OPENSEESPY TUTORIAL

Modal Analysis

A CASE STUDY: DYNAMIC ANALYSIS OF A SHAFT WITH MASS IMBALANCE

Length (L): 1.5 m

Diameter (D): 0.5 inches

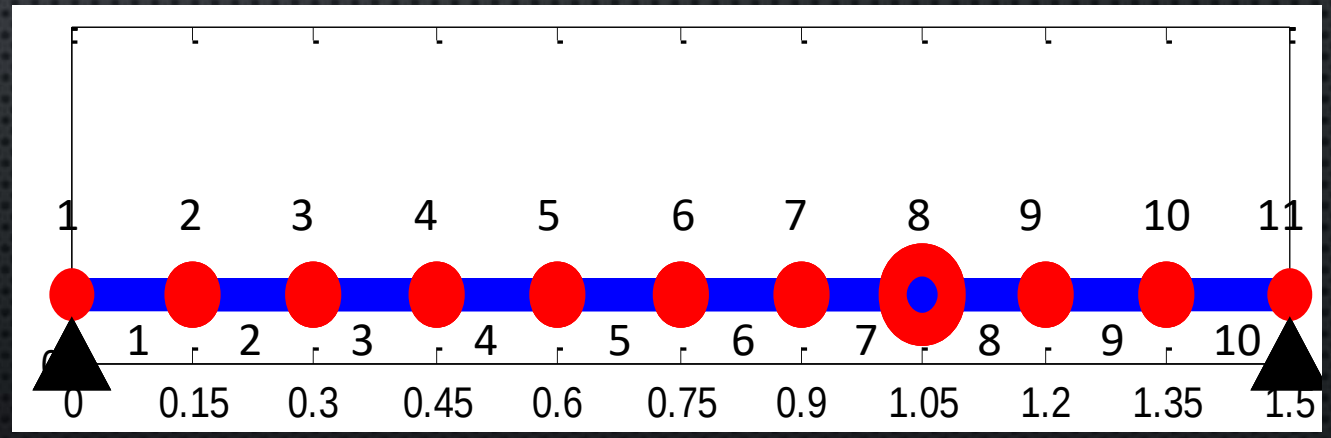
Mass (m): 40 kg

Density (rho): 7850 kg/m³

Young's Modulus (E): 2.1 GPa

Simply supported shaft.

Mass excess at 0.7L from left.



MODEL DEFINITION

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

############################ PHYSICAL PROPERTIES ##############################
L = 1.5                     # (m)
D = 0.5 * 0.0254            # (m)
m = 40                      # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                  # (Pa)
ro = 7850                   # (kg/m^3)
A = 0.25 * pi * D**2        # (m^2)
Iz = pi * D**4 / 64         # (m^4)
transTag = 1                # (kg)

############################## DEFINE NODES ###################################
Nmax = 11
for i in range(1, Nmax+1):
    op.node(i, (i - 1) * L / (Nmax - 1), 0, 0)

############################## DOF CONSTRAINTS ################################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS ###########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)
op.geomTransf('Linear', transTag)
```

wipe() command ensures that **all openseespy variables** and previously defined commands are no longer active in the current model.

As a common practice to prevent interference from other analyses, it is recommended to initiate the model with this command."

MODEL DEFINITION

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

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import math
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E = 2.1e11                # (Pa)
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A = 0.25 * pi * D**2      # (m^2)
Iz = pi * D**4 / 64       # (m^4)
transTag = 1              # (kg)

############################## DEFINE NODES #################################
Nmax = 11
for i in range(1, Nmax+1):
    op.node(i, (i - 1) * L / (Nmax - 1), 0, 0)

############################## DOF CONSTRAINTS ##############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS #########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)
op.geomTransf('Linear', transTag)
```

The model command is a necessary step to define the model domain. The syntax for this command is as follow:

model(‘basic’, ‘-ndm’, ndm, ’-ndf’, ndf)

where:

- ‘basic’ represents the model type.
- ‘-ndm’ denotes he number of dimensions.
- ndm is an integer representing the dimension
- ‘-ndf’ indicates the number of degrees of freedom.
- ndf is the integer representing the number of degrees of freedom.

It is important to note that ndf is an optional argument, if not specified, its default is the same as ndm.

GEOMETRY VARIABLES

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

############################ PHYSICAL PROPERTIES ##############################
L = 1.5                     # (m)
D = 0.5 * 0.0254            # (m)
m = 40                      # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                  # (Pa)
ro = 7850                   # (kg/m^3)
A = 0.25 * pi * D**2        # (m^2)
Iz = pi * D**4 / 64         # (m^4)

############################### DEFINE NODES ##################################
Nmax = 11
for i in range(1, Nmax+1):
    op.node(i, (i - 1) * L / (Nmax - 1), 0, 0)

############################## DOF CONSTRAINTS ################################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS ###########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1                # (kg)
op.geomTransf('Linear', transTag)
```

For complex models or those with a significant number of nodes and elements, it is a best practice to define variables containing geometry and material attributes. This helps both you and others understand and the analysis more effectively.

Even though this analysis is relative simple, we have defined the physical properties of the model as provided in the problem description.

NODE DEFINITION

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

############################ PHYSICAL PROPERTIES ##############################
L = 1.5                 # (m)
D = 0.5 * 0.0254        # (m)
m = 40                  # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11               # (Pa)
ro = 7850                # (kg/m^3)
A = 0.25 * pi * D**2     # (m^2)
Iz = pi * D**4 / 64      # (m^4)

############################### DEFINE NODES ##################################
Nmax = 11
for i in range(1, Nmax+1):
    op.node(i, (i - 1) * L / (Nmax - 1), 0)

############################### DOF CONSTRAINTS ###############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

###################### ADDITION OF CONCENTRATION MASS #########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1                # (kg)
op.geomTransf('Linear', transTag)
```

After defining the model, the next cruscial step is to define the nodes. This is accomplished using the node command, which follows this syntax:

node(nodeTag, *crds, ‘-ndf’, ndf, ‘-mass’, mass, ‘-disp’, *disp, ‘vel’, *vel, ‘-accel’, *accel)

Where:

- nodeTag is a **unique** identifier for each node.
- *crds represents the spatial coordinates of the nodes (consistent with the dimension defined in the model command).
- The remaining command options are optional but refer to nodal properties, including nodal degree of freedom (‘-ndf’, ndf), nodal mass (‘-mass’, mass´), nodal displacement (‘-disp’, *disp), nodal velocity (‘vel’, *vel) and nodal acceleration (‘-accel’, *accel)

NODE DEFINITION

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

############################ PHYSICAL PROPERTIES ################################
L = 1.5                    # (m)
D = 0.5 * 0.0254           # (m)
m = 40                     # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                 # (Pa)
ro = 7850                  # (kg/m^3)
A = 0.25 * pi * D**2       # (m^2)
Iz = pi * D**4 / 64        # (m^4)

############################### DEFINE N                          ###########
Nmax = 11
for i in range(1, Nmax+1):
    op.node(i, (i - 1) * L / (Nmax - 1),

############################### DOF CONST                         ###########
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

##################### ADDITION OF CONCEN                          ###########
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1               # (kg)
op.geomTransf('Linear', transTag)
```

```
op.node(1, 0.0, 0)
op.node(2, 0.15, 0)
op.node(3, 0.3, 0)
op.node(4, 0.45, 0)
op.node(5, 0.6, 0)
op.node(6, 0.75, 0)
op.node(7, 0.9, 0)
op.node(8, 1.05, 0)
op.node(9, 1.2, 0)
op.node(10, 1.35, 0)
op.node(11, 1.5, 0)
```

The node definitions were accomplisched iteratively using a for command. It´s important to note tha this approach is equivalent to defining each node individually, as illustrated in the figure.

Furthermore, it is worth mentioning that, in this 2D model (as specified in the model command), only two coordinates are required for each node.

RESTRAINTS

```
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

########################### PHYSICAL PROPERTIES ##############################
L = 1.5                  # (m)
D = 0.5 * 0.0254         # (m)
m = 40                   # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                # (Pa)
ro = 7850                 # (kg/m^3)
A = 0.25 * pi * D**2      # (m^2)
Iz = pi * D**4 / 64       # (m^4)

############################## DEFINE NODES ##################################
Nmax = 11
for i in range(1, Nmax+1):
     op.node(i, (i - 1) * L / (Nmax - 1), 0)

############################## DOF CONSTRAINTS ###############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS ##########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1              # (kg)
op.geomTransf('Linear', transTag)
```

The fix command is used to impose constraints on a specific node in the model. The syntax for this command is aas follows:

fix(nodeTag, *constrValues)

Where:

- Node tag represents the node's unique identifier, which was defined during node creation.
- *constrValues are Boolean constraint values (0 for free degrees of freedom (dof) and 1 for fixed dof)

In this example, only the initial node (i=1) and the last node (i = Nmax) are restrained. This means that both nodes have fixed displacements in the x and y directions, while allowing free rotation about the z-axis.

LUMPED MASS

```python
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

############################ PHYSICAL PROPERTIES ##############################
L = 1.5                  # (m)
D = 0.5 * 0.0254         # (m)
m = 40                   # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                # (Pa)
ro = 7850                 # (kg/m^3)
A = 0.25 * pi * D**2      # (m^2)
Iz = pi * D**4 / 64       # (m^4)

############################### DEFINE NODES ##################################
Nmax = 11
for i in range(1, Nmax+1):
     op.node(i, (i - 1) * L / (Nmax - 1), 0)

############################### DOF CONSTRAINTS ###############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS ###########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1              # (kg)
op.geomTransf('Linear', transTag)
```

The definition of mass is necessary in this example due to the presence of a concentrater mass at one of the nodes. However, for distributed mass related to the density of the shaft, it will be defined along with the elements, as we will demonstrate later.

The syntax for the mass command is as follow:

mass(nodeTag, *massValues)

Where:

- node Tag refers to the corresponding node ID.
- *massValues are the values of the mass in the respective degree of freedom.

GEOMETRIC TRANSFORMATION

```
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

########################### PHYSICAL PROPERTIES ##############################
L = 1.5                  # (m)
D = 0.5 * 0.0254         # (m)
m = 40                   # (kg)
import math
pi = math.acos(-1.0)
E = 2.1e11                # (Pa)
ro = 7850                 # (kg/m^3)
A = 0.25 * pi * D**2      # (m^2)
Iz = pi * D**4 / 64       # (m^4)

############################### DEFINE NODES #################################
Nmax = 11
for i in range(1, Nmax+1):
     op.node(i, (i - 1) * L / (Nmax - 1), 0)

############################### DOF CONSTRAINTS ##############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS ##########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1              # (kg)
op.geomTransf('Linear', transTag)
```

Since we plan to use a an elastic beam element to model the shaft, a geometric transformation is necessary to convert the local coordinate system to the global coordinate system. The syntax for this commad is as follows:

geoTrasnf(transfType, transTag, *trasnfArgs)

Where:

- transfType represents the type of trasnfoamrtion (Linear, Pdelta or corotational)
- trasnfTag is a unique transformation ID
- transfArgs is a list of arguments for the geometric trasnfromation.

GEOMETRIC TRANSFORMATION

```
import openseespy.opensees as op

op.wipe()
# General model definition (2 simensions and 3 deegrees of freedom)
op.model('Basic', '-ndm', 2, '-ndf', 3)

########################## PHYSICAL PROPERTIES ##############################
L = 1.5                  # (m)
D = 0.5 * 0.0254         # (m)
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A = 0.25 * pi * D**2      # (m^2)
Iz = pi * D**4 / 64       # (m^4)

############################## DEFINE NODES #################################
Nmax = 11
for i in range(1, Nmax+1):
     op.node(i, (i - 1) * L / (Nmax - 1), 0)

############################## DOF CONSTRAINTS ##############################
op.fix(   1, 1, 1, 0)
op.fix(Nmax, 1, 1, 0)

#################### ADDITION OF CONCENTRATION MASS #########################
node_loaded = 8
op.mass(node_loaded, 0.0, m, 0.0)

transTag = 1              # (kg)
op.geomTransf('Linear', transTag)
```

In this example, a linear trasnformation was used. When using the geoTransf command, the general format resembles the following:

geoTransf('Linear', tranfTag, *vecxz, '-jntOffset', *dI, *dJ)

Where:
Vecxz represents the x,y and z components of the vector used to define the local x-z plane of the local coordinate system (applicable to 3D beam element)
dI and dJ are joint offset values (optional in this context but required for 3D models)

ELEMENT DEFINITION

```
############################## DEFINE ELEMENTS #################################
for index in range(1, Nmax):
    op.element('elasticBeamColumn', index, *[index, index+1], A, E, Iz,
               transTag, '-mass', ro*A)
import openseespy.postprocessing.ops_vis as ops
ops.plot_model("nodes")

############################ EIGENVALUES CALCULATION ###########################

lamda = op.eigen('-fullGenLapack', 6)
# op.record()
freq_Ang = []                # (rad/s)
for eigenvalue in lamda:
    freq_Ang.append(eigenvalue**0.5)


# import openseespy.postprocessing.ops_vis as ops
import openseespy.postprocessing.Get_Rendering as ops

ops.plot_modeshape(1, 300)
ops.plot_modeshape(2, 300)
ops.plot_modeshape(3, 300)
ops.plot_modeshape(4, 300)
ops.plot_modeshape(5, 300)
```

The preceding steps were essential to define the element. In this example, we have defined elastic BeamColumn elements. However, it's worth noting that the list of elements can vary and include zero-length, truss, joint, link elements, and more.

The syntax for the used for the elasticBeamColumn is described as follow:

Element('elasticBeamColumn', eleTag, *eleNodes, Area, E_mod, Iz, transfTag, <'-mass', mass>, <'-cMass'>, <'-release', releaseCode>)

Where:

- eleTag refers to the element ID
- *eleNodes are the two nodes that define the element

ELEMENT DEFINITION

```
############################## DEFINE ELEMENTS #################################
for index in range(1, Nmax):
    op.element('elasticBeamColumn', index, *[index, index+1], A, E, Iz,
               transTag, '-mass', ro*A)
import openseespy.postprocessing.ops_vis as ops
ops.plot_model("nodes")

############################ EIGENVALUES CALCULATION ###########################

lamda = op.eigen('-fullGenLapack', 6)
# op.record()
freq_Ang = []                # (rad/s)
for eigenvalue in lamda:
    freq_Ang.append(eigenvalue**0.5)


# import openseespy.postprocessing.ops_vis as ops
import openseespy.postprocessing.Get_Rendering as ops

ops.plot_modeshape(1, 300)
ops.plot_modeshape(2, 300)
ops.plot_modeshape(3, 300)
ops.plot_modeshape(4, 300)
ops.plot_modeshape(5, 300)
```

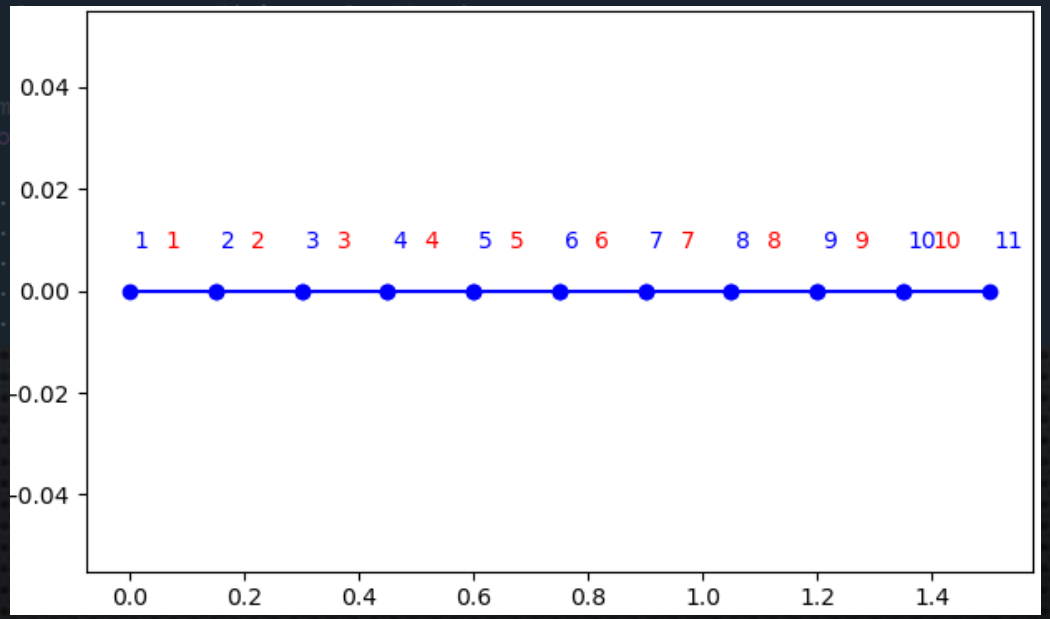
- Area, E_mod and Iz are the cross sectional area, Young's modulus and second moment of Inertia, respectivetly.
- transfTag is the transformation tag
- '-mass' is the identifier for the mass per unit length
- mass is the value of the mass per unit length
- Release is an optional value that represent the release conditions.

NODES & ELEMENTS VISUALIZATION

```
############################## DEFINE ELEMENTS ##################################
for index in range(1, Nmax):
    op.element('elasticBeamColumn', index, *[index, index+1], A, E, Iz,
               transTag,'-mass', ro*A)
import openseespy.postprocessing.ops_vis as ops
ops.plot_model("nodes")

########################### EIGENVALUES CALCULATION ###########################

lamda = op.eigen('-fullGenLapack', 6)
# op.record()
freq_Ang = []                # (rad/s)
for eigenvalue in lamda:
```



Now that we have already defined the elements and nodes in the model, it might be valuable to obtain a graphical representation to confirm whether the intended model definition was achieved as intended.

To achieve this, we can import the openseespostprocessing library. Then, we can use the plot_model() command to generate a graphical representation of the model.

EIGENVALUES CALCULATION

```
############################ DEFINE ELEMENTS #################################
for index in range(1, Nmax):
    op.element('elasticBeamColumn', index, *[index, index+1], A, E, Iz,
               transTag,'-mass', ro*A)
import openseespy.postprocessing.ops_vis as ops
ops.plot_model("nodes")

########################### EIGENVALUES CALCULATION ##########################

lamda = op.eigen('-fullGenLapack', 6)
# op.record()
freq_Ang = []                # (rad/s)
for eigenvalue in lamda:
    freq_Ang.append(eigenvalue**0.5)


# import openseespy.postprocessing.ops_vis as ops
import openseespy.postprocessing.Get_Rendering as ops

ops.plot_modeshape(1, 300)
ops.plot_modeshape(2, 300)
ops.plot_modeshape(3, 300)
ops.plot_modeshape(4, 300)
ops.plot_modeshape(5, 300)
```

After the elements are properly defined, we proceed to calculate the eigenvalues using the eigen command. This command, in a general form, is represented as follow:

eigen(solver, numEigenValues)

Where:

- solver is the type of solver to use (optional parameter), with two available types (‘-genBandArpack’ and ‘-fullGenLapack’)
- numEigenValues is the number of eigenvalues to calculate.

EIGENVALUES CALCULATION

```
############################ DEFINE ELEMENTS #################################
for index in range(1, Nmax):
    op.element('elasticBeamColumn', index, *[index, index+1], A, E, Iz,
               transTag,'-mass', ro*A)
import openseespy.postprocessing.ops_vis as ops
ops.plot_model("nodes")

########################### EIGENVALUES CALCULATION ##########################

lamda = op.eigen('-fullGenLapack', 6)
# op.record()
freq_Ang = []                # (rad/s)
for eigenvalue in lamda:
    freq_Ang.append(eigenvalue**0.5)


# import openseespy.postprocessing.ops_vis as ops
import openseespy.postprocessing.Get_Rendering as ops

ops.plot_modeshape(1, 300)
ops.plot_modeshape(2, 300)
ops.plot_modeshape(3, 300)
ops.plot_modeshape(4, 300)
ops.plot_modeshape(5, 300)
```

In the final step, once we have obtained the eigenvalues, we proceed to calculate the angular frequencies.

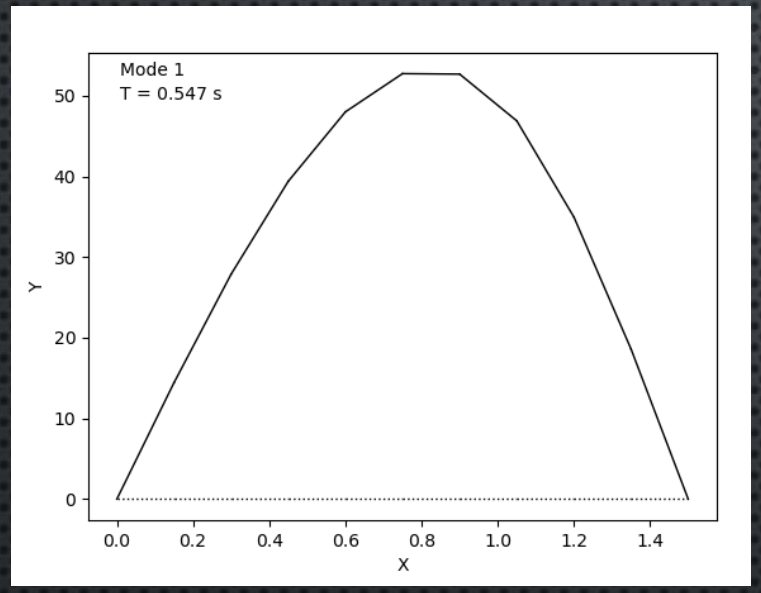
For visualizing the eigenmode, we once again import openseespy.postprocessing. In this case, we utilize the plot_modeshape command with the following syntax:

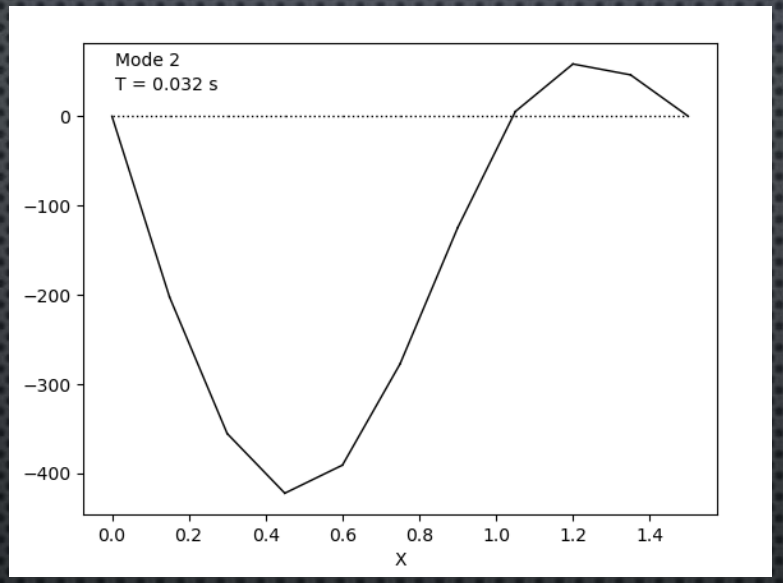
plot_modeshape(modeNumber, <scale>, <Model="modeName">)

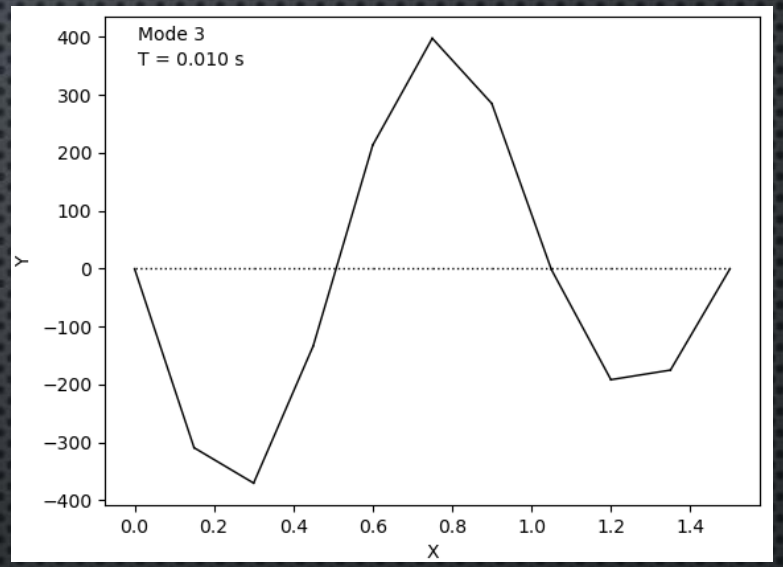
Where:

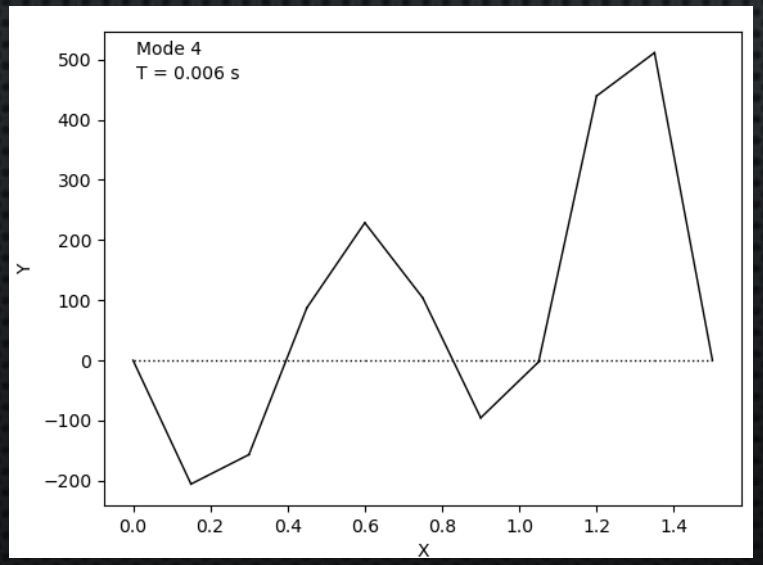
- modeNumber corresponds to the mode number you want to visualize.
- <scale> (optional) can be used to adjust the scale of the visualization.
- <Model="modeName">' (optional) specifies the

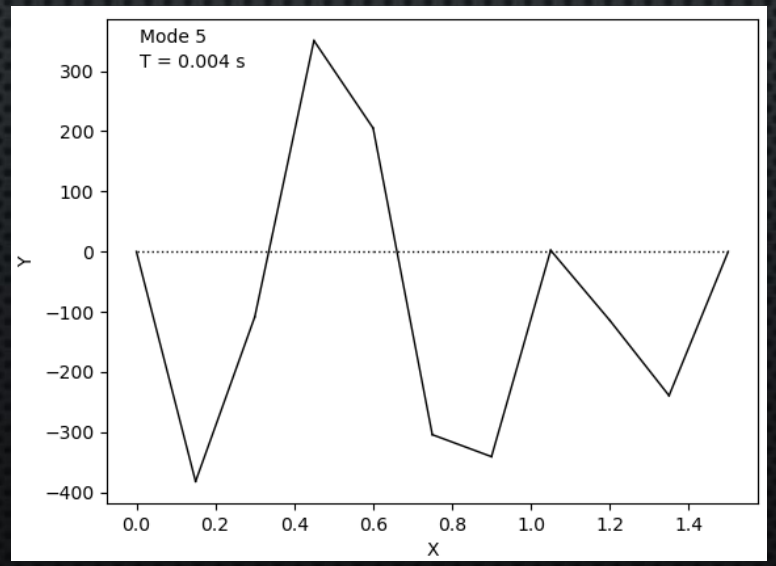
EIGENMODES VISUALIZATION

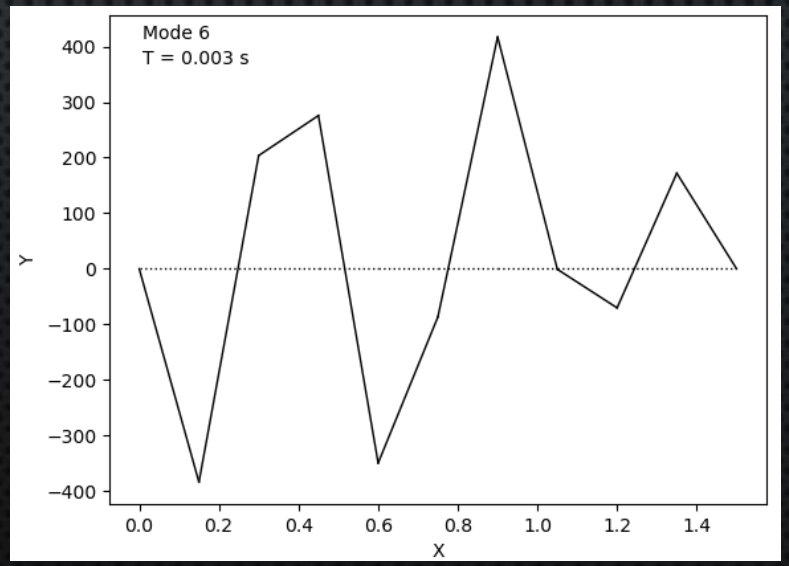












REFERENCES

For more detailed information about these commands, you can refer to the official documentation at:

https://openseespydoc.readthedocs.io/en/latest/index.html