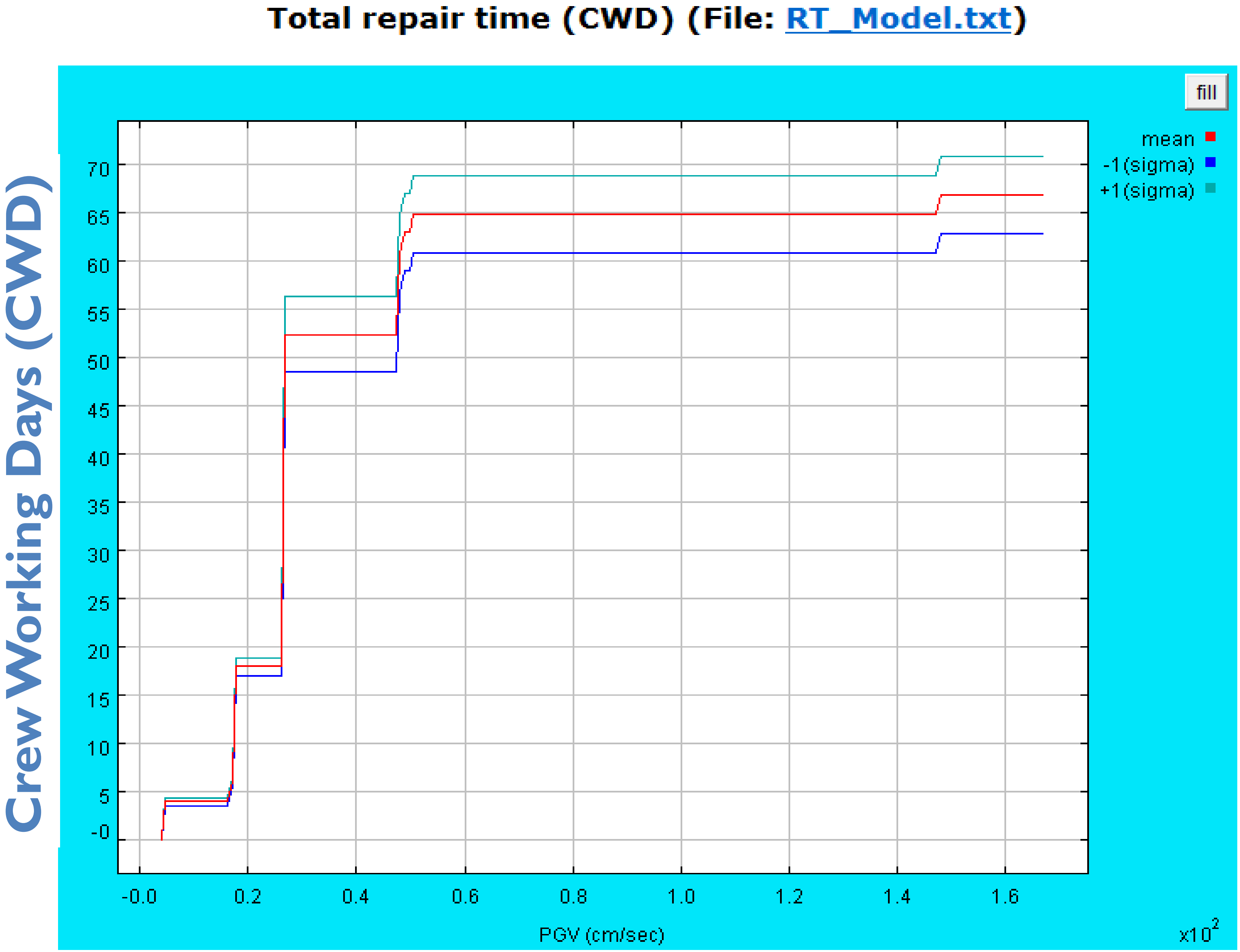

PBEE Analysis
PBEE Analysis
Damage States
Repair
Unit Costs
Production Rates
Intensity Measure (SRSS)
PGV
PGA
PGV
PGD
D(5-95)
CAV
Arias Intensity
SA (Period = 1 sec)
SV (Period = 1 sec)
SD (Period = 1 sec)
PSA (Period = 1 sec)
PSV (Period = 1 sec)
Free-field PA
Free-field PV
Free-field PD
Free-field D(5-95)
Free-field CAV
Free-field Arias Intensity
Free-field SA (Period = 1 sec)
Free-field SV (Period = 1 sec)
Free-field SD (Period = 1 sec)
Free-field PSA (Period = 1 sec)
Free-field PSV (Period = 1 sec)
Intensity Measure (SRSS)
[cm/sec]
[cm/sec]
[cm/sec]
Interval (in Year)
[Year]

Contribution to expected repair cost ($) from each performance group
(File: PGsens_E.txt)

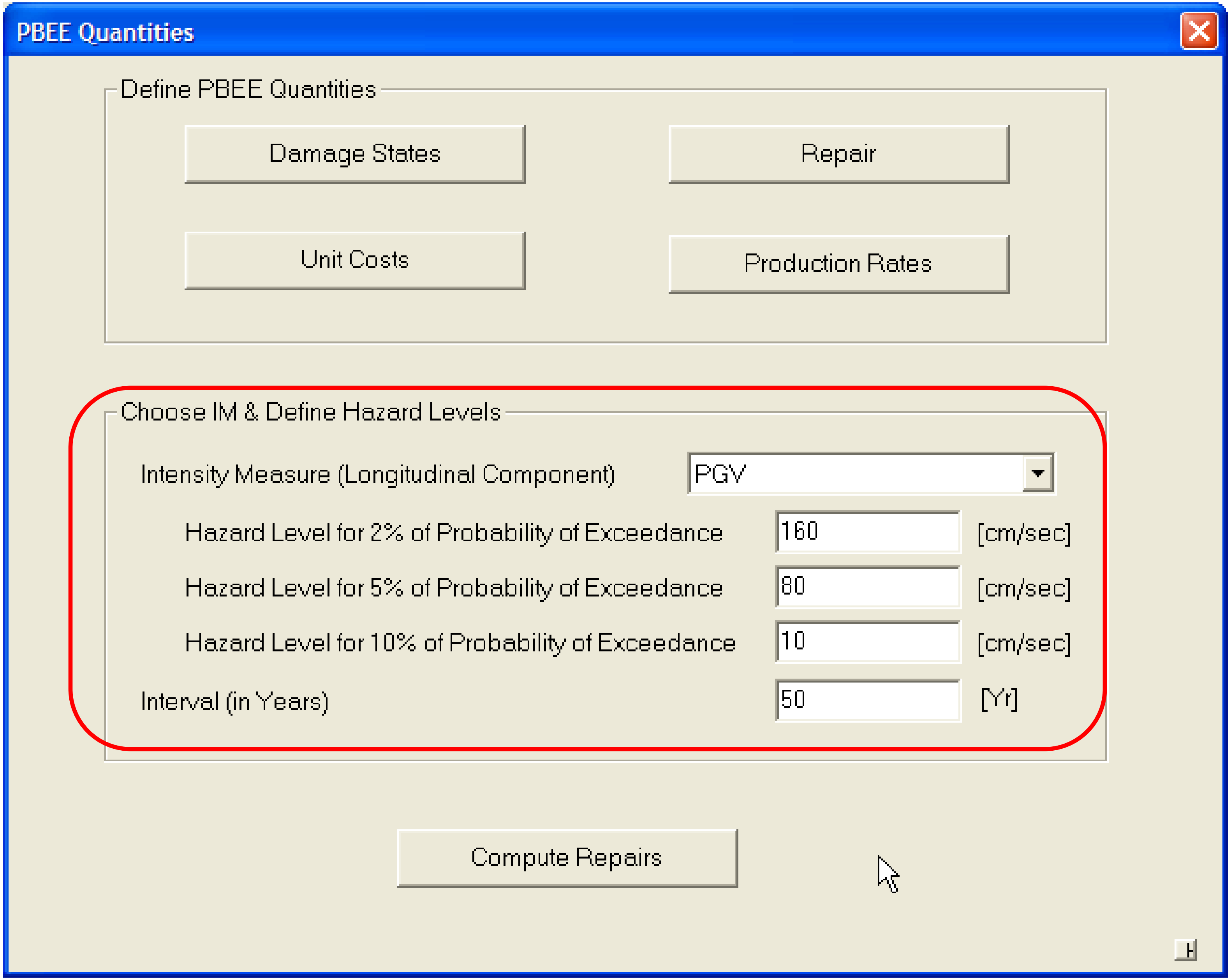


Total repair cost ratio (%) (File: RCR_Model.txt)

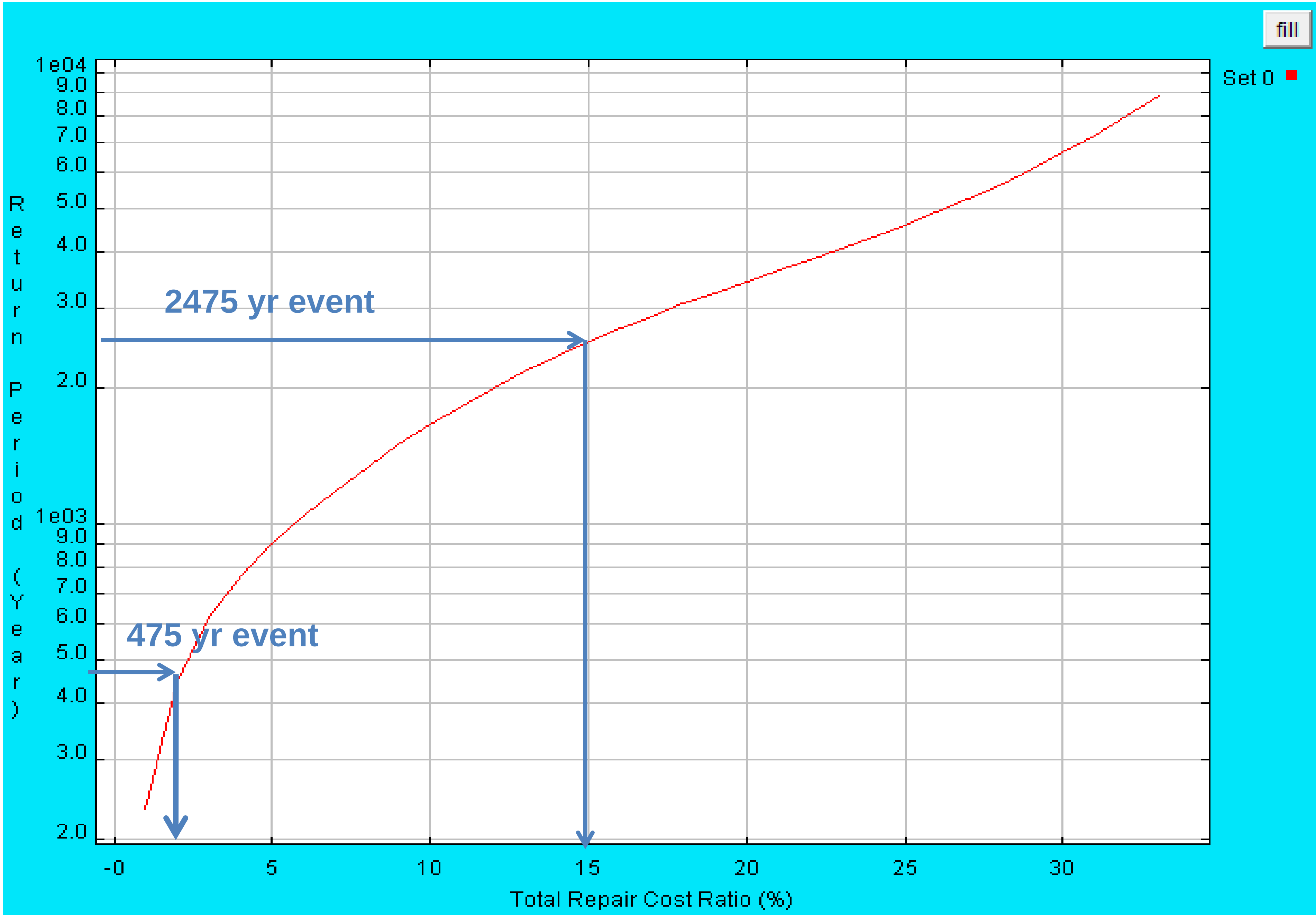



Total repair time (CWD) (File: RT_Model.txt)
fill
mean
-1(sigma)
+1(sigma)
Crew Working Days (CWD)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-0
-0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
PGV (cm/sec)
x10^2

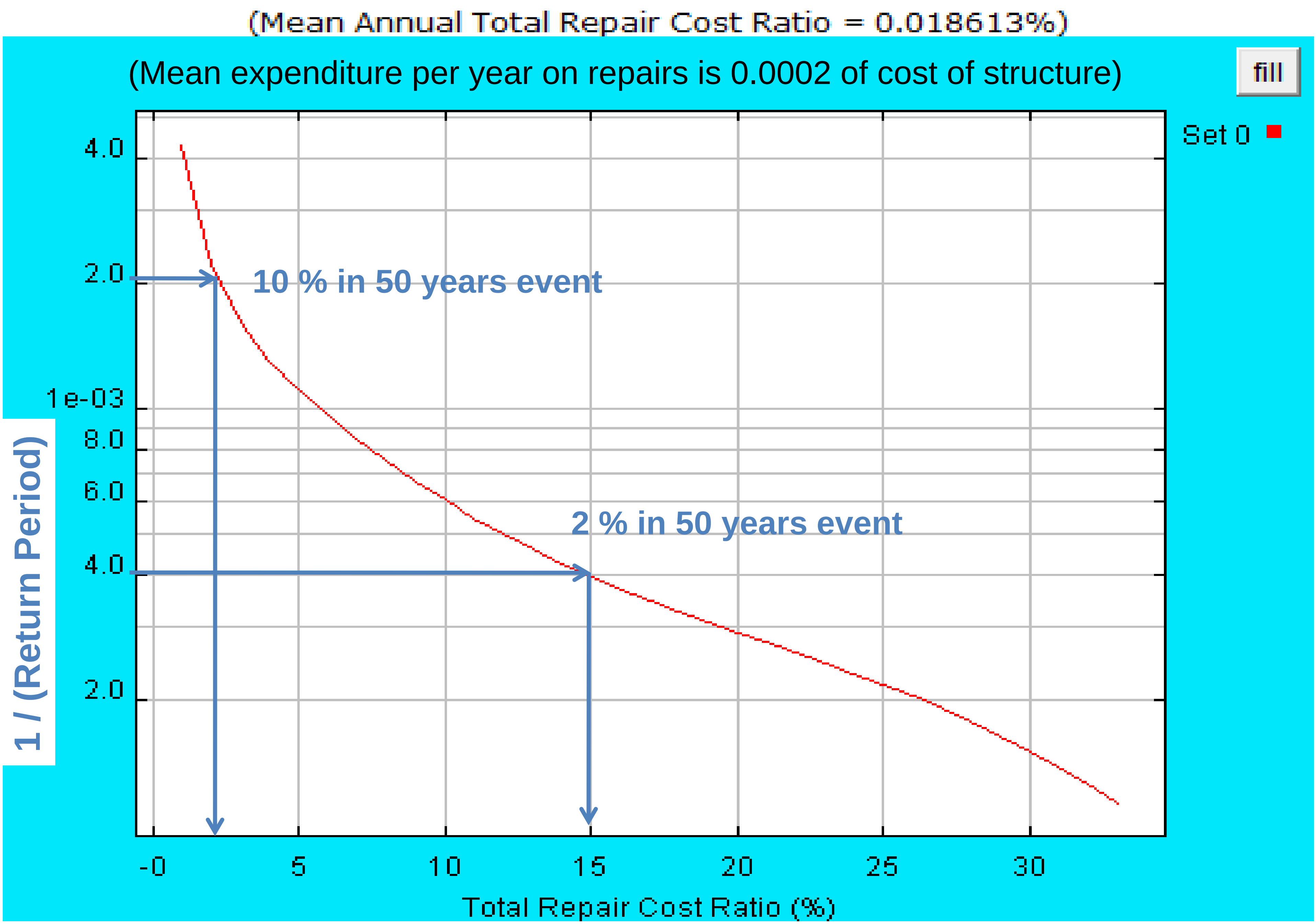
Definition of Hazard Level at Specific Bridge Location

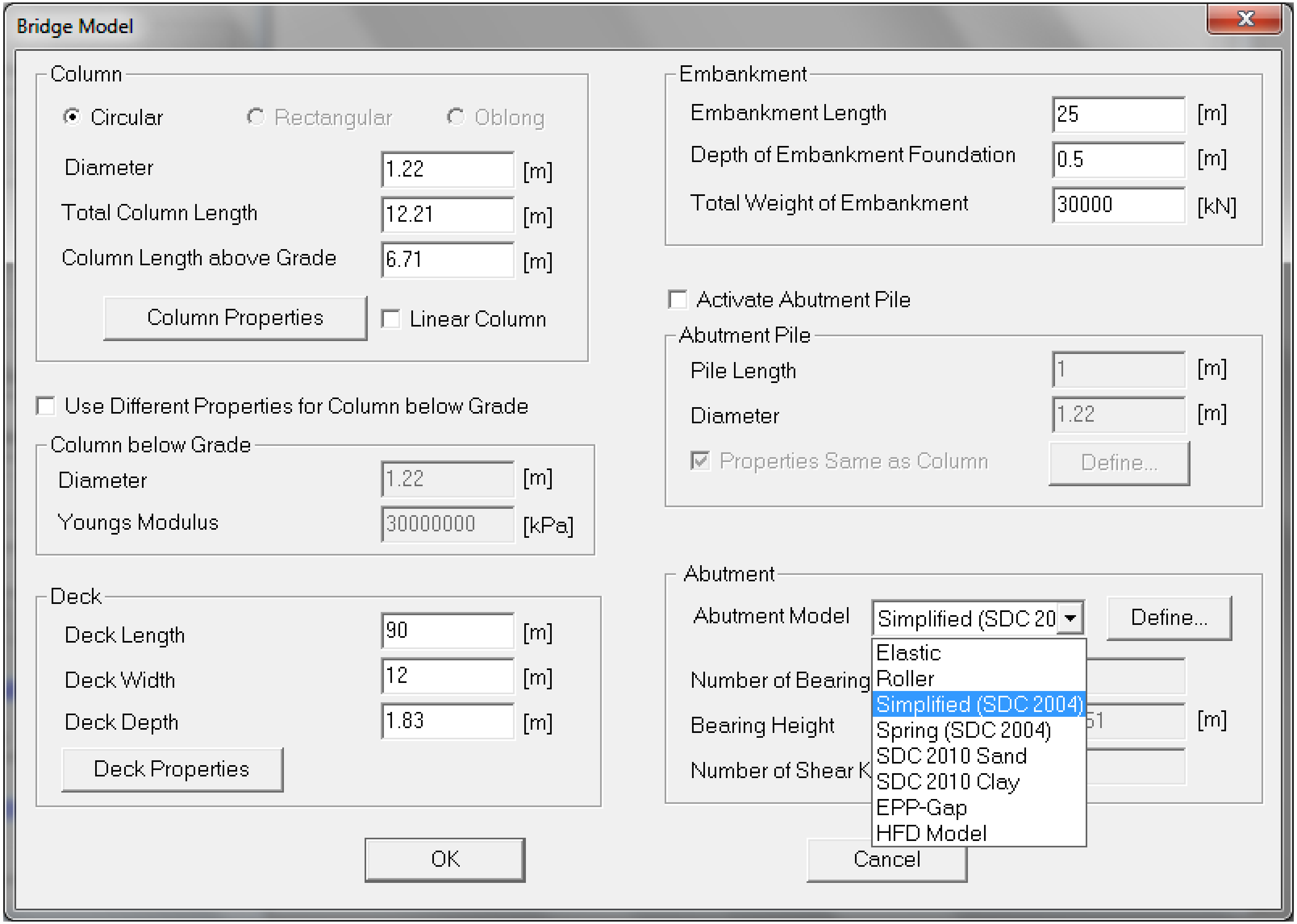


Return Period (File: ReturnPd.txt)



Mean Annual Frequency of Exceedance (Loss) (File: HazardDV.txt)




Bridge Model
Column
Circular
Rectangular
Oblong
Diameter
1.22
[m]
Total Column Length
12.21
[m]
Column Length above Grade
6.71
[m]
Column Properties
Linear Column
Use Different Properties for Column below Grade
Column below Grade
Diameter
1.22
[m]
Youngs Modulus
30000000
[kPa]
Deck
Deck Length
90
[m]
Deck Width
12
[m]
Deck Depth
1.83
[m]
Deck Properties
OK
Embankment
Embankment Length
25
[m]
Depth of Embankment Foundation
0.5
[m]
Total Weight of Embankment
30000
[kN]
Activate Abutment Pile
Abutment Pile
Pile Length
1
[m]
Diameter
1.22
[m]
Properties Same as Column
Define...
Abutment
Abutment Model
Simplified (SDC 20
Define...
Number of Bearing
Bearing Height
[m]
Number of Shear K
Elastic
Roller
Simplified (SDC 2004)
Spring (SDC 2004)
SDC 2010 Sand
SDC 2010 Clay
EPP-Gap
HFD Model
Cancel

The elastic abutment model consists of a simple 6 elastic springs in each dof: longitudinal, transversal, vertical displacements and across longitudinal, transversal and vertical rotations. By default the rotations are set with zero value.

Roller Model

The roller abutment model consists of a simple boundary condition module that applies single-point constraints against displacement in the vertical direction (vertical support), as seen in Fig. 1. This model can be used to provide a lower-bound estimate of the longitudinal and transverse resistance of the bridge, captured through a pushover analysis. For more details, see [*]

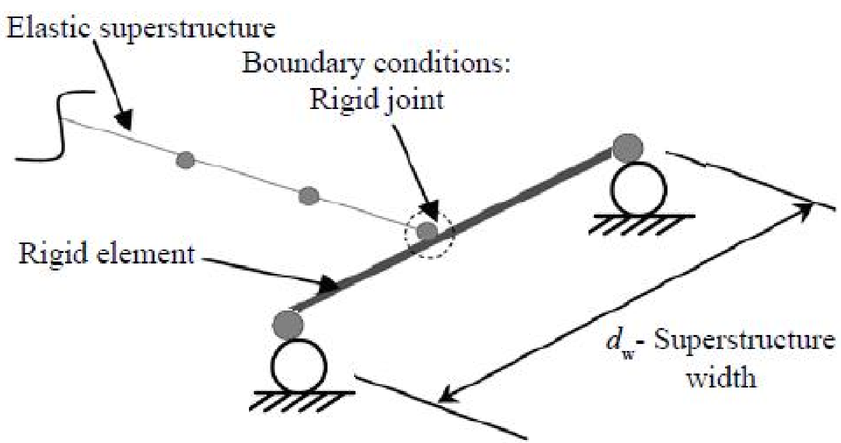


Fig. 1 General scheme of the Roller abutment model

Simplified Model

The simplified abutment model consists of a simplification of the spring abutment model. The general scheme of the simplified model is presented in Fig. 2.It consists of a rigid element of length dw (superstructure width), connected through a rigid joint to the superstructure centerline, with defined longitudinal, transverse and vertical nonlinear response at each end. In the longitudinal direction, a series system is defined (see Fig. 3), consisting of a rigid element with shear and moment releases, a gap element with boundary conditions at each end allowing only longitudinal translation, and a zero-length element. The latter element is assigned an elastic-perfectly-plastic (EPP) backbone curve with abutment stiffness (Kabt) and ultimate strength (Pbw) obtained from section 7.8.1 of the Caltrans SDC (2004), see fig. 4. The longitudinal response defined for the simplified model accounts only for the gap and the embankment fill response, where passive pressures are

Abutment Models - PEERBridgePBEEWiki - Mozilla Firefox

http://peerbridgepbee.net/index.php?title=Abutment_Models

Abutment Models - PEERBridgeP...

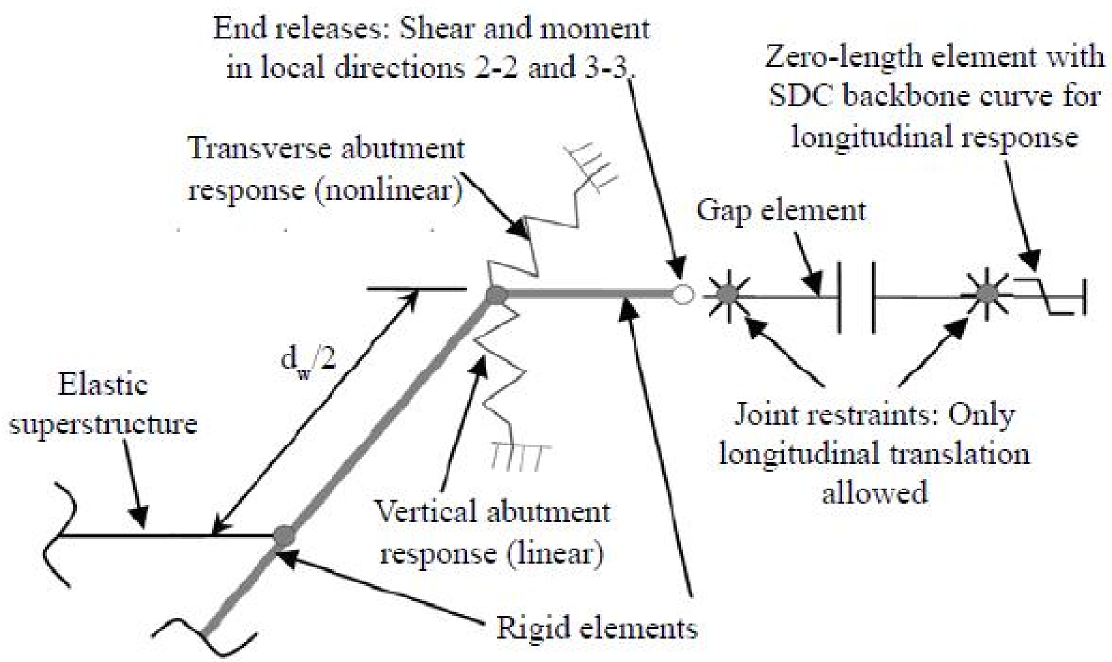
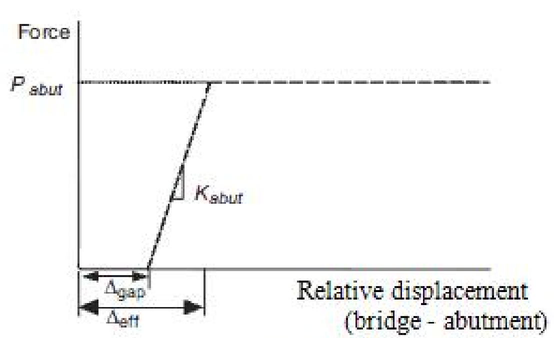


Fig. 3 Series system of the longitudinal simplified abutment response



Abutments

presented in Fig. 2.it consists of a rigid element of length dw (superstructure width), connected through a rigid joint to the superstructure centerline, with defined longitudinal, transverse and vertical nonlinear response at each end. In the longitudinal direction, a series system is defined (see Fig. 3), consisting of a rigid element with shear and moment releases, a gap element with boundary conditions at each end allowing only longitudinal translation, and a zero-length element. The latter element is assigned an elastic-perfectly-plastic (EPP) backbone curve with abutment stiffness (Kabt) and ultimate strength (Pbw) obtained from section 7.8.1 of the Caltrans SDC (2004), see fig. 4. The longitudinal response defined for the simplified model accounts only for the gap and the embankment fill response, where passive pressures are produced by the abutment back wall. The shear resistance of the bearing pads is ignored. In the transverse direction, a zero-length element is defined at each end of the rigid link with an assigned EPP backbone curve representing the backfill, wing wall and pile system response. The resistance of the brittle shear keys and distributed bearing pads is ignored in this model for simplicity. In the vertical direction, an elastic spring is defined at each end of the rigid link, with a stiffness corresponding to the bearing pads stiffness kv. The stiffness of the pads in compression and tension is assumed to be identical. Each bearing is assumed to have a cross-sectional area as specified on the plans. The distribution of the bearing pads along the stem wall and the vertical embankment stiffness are not accounted for in the model, assuming rigid soil conditions. For more details, see [*]

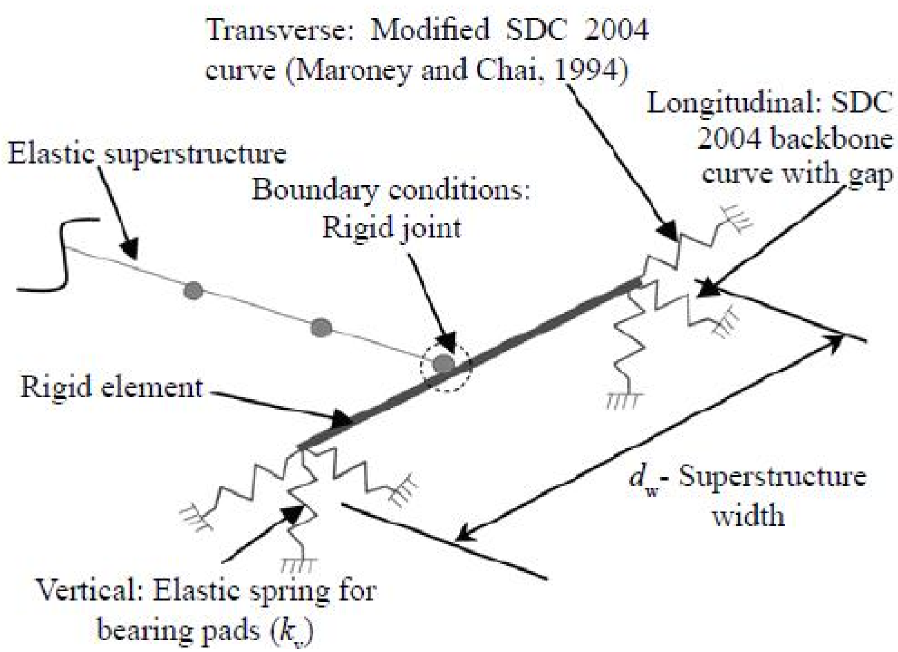
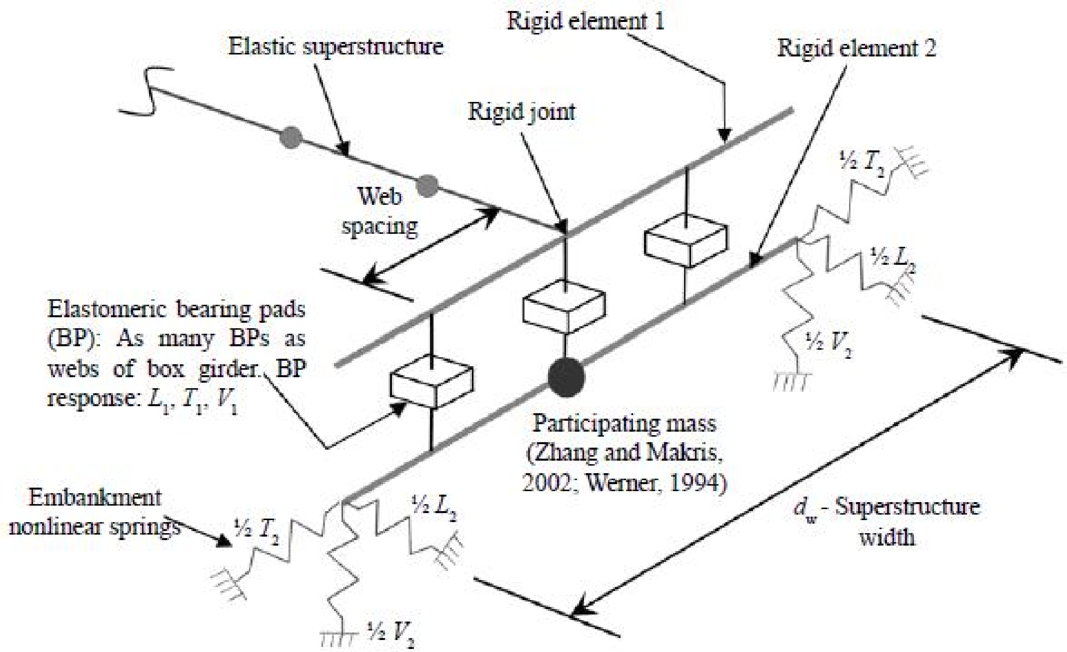


Fig. 2 General scheme of the Simplified abutment model

superstructure dead load at the abutment, including a contribution from structural concrete as well as the participating soil mass. An average of the embankment lengths obtained from Zhang and Makris (2002) and Werner (1994) is included in the calculation of the participating mass due to the embankment of the abutment. For more details, see [*]

Specifically, the user can modify the vertical tensile force factor for the bearing pads.



Bearing pads response:

- Longitudinal L_1: BP shear resistance and backwall gap contact element in parallel.
- Transverse T_1: BP shear resistance and brittle shear keys (extreme BPs only) in parallel.
- Vertical V_1: BP vertical stiffness and contact element for stem wall in parallel.

Embankment response:

- Longitudinal L_2: SDC (2004) backbone curve.
- Transverse T_2: Modified SDC (2004) backbone curve.
- Vertical V_2: Embankment vertical stiffness.

Fig. 5 General scheme of the Spring abutment model

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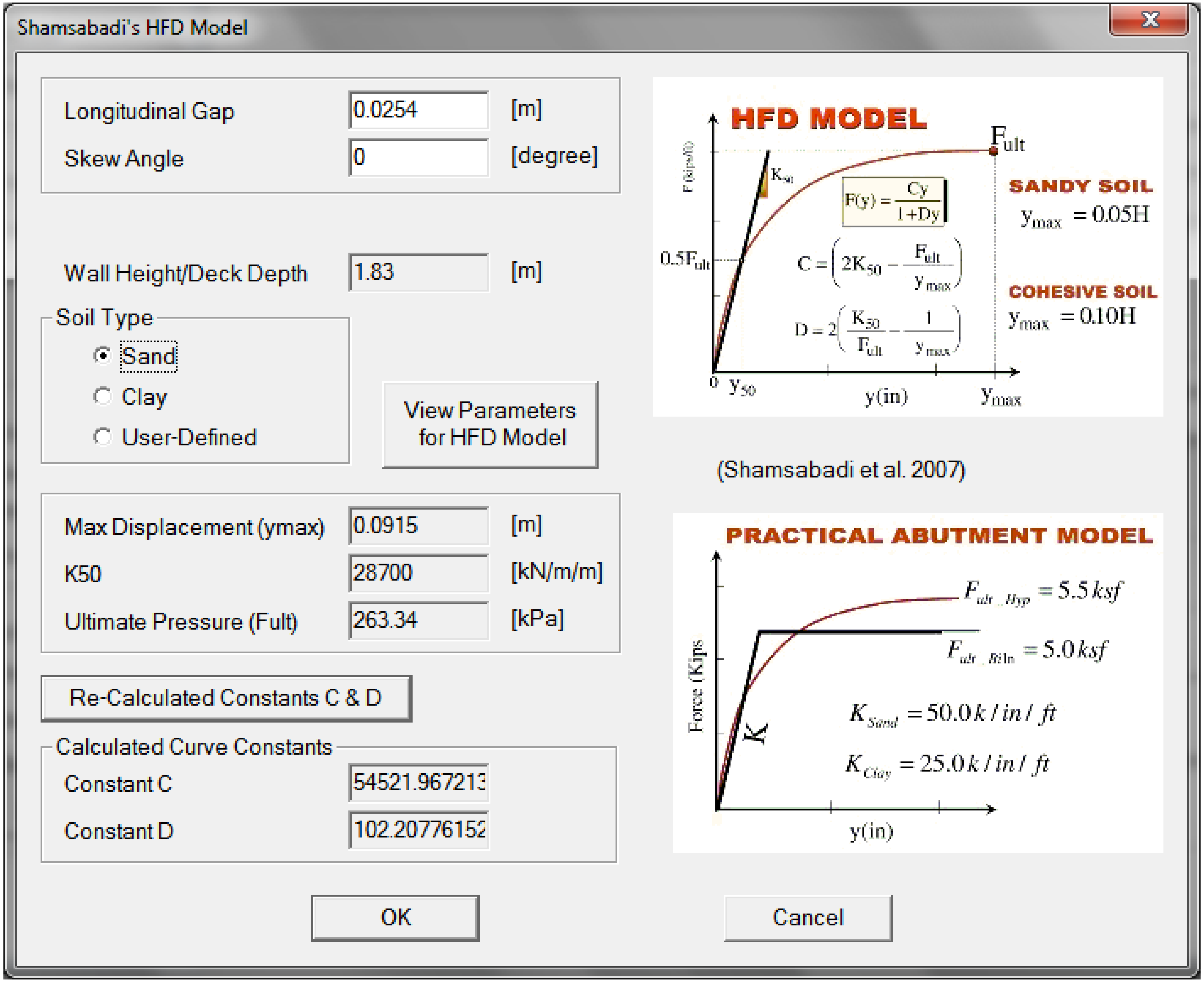
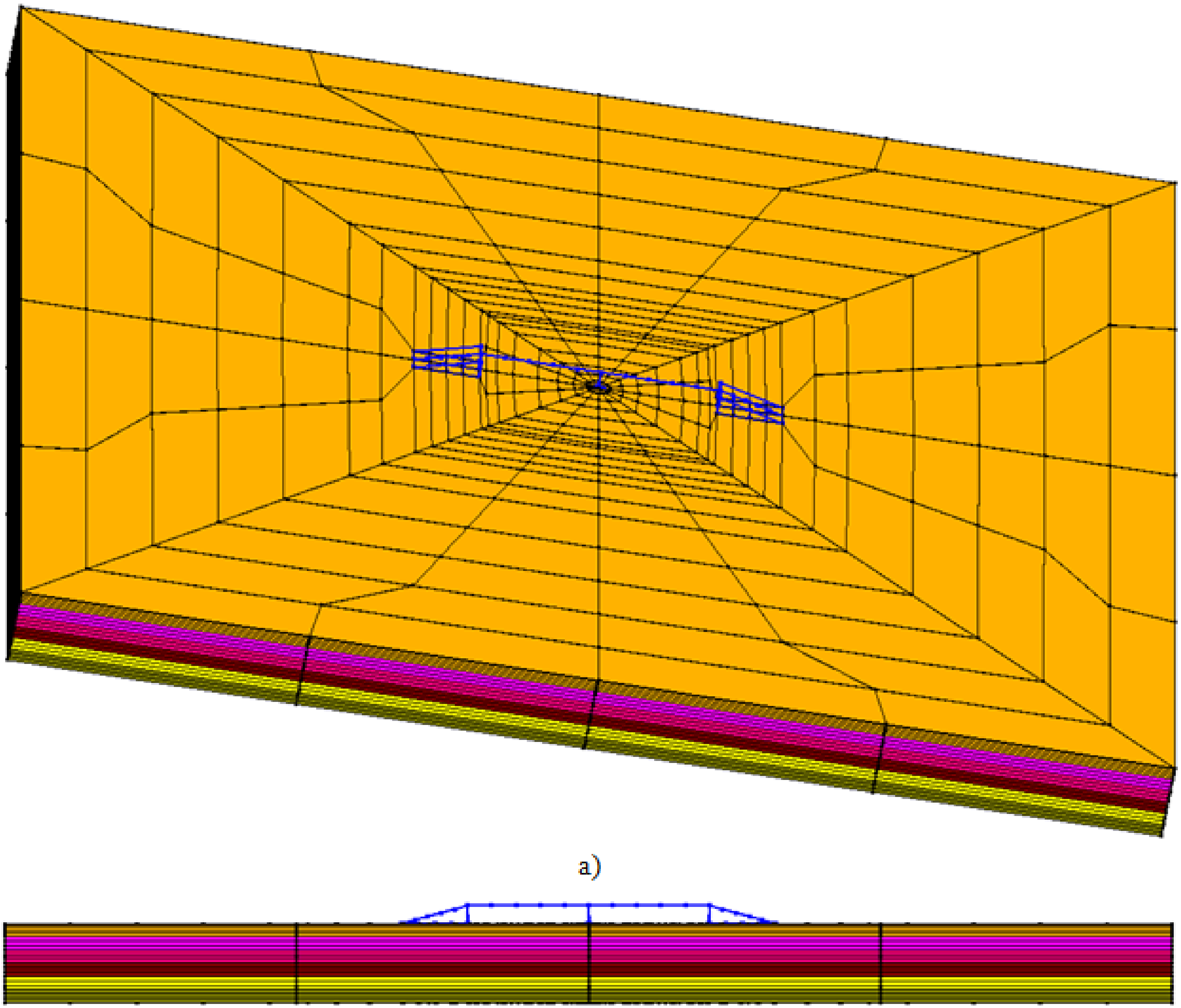

Shamsabadi's HFD Model
Longitudinal Gap
0.0254
[m]
Skew Angle
0
[degree]
Wall Height/Deck Depth
1.83
[m]
Soil Type
Sand
Clay
User-Defined
View Parameters for HFD Model
Max Displacement (ymax)
0.0915
[m]
K50
28700
[kN/m/m]
Ultimate Pressure (Fult)
263.34
[kPa]
Re-Calculated Constants C & D
Calculated Curve Constants
Constant C
54521.967213
Constant D
102.20776152
OK
Cancel
HFD MODEL
F(y) = Cy / (1+Dy)
C = (2K50 − Fult / ymax)
D = 2(K50 / Fult − 1 / ymax)
SANDY SOIL
ymax = 0.05H
COHESIVE SOIL
ymax = 0.10H
y(in)
(Shamsabadi et al. 2007)
PRACTICAL ABUTMENT MODEL
Fult_Hyp = 5.5 ksf
Fult_Biln = 5.0 ksf
KSand = 50.0 k/in/ft
KClay = 25.0 k/in/ft
Force (Kips)
y(in)



a)

b)

Case 1: Stiff soil and Case 2: Soft soil

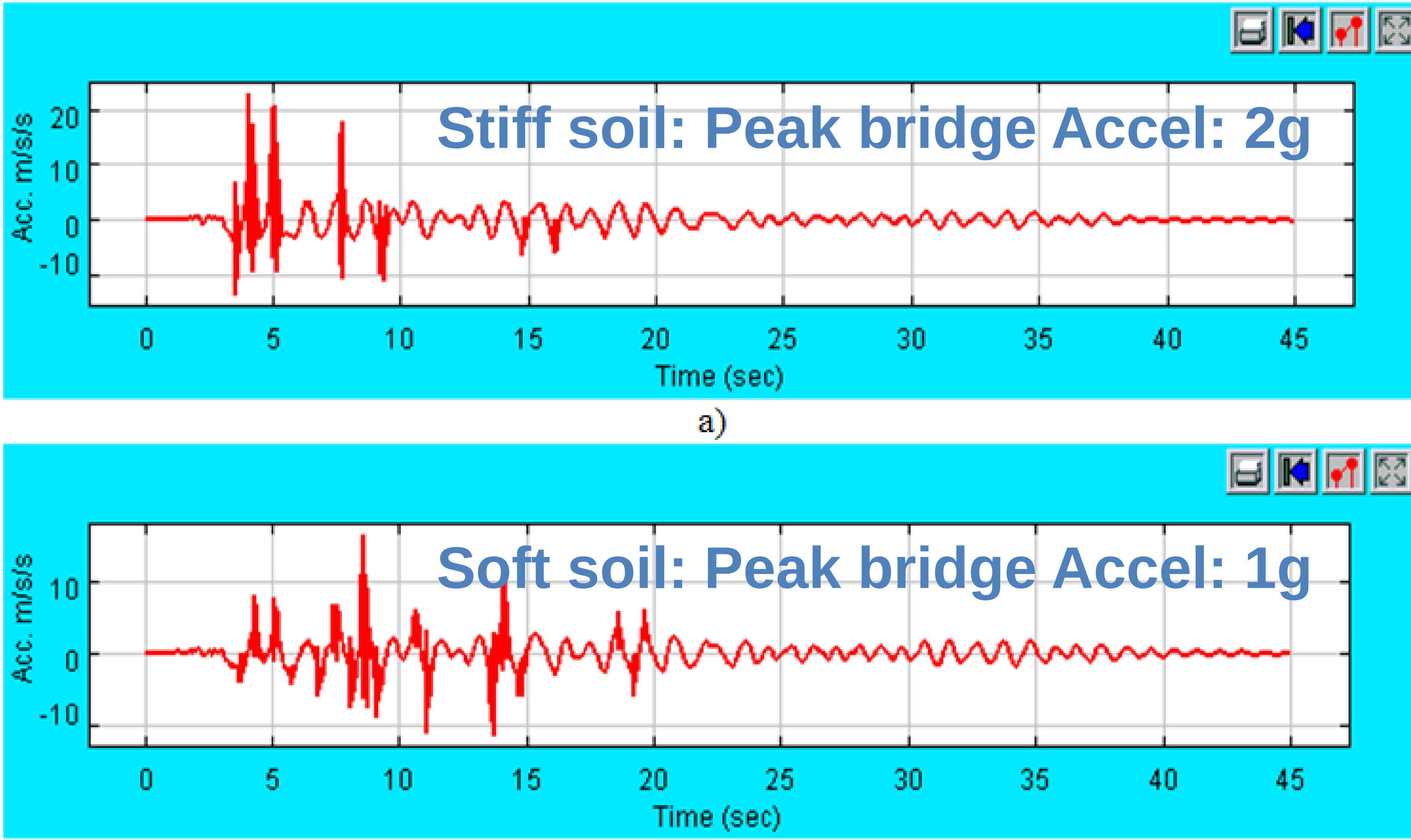
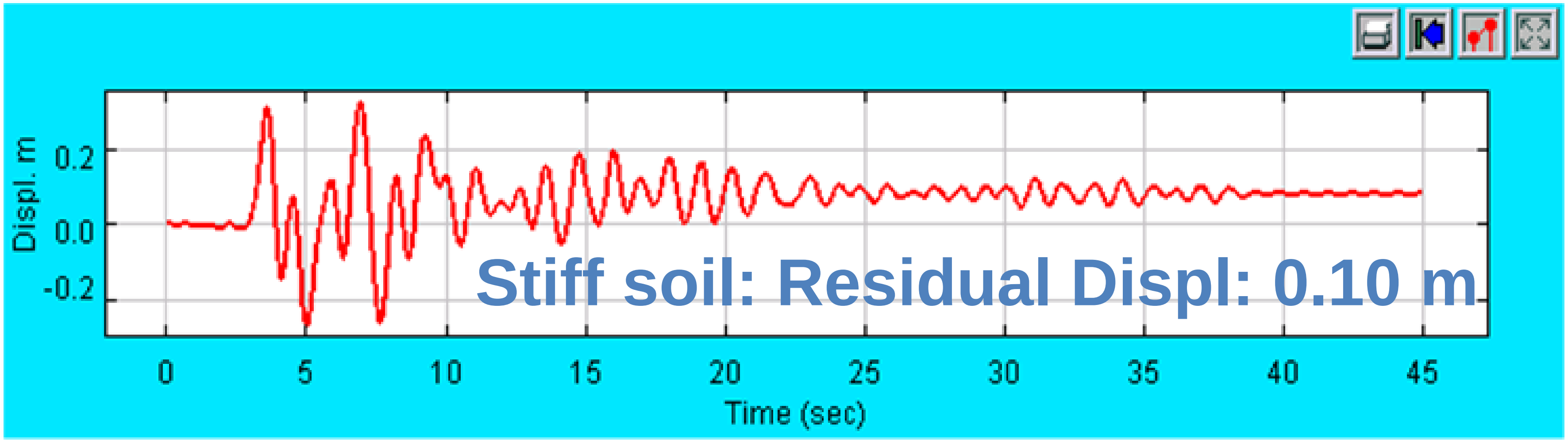
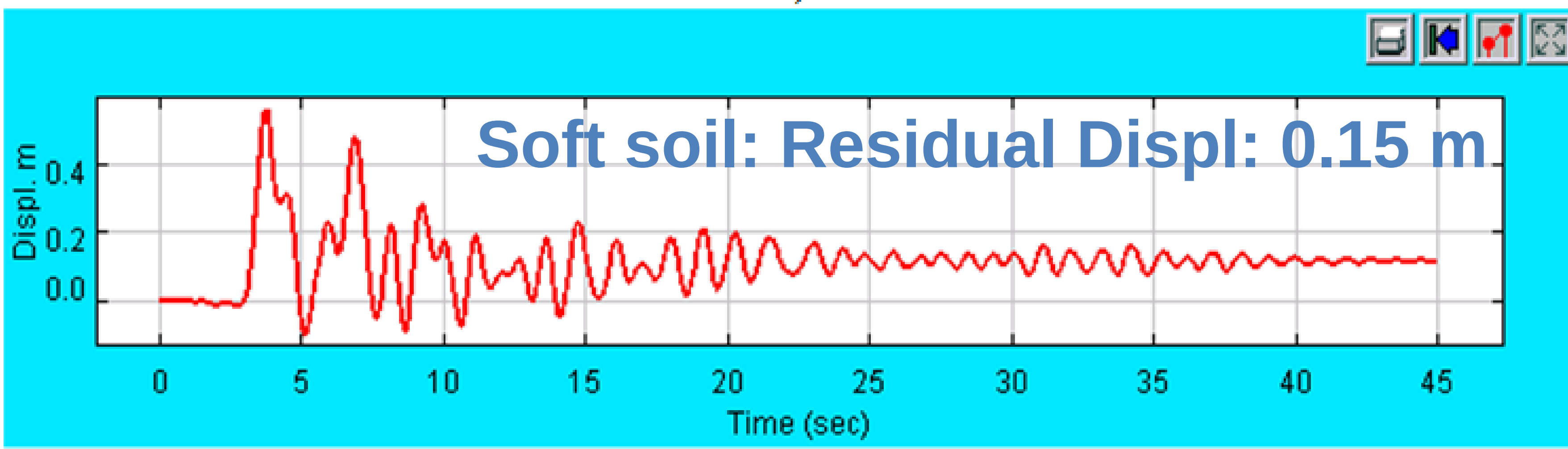


Fig. 11. Column top longitudinal acceleration time histories: a) Case 1; b) Case 2



a)



b)

Fig. 7. Column top longitudinal displacement time histories: a) Case 1; b) Case 2

Fine mesh: Comparison of total repair cost ratio (%) for Cases 1 & 2