UNIVERSITAT POLITÈCNICA DE CATALUNYA, BARCELONA

MSC. COMPUTATIONAL MECHANICS ERASMUS MUNDUS

GID ASSIGNMENT 5

Computational Structural Mechanics & Dynamics

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Exercise 1: Plane frame

Calculate the natural frequencies and modes of the plane frame in the figure. Perform a modal analysis and direct integration. Use a dynamic load frequency with the values $\omega_p = 0.75\omega_1$, $1.0\omega_1$ and $1.25\omega_1$, where ω_1 is the principal natural frequency.

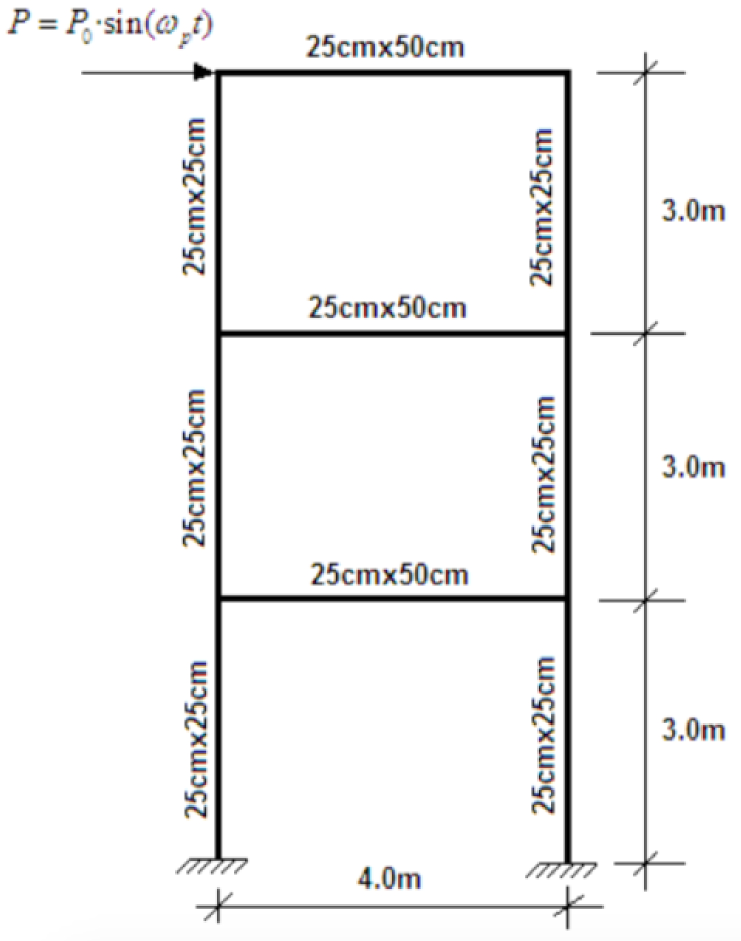


Figure 1: Plane Frame

Solution:

1.1. Purpose of the exercise

The objective of this exercise is perform a modal analysis of the frame. Firstly, we will find the natural frequencies and modes of the plane frame. This is followed by analysing the frame with application of a point sinusoidal load to understand its behaviour.

1.2 Free vibrations: Natural frequencies

1.2.1 Pre-processing

(i) Geometry

The first step of pre-processing is to model the geometry as per the given dimensions in Ram-Series as shown in Figure 2.

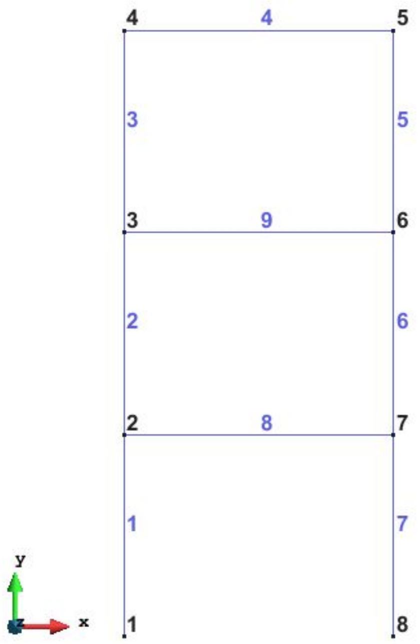


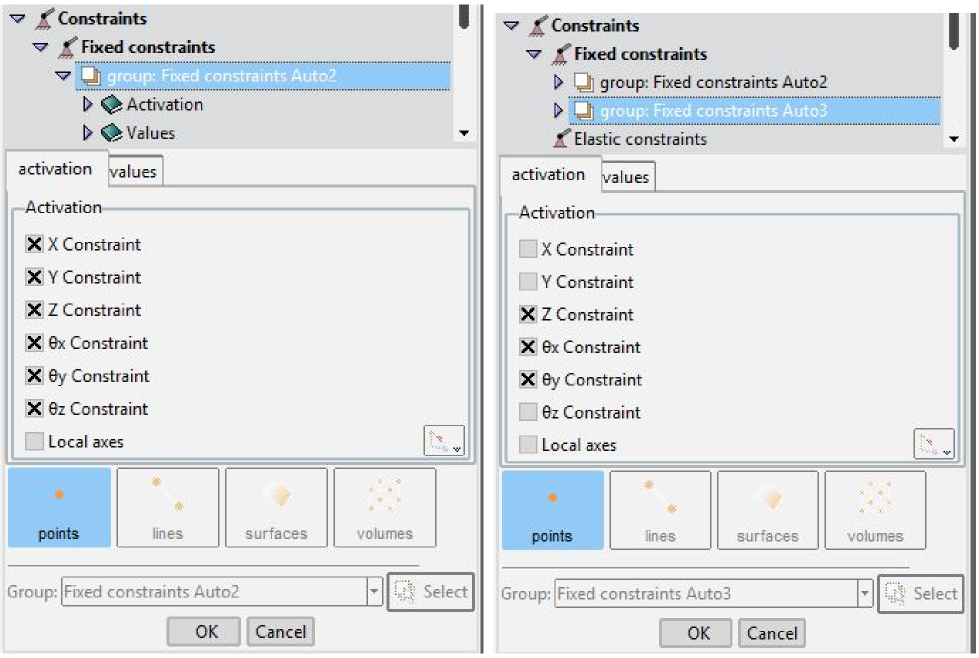
Figure 2: Defining the geometry

(ii) Data

Once the geometry is defined, we apply the given data to the model.

Boundary Conditions

Next, we define the boundary conditions as shown in Figures 3 and 4. The bottom nodes of the frame are fixed in all dofs while the other nodes cannot have a movement in the z-direction or rotation along x or y-axis. This is the usual condition to solve a plane state problem.



(a) (b)

Figure 3: Boundary conditions - fixed constraint

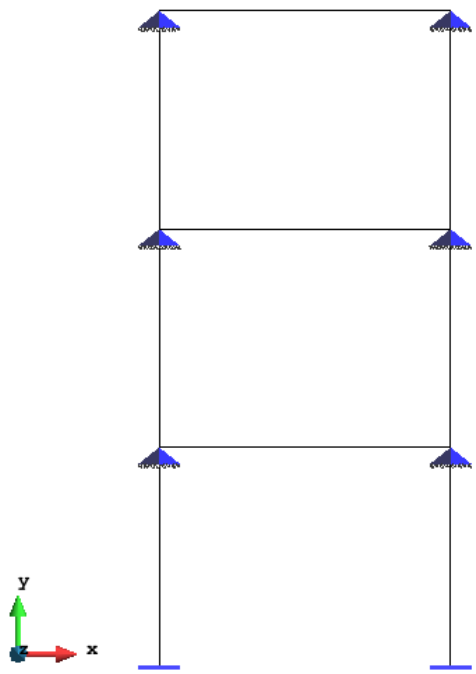
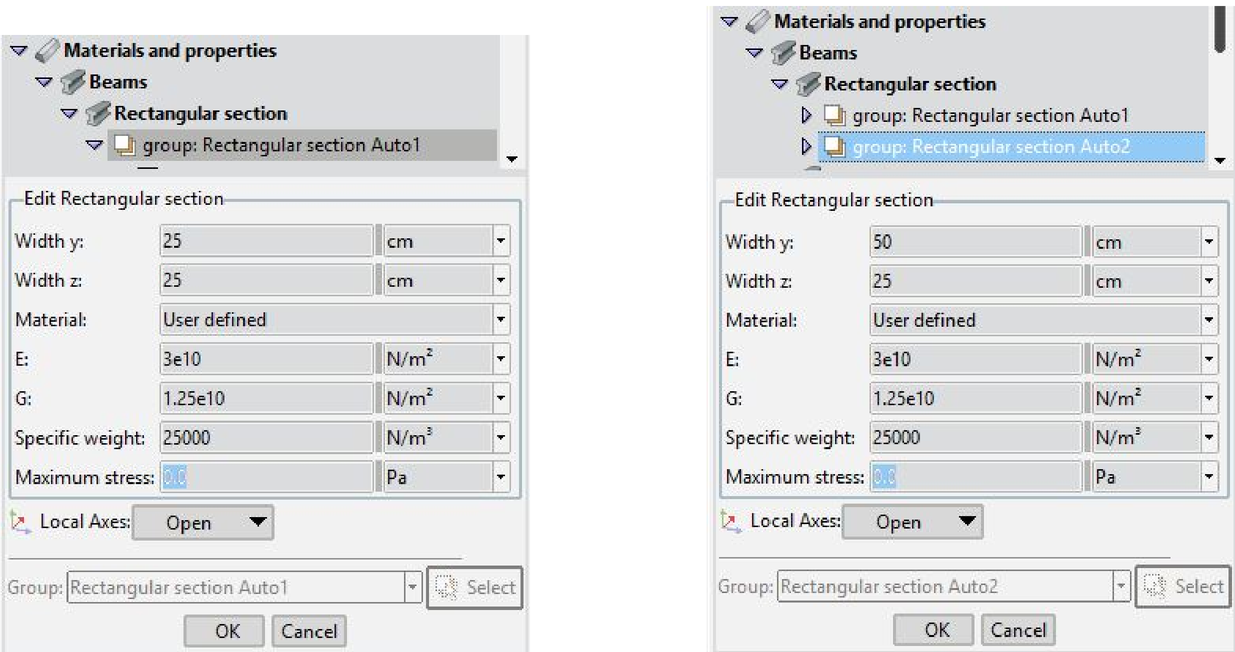


Figure 4: Boundary conditions - fixed constraint applied

Material

The material properties of the structure are defined with the given parameters as shown in Figure 5. For the thickness of the beams, we assign different width parameters for the vertical and horizontal rectangular sections as shown in the Figures 5(a), 5(b) and 6, respectively.



(a) Vertical rectangular sections

(b) Horizontal rectangular sections

Figure 5: Material properties defined

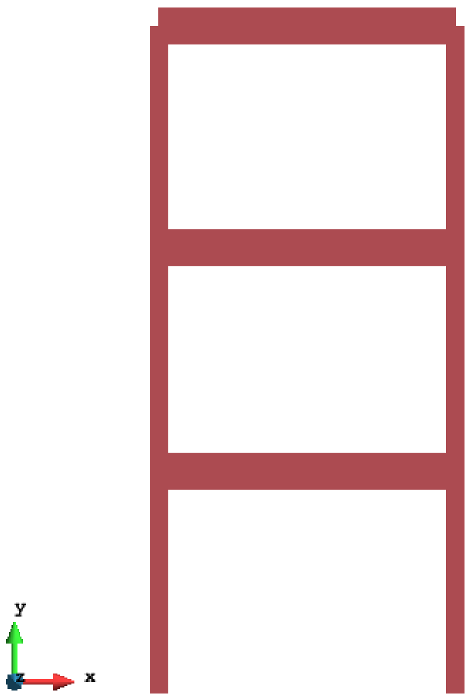
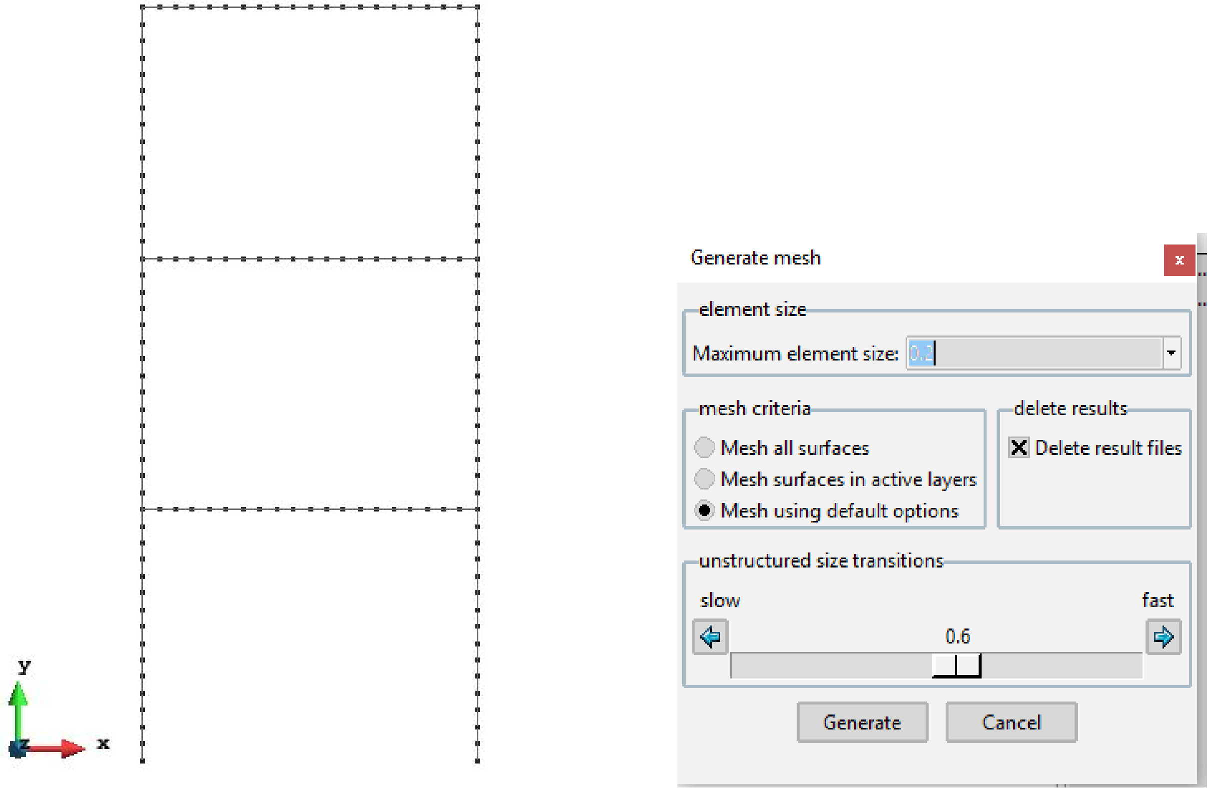


Figure 6: Material properties applied

Mesh

In this problem, we consider a mesh of line elements as shown in Figure 7.



(a) (b)

Figure 7: Mesh generated

Problem type

For the given problem we use Dynamic Analysis as the analysis type in Ramseries Structural analysis. To choose the analysis data, we use two specific data specific to the problem we are solving. As discussed earlier, first we obtain the natural frequencies and modes of plane frame and later analyse the dynamic response under the influence of a sinusoidal point load. For the first part of this exercise to find the natural frequencies of the problem, we select the modal analysis data 'Only calculate natural freqs: 1' as shown in Figure 8.

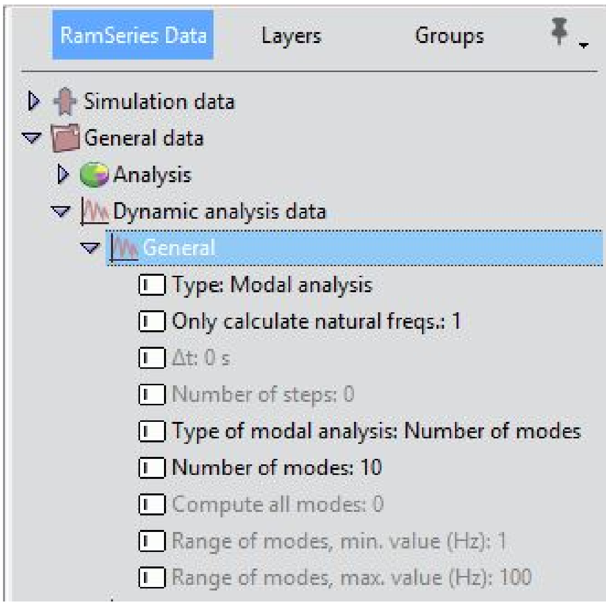


Figure 8: Modal analysis data: Free vibrations case

1.2.2 Post-processing: Free vibrations

In this section, we show the solution of the free vibrations case in Figure 9. The first six modes of vibration of the frame are shown in Figures 10-15.

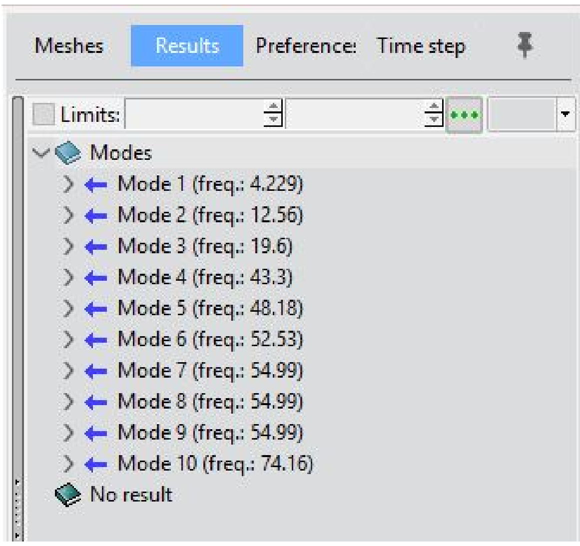


Figure 9: Result: first ten modes of vibration with natural frequencies

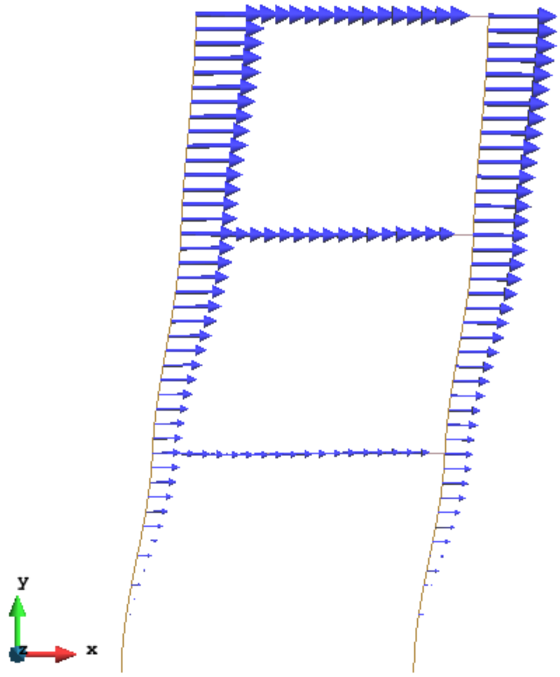


Figure 10: Result: Mode 1 of vibration with natural frequency of 4.229

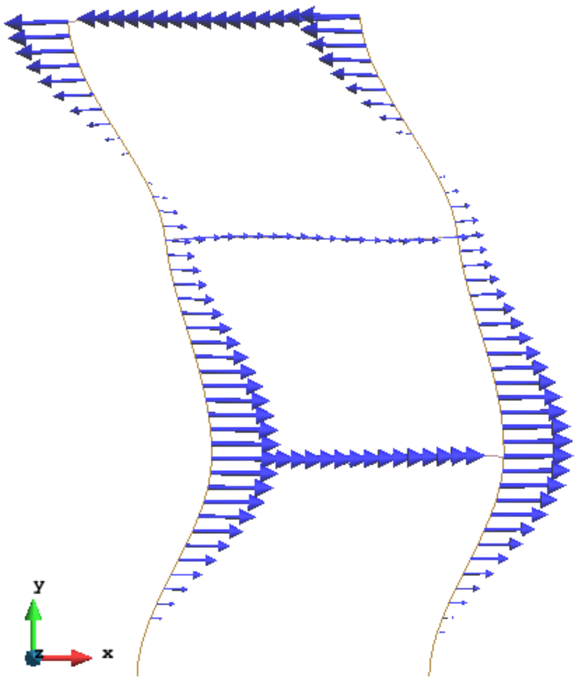


Figure 11: Result: Mode 2 of vibration with natural frequency of 12.56

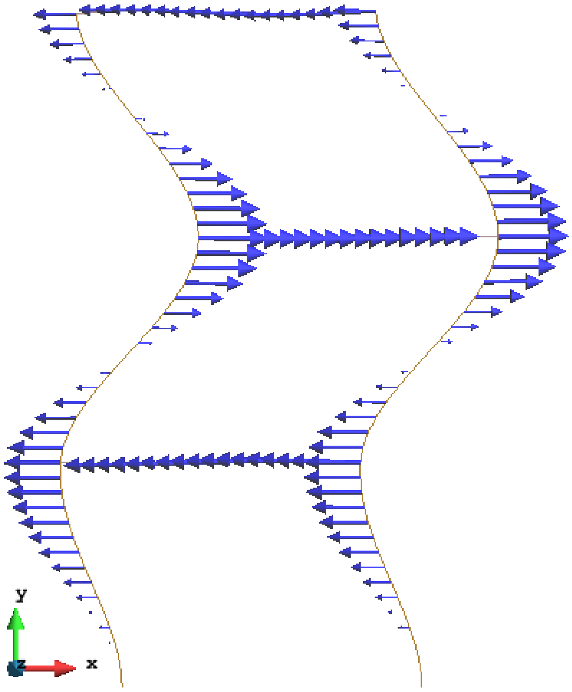


Figure 12: Result: Mode 3 of vibration with natural frequency of 19.6

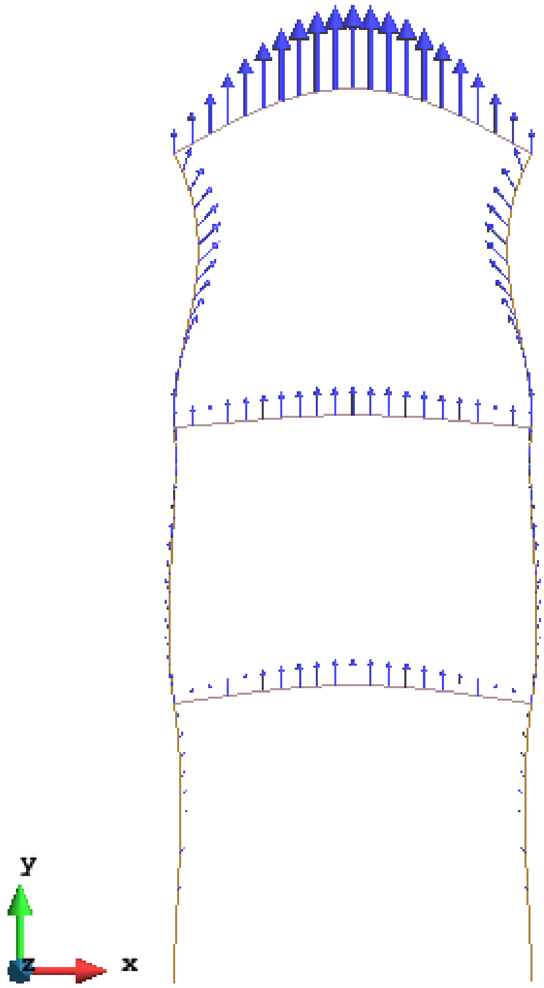


Figure 13: Result: Mode 4 of vibration with natural frequency of 43.3

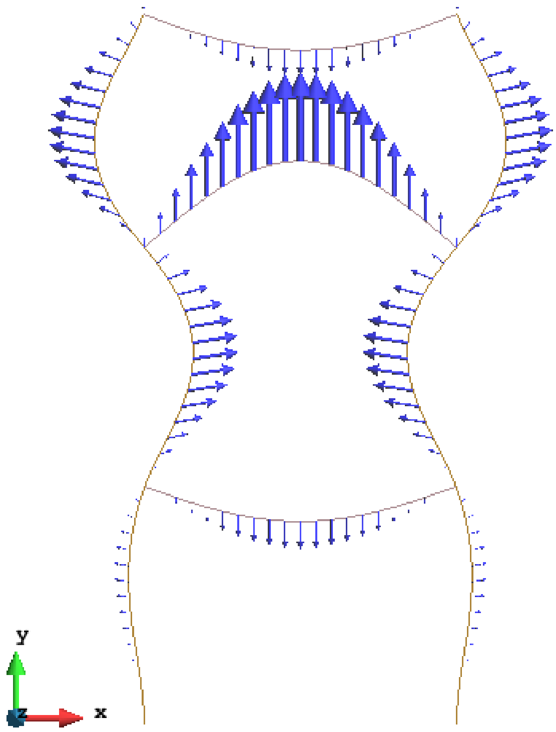


Figure 14: Result: Mode 5 of vibration with natural frequency of 48.18

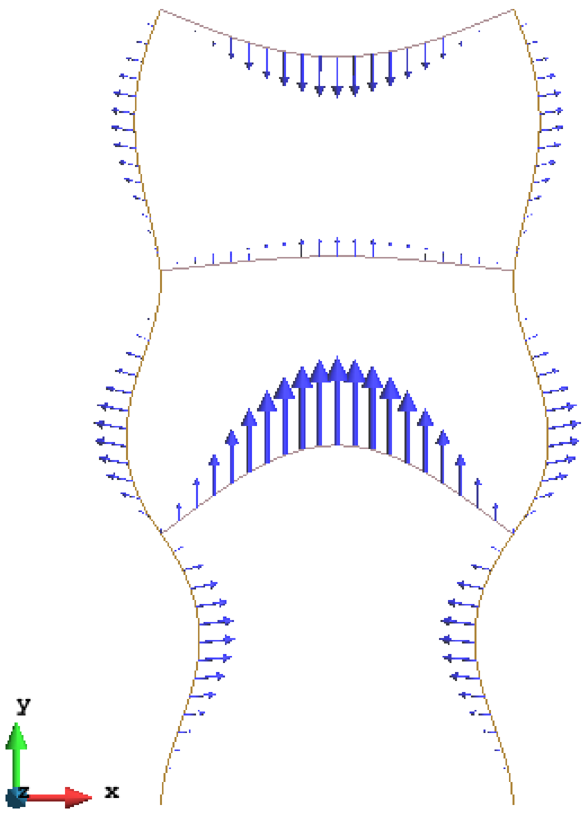


Figure 15: Result: Mode 6 of vibration with natural frequency of 52.53

1.3 Dynamic response under point load

Problem type

For the second part of this exercise to analyse the behaviour of the frame under point sinusoidal load, we select the modal analysis data 'Only calculate natural freqs: 0'. Also, we know that all modes shown in the previous section are not required in complete dynamic analysis. The dynamic system is defined with the condition,

$$\omega_p^{max} > \frac{1}{4}\,\omega_0$$

where, we consider $\omega_p^{max} = 1.25\ \omega_1$ and ω_1 is the frequency (corresponding to mode 1) found in the last section. Computing this we get $\omega_p^{max} = 5.28625$ and therefore, $\omega_0 < 21.145$. It is interesting to note that this condition is only satisfied by the first three modes presented above. Therefore, we need to study these modes for analysing the dynamic response under point load.

To perform this dynamic analysis, we need to specify the time step and total simulation time. Considering a total time $t = 1\ s$, we need to define a small time step to capture the oscillations but avoid unnecessary computation time. We use the highest frequency (corresponding to mode 3) satisfying the dynamic condition in our analysis of $\omega_0 = 19.6$. Therefore, we get,

$$\Delta t = \frac{T}{20} = \frac{1}{20\ \omega_0} = 2.55e - 3\ s$$

and

$$\text{Number of steps} = \frac{t}{\Delta t} = \frac{1}{2.55e - 3} = 392\ \text{steps}$$

We specify these data in the general dynamic analysis data as shown in Figure 16.

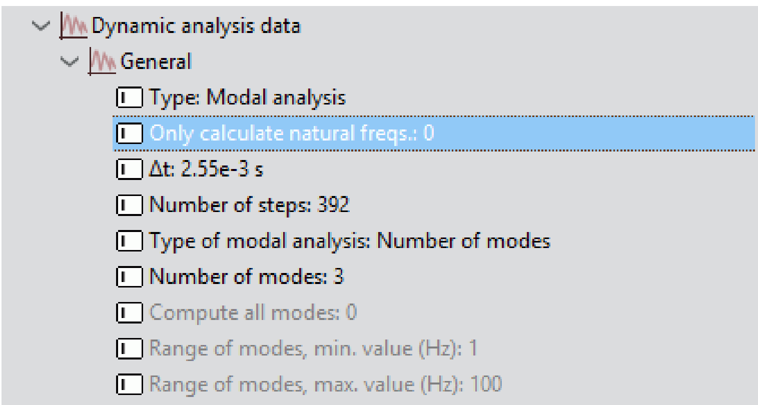


Figure 16: Modal analysis data: Dynamic analysis case

Define load

We define a sinusoidal load for the dynamic analysis at the top-left node (node 4) of the frame as given in the problem. We specify the required parameters as shown in Figure 17 with varying frequency field for simulating different cases i.e $\omega_p = 0.75\omega_1$, $1.0\omega_1$ and $1.25\omega_1$. Next, we define the value of the load given in the x-direction as shown in Figure 18.

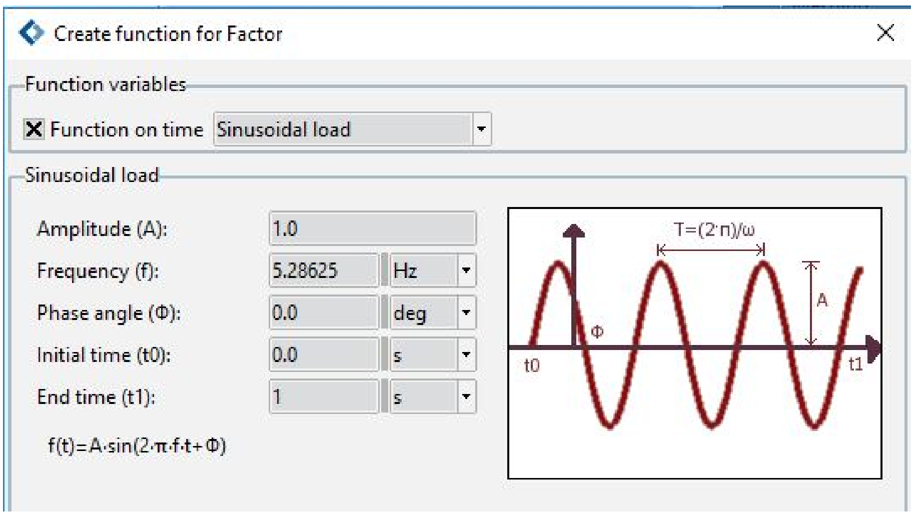
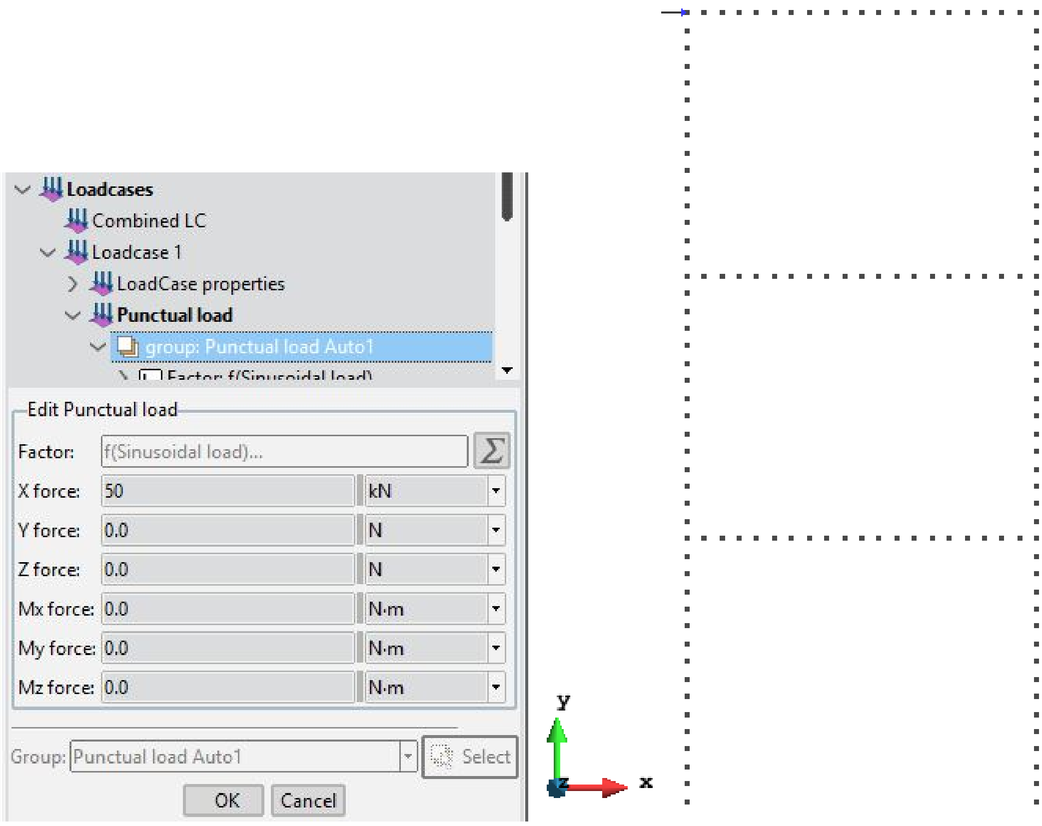


Figure 17: Define sinusoidal load for dynamic analysis



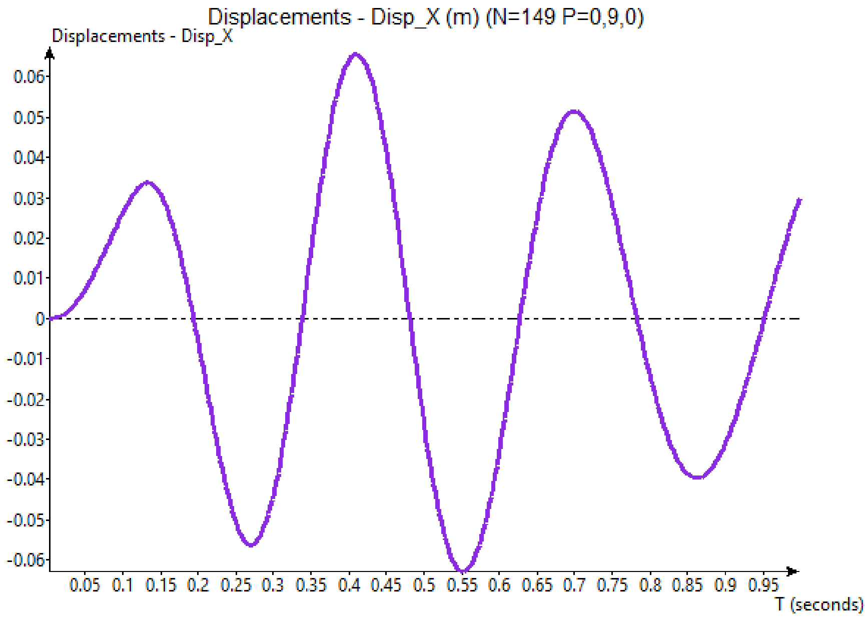
(a) (b)

Figure 18: Define the point load at top-left node (node 4) of the frame

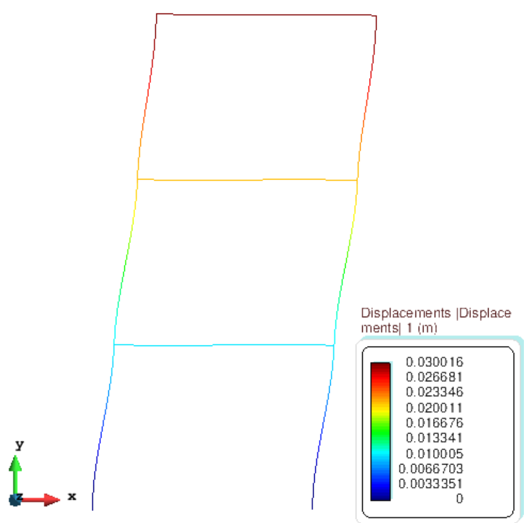
1.3.1 Post-processing: Dynamic response

The following figures present the post-processed results for the dynamic analysis by showing the horizontal displacement vs time plots of the left-top node (node 4, where the load was applied) and the deformation at total time as a representation.

Firstly, considering $\omega_p = 0.75\omega_1$, we have the results shown in Figure 19. The sinusoidal behaviour of the load applied is clearly seen in the results obtained. As the frequency is not equal to the natural frequency of the structure, the displacements seem to be within an acceptable range. This is an expected results since the load frequency is not close enough to the natural frequency of the structure.



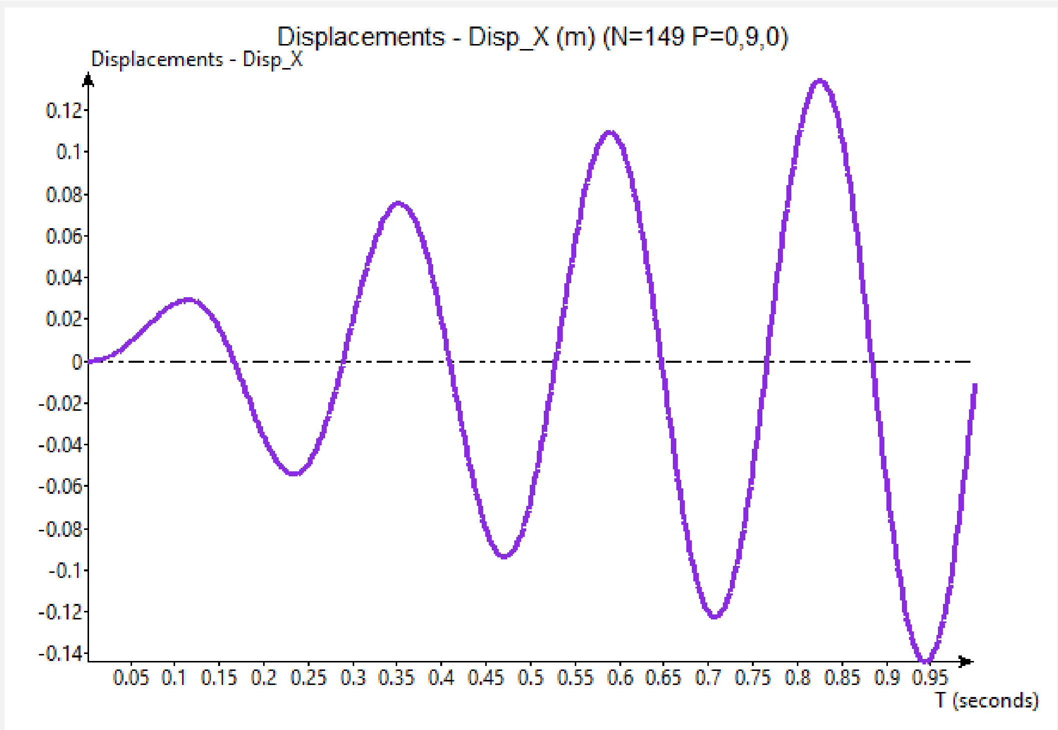
(a)



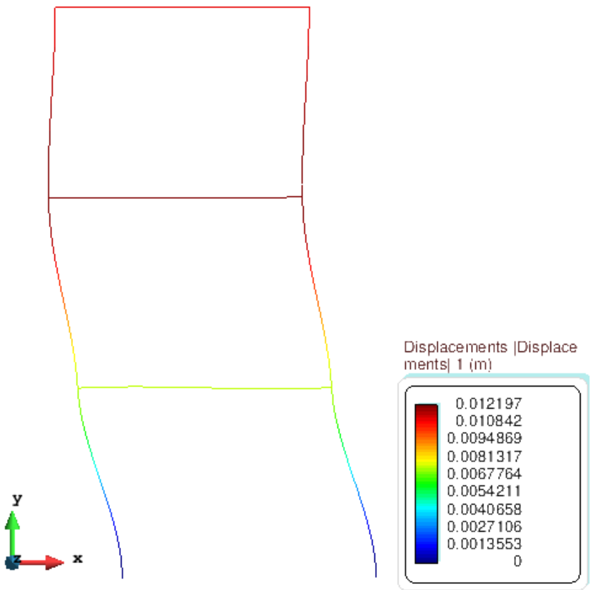
(b)

Figure 19: Result: Horizontal displacement vs. time plot and deformed surface at total time for ω_p = 0.75 ω_1 = 3.17175

Next, we consider the case of $\omega_p = \omega_1$, which is an interesting case to analyse since the load frequency is exactly equal to the natural frequency of the structure. It is expected that the displacement in this case would drastically increase without control due to resonance. In the resonance phenomenon, the external force drives the structure to oscillate with greater amplitude and could potentially lead to failure. This effect is clearly seen in the results obtained as shown in Figure 20.



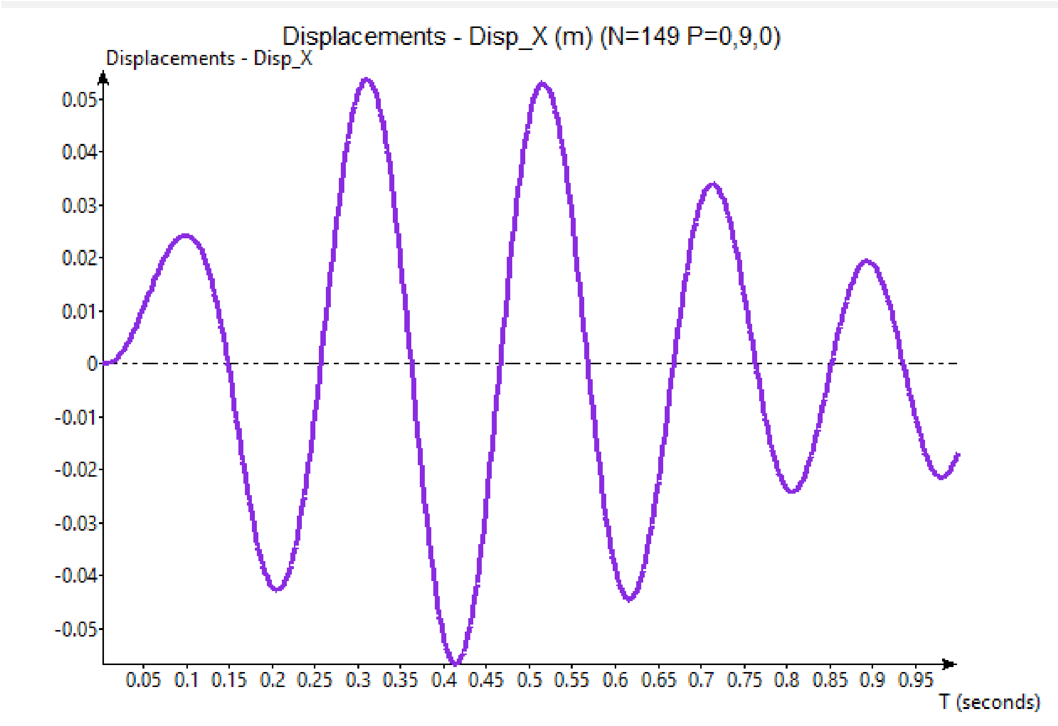
(a)



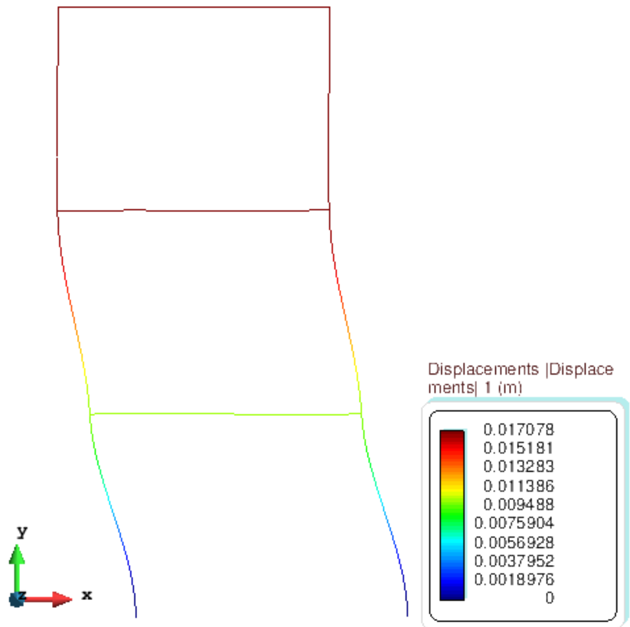
(b)

Figure 20: Result: Horizontal displacement vs. time plot and deformed surface at total time for $\omega_p = \omega_1 = 4.229$

Finally, we analyse the case with $\omega_p = 1.25\omega_1$. The oscillations in this case are not expected to increase drastically since the load frequency is not close to the natural frequency of the structure. As seen in Figure 21, the results show the expected behaviour and the oscillations are damped with time.



(a)



(b)

Figure 21: Result: Horizontal displacement vs. time plot and deformed surface at total time for $\omega_p = 1.25\ \omega_1 = 5.28625$

Exercise 2: Spatial shell

Calculate the natural frequencies and modes of the spatial shell in the figure. Perform a modal analysis and direct integration. Use a dynamic load frequency with the values $\omega_p = 0.75\omega_1$, $1.0\omega_1$ and $1.25\omega_1$, where ω_1 is the principal natural frequency.

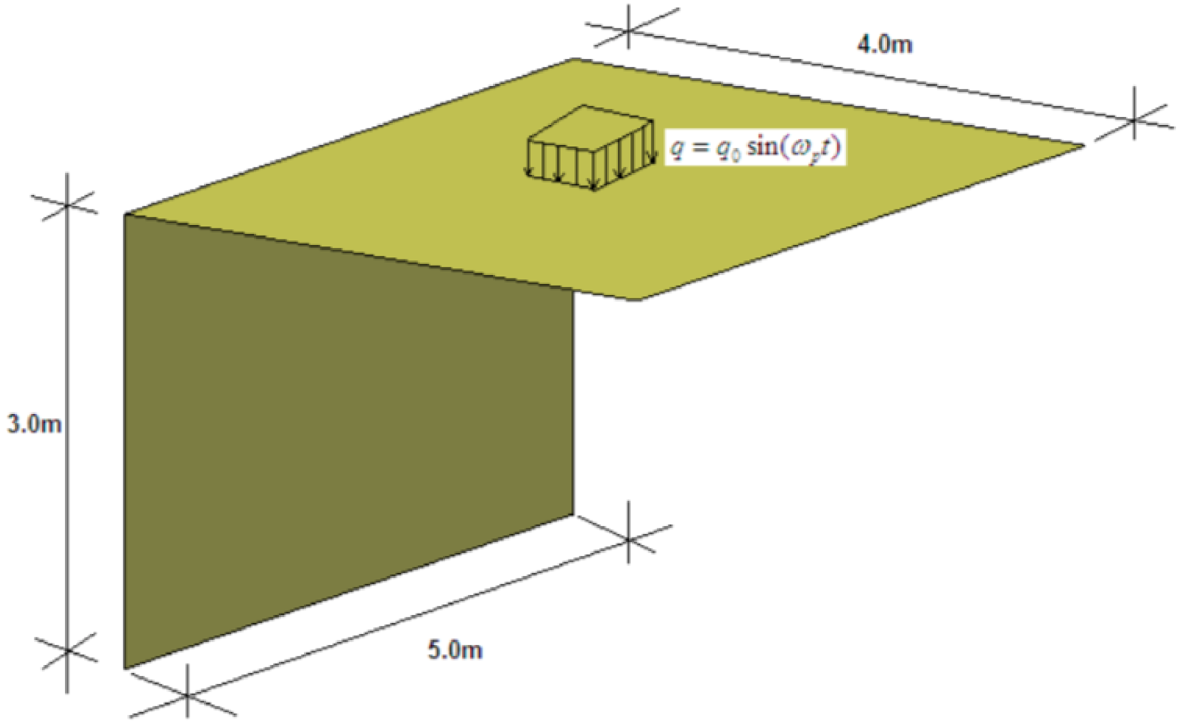


Figure 22: Spatial shell

Solution:

2.1. Purpose of the exercise

The objective of this exercise is perform a modal analysis of the shell. Firstly, we will find the natural frequencies and modes of the shell structure. This is followed by analysing the shell with application of a distributed sinusoidal force to understand its behaviour.

2.2 Free vibrations: Natural frequencies

2.2.1 Pre-processing

(i) Geometry

The first step of pre-processing is to model the geometry as per the given dimensions in Ram-Series as shown in Figure 23.

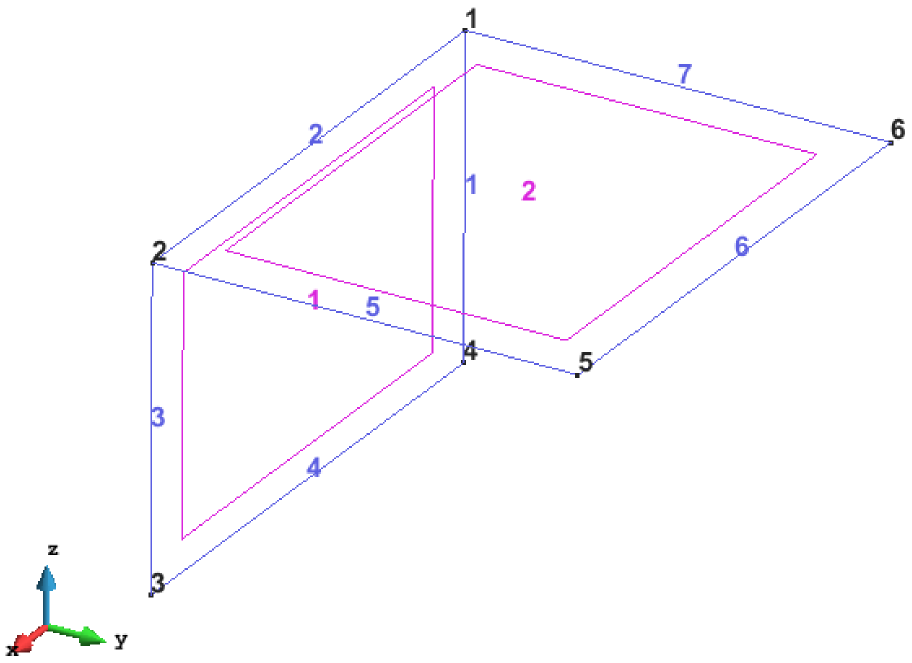


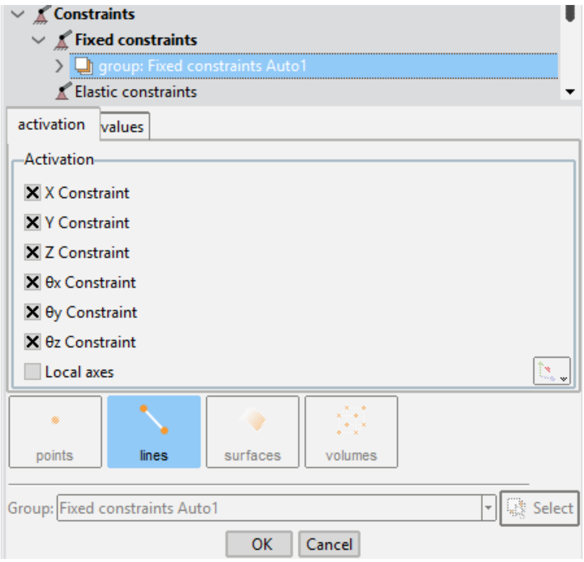
Figure 23: Defining the geometry

(ii) Data

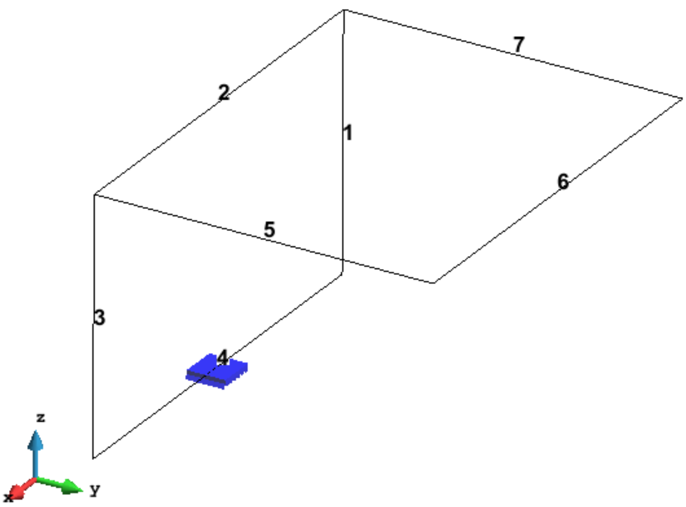
Once the geometry is defined, we apply the given data to the model.

Boundary Conditions

Next, we define the boundary conditions with the bottom line of the shell (line 4) is fixed in all dofs as shown in Figure 24.



(a)

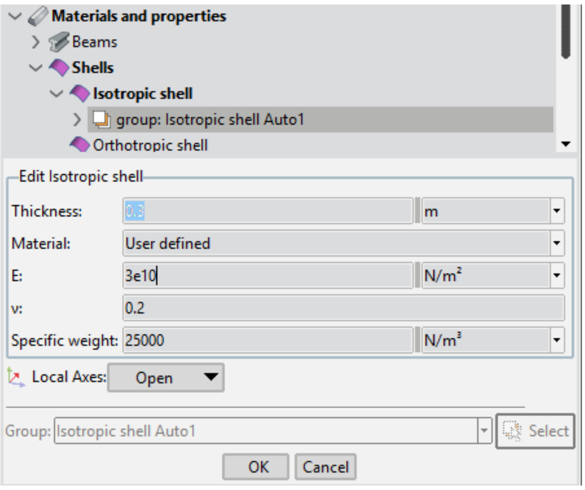


(b)

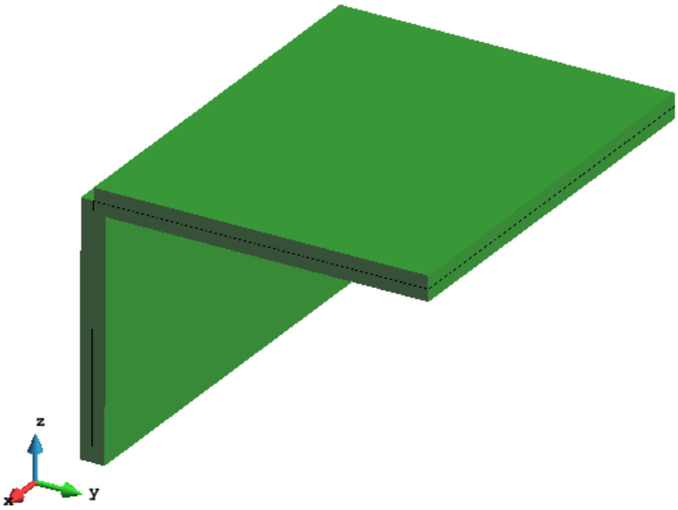
Figure 24: Boundary conditions - fixed constraint

Material

The material properties of the shell structure are defined with the given parameters as shown in Figure 25. For the thickness of the structure, we select an isotropic shell in order to define a thickness of 0.3 m.



(a)

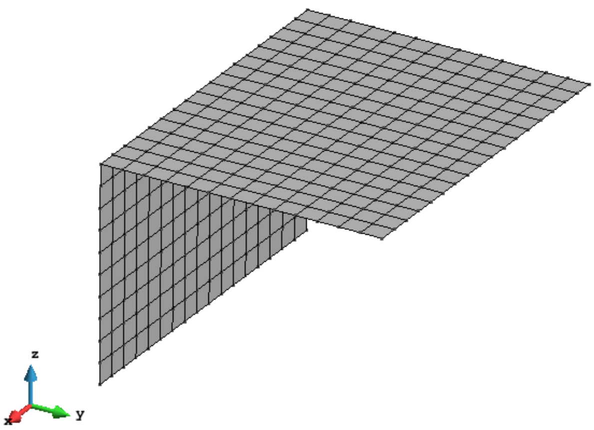


(b)

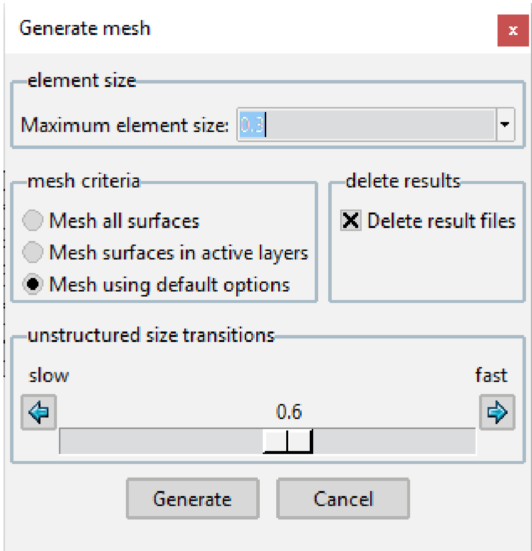
Figure 25: Material properties defined

Mesh

In this problem, we consider a structured mesh of linear quadrilateral elements as shown in Figure 26.



(a)



(b)

Figure 26: Mesh generated

Problem type

For the given problem we use Dynamic Analysis as the analysis type in Ramseries Structural analysis. To choose the analysis data, we use two specific data specific to the problem we are solving. As discussed earlier, first we obtain the natural frequencies and modes of shell structure and later analyse the dynamic response under the influence of a sinusoidal distributed load. For the first part of this exercise to find the natural frequencies of the problem, we select the modal analysis data 'Only calculate natural freqs: 1' as shown in Figure 27.

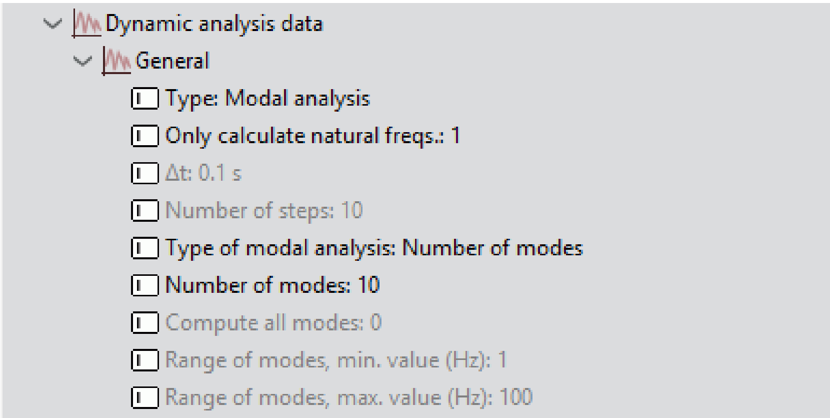


Figure 27: Modal analysis data: Free vibrations case

2.2.2 Post-processing: Free vibrations

In this section, we show the solution of the free vibrations case in Figure 28. The first six modes of vibration of the shell are shown in Figures 29-34.

Figure 28: Result: first ten modes of vibration with natural frequencies

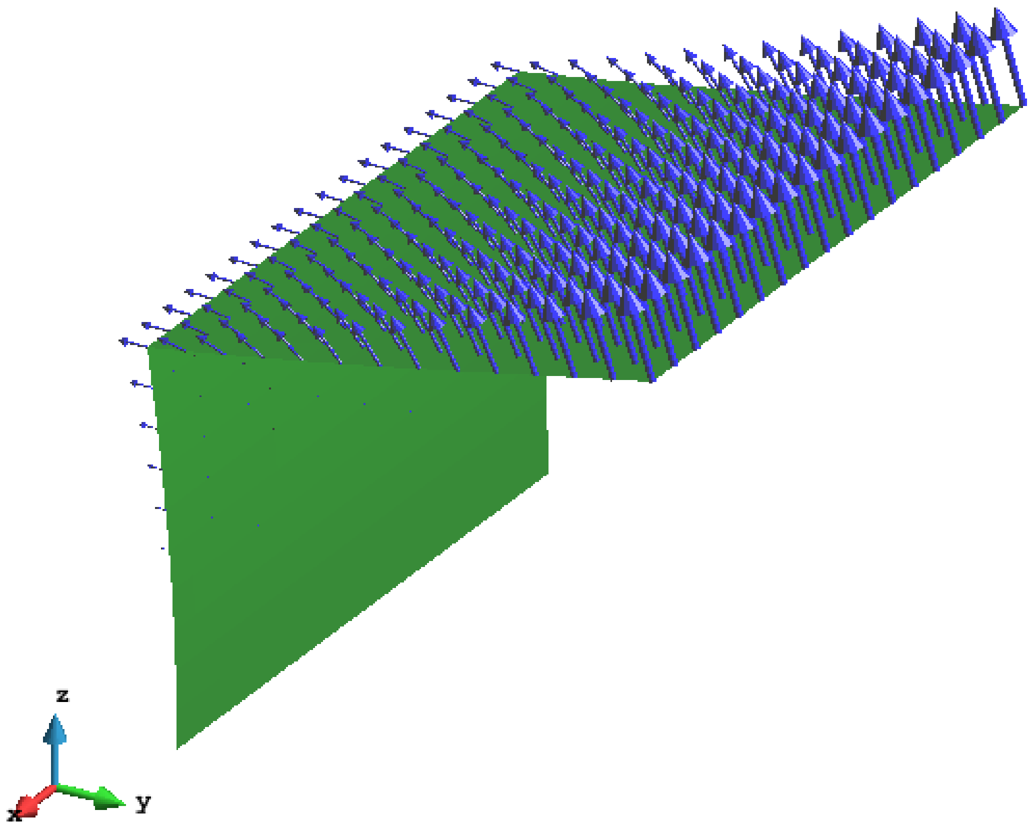


Figure 29: Result: Mode 1 of vibration with natural frequency of 4.52

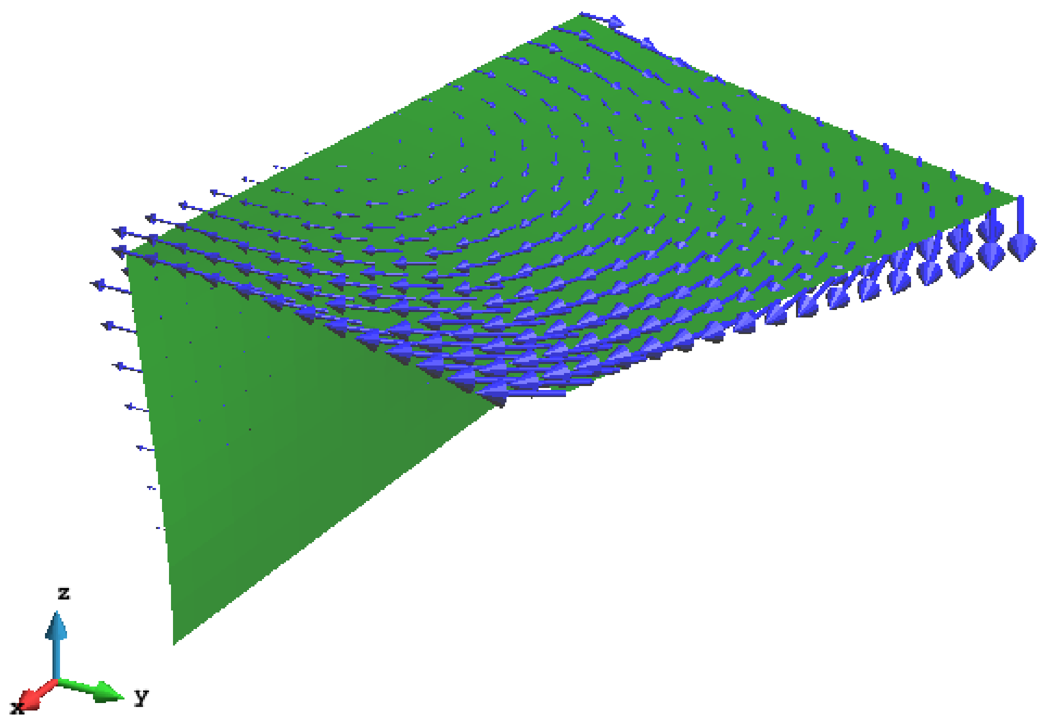


Figure 30: Result: Mode 2 of vibration with natural frequency of 8.62

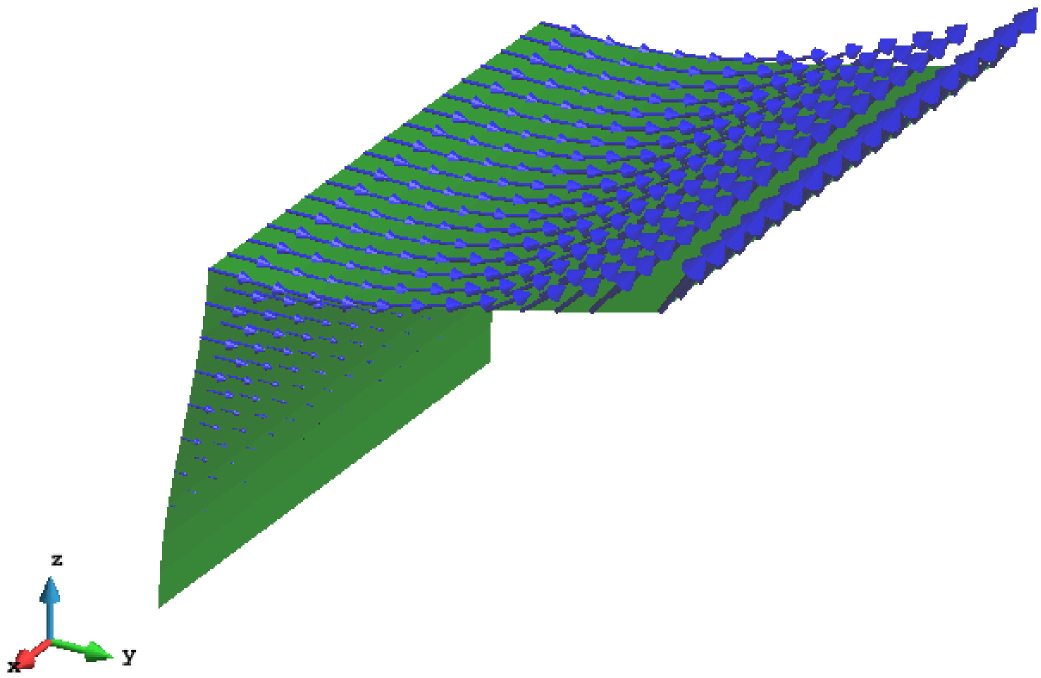


Figure 31: Result: Mode 3 of vibration with natural frequency of 12.57

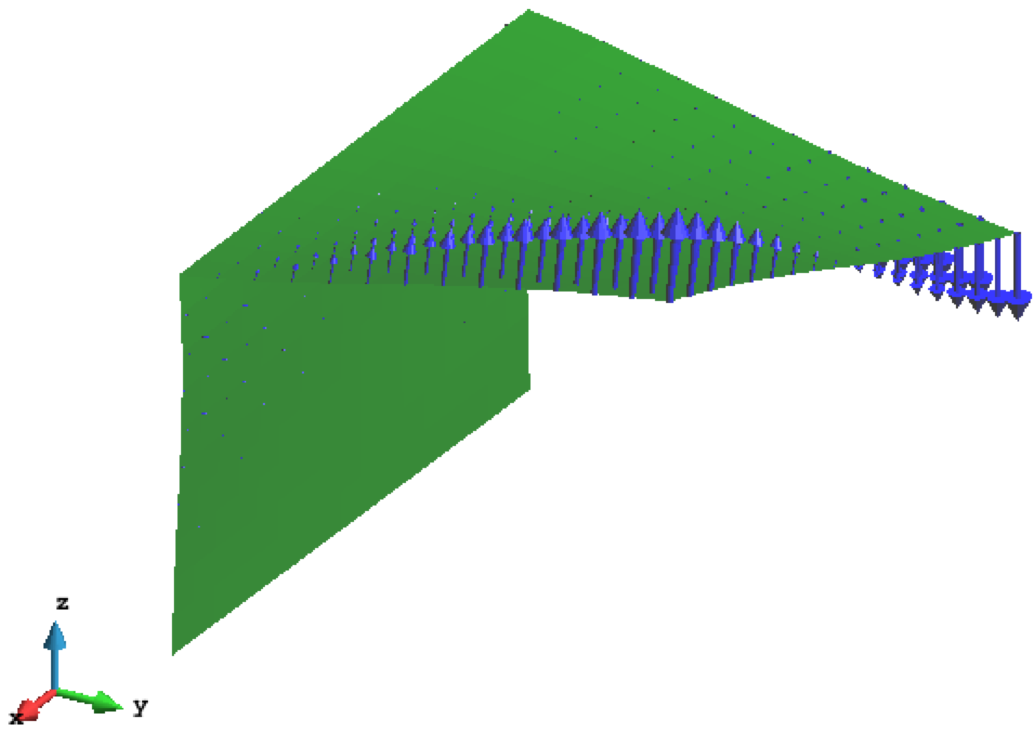


Figure 32: Result: Mode 4 of vibration with natural frequency of 19.8

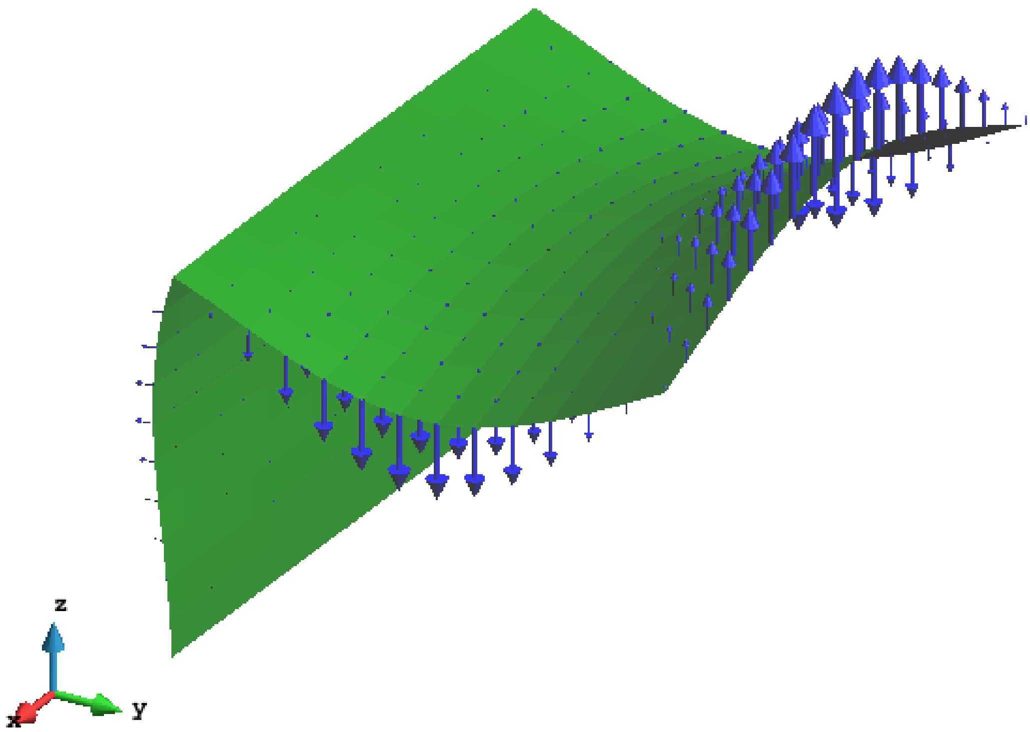


Figure 33: Result: Mode 5 of vibration with natural frequency of 51.06

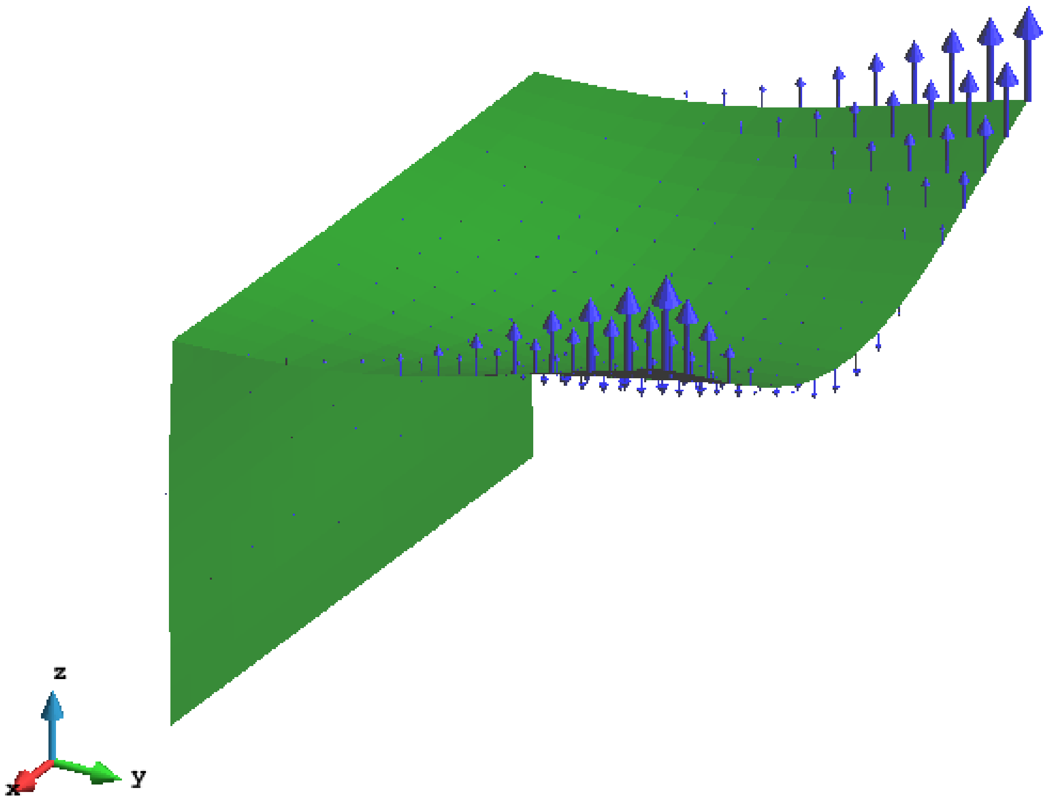


Figure 34: Result: Mode 6 of vibration with natural frequency of 56.34

2.3 Dynamic response under point load

Problem type

For the second part of this exercise to analyse the behaviour of the shell under distributed sinusoidal load, we select the modal analysis data 'Only calculate natural freqs: 0'. Also, we know that all modes shown in the previous section are not required in complete dynamic analysis. The dynamic system is defined with the condition,

$$\omega_p^{max} > \frac{1}{4}\,\omega_0$$

where, we consider $\omega_p^{max} = 1.25\,\omega_1$ and ω_1 is the frequency (corresponding to mode 1) found in the last section. Computing this we get $\omega_p^{max} = 5.65$ and therefore, $\omega_0 < 22.6$. It is interesting to note that this condition is only satisfied by the first four modes presented above. Therefore, we need to study these modes for analysing the dynamic response under distributed load.

To perform this dynamic analysis, we need to specify the time step and total simulation time. Considering a total time $t = 1\ s$, we need to define a small time step to capture the oscillations but avoid unnecessary computation time. We use the highest frequency (corresponding to mode 4) satisfying the dynamic condition in our analysis of $\omega_0 = 19.8$. Therefore, we get,

$$\Delta t = \frac{T}{20} = \frac{1}{20\,\omega_0} = 2.53e-3\ s$$

and

$$\text{Number of steps} = \frac{t}{\Delta t} = \frac{1}{2.53e-3} = 396 \text{ steps}$$

We specify these data in the general dynamic analysis data as shown in Figure 35.

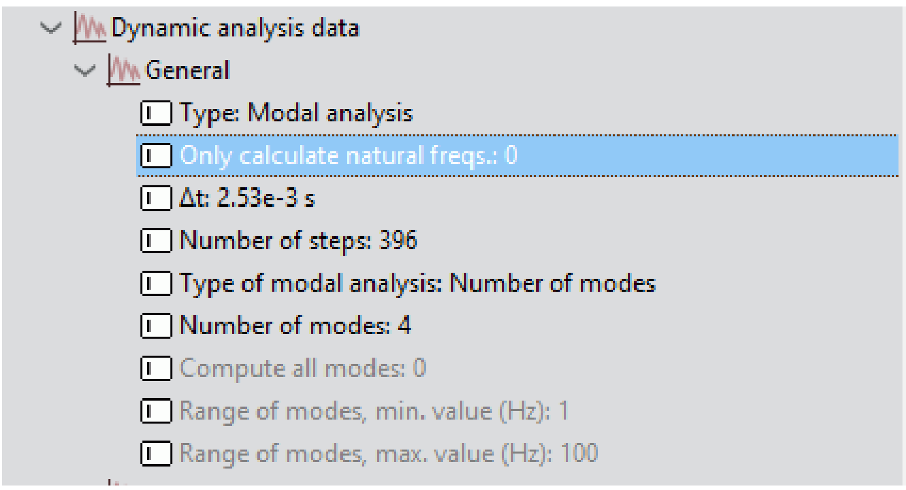


Figure 35: Modal analysis data: Dynamic analysis case

Define load

We define a sinusoidal load for the dynamic analysis on the surface 2 of the structure as given in the problem. We specify the required parameters as shown in Figure 36 with varying frequency field for simulating different cases i.e $\omega_p = 0.75\omega_1$, $1.0\omega_1$ and $1.25\omega_1$. Next, we define the value of the pressure load given in the negative z-direction and consider the self-weight of the structure as shown in Figure 37.

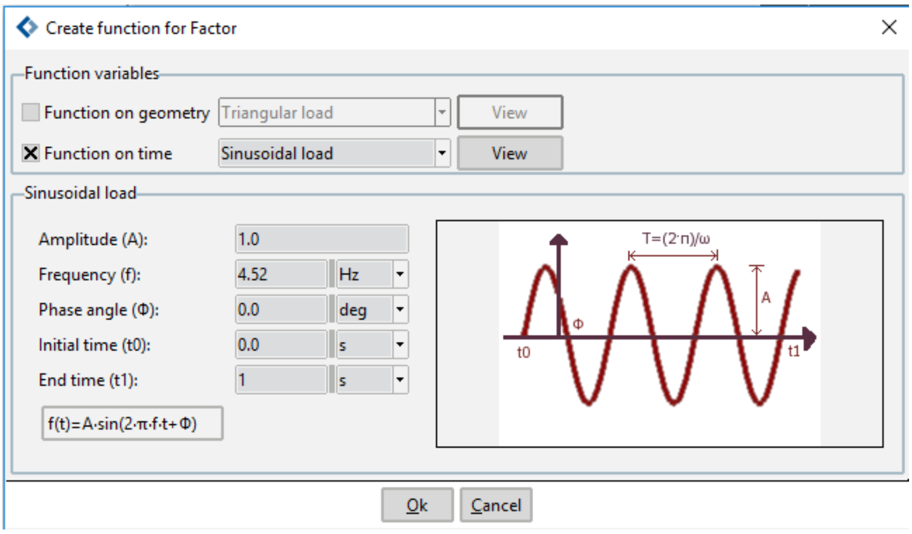
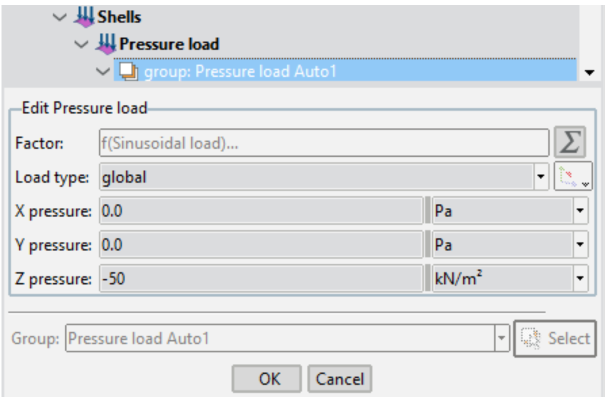
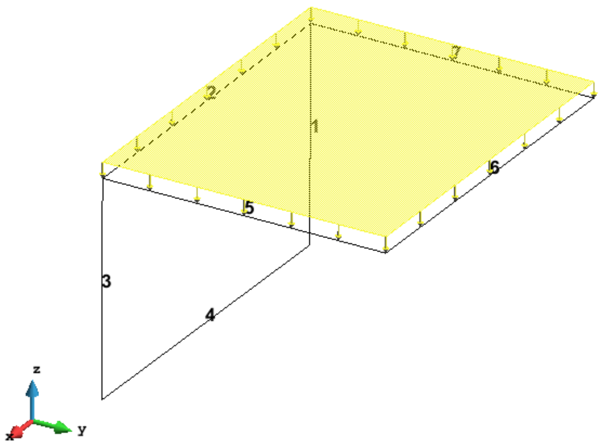


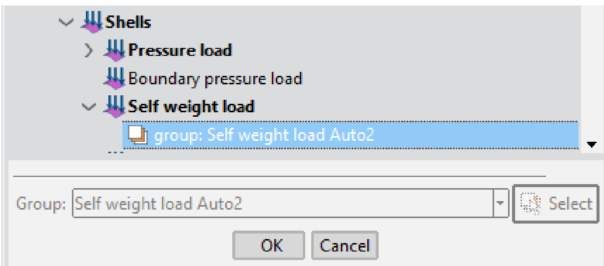
Figure 36: Define sinusoidal load for dynamic analysis



(a)



(b)



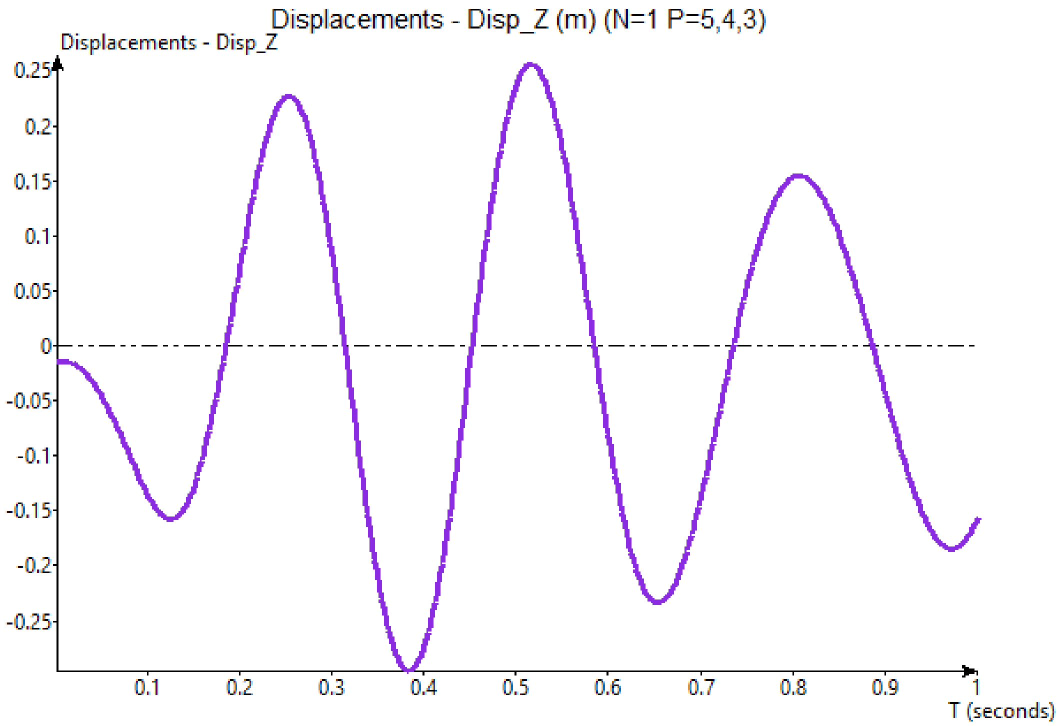
(c)

Figure 37: Define the distributed load on the surface 2 of the structure and considered self-weight.

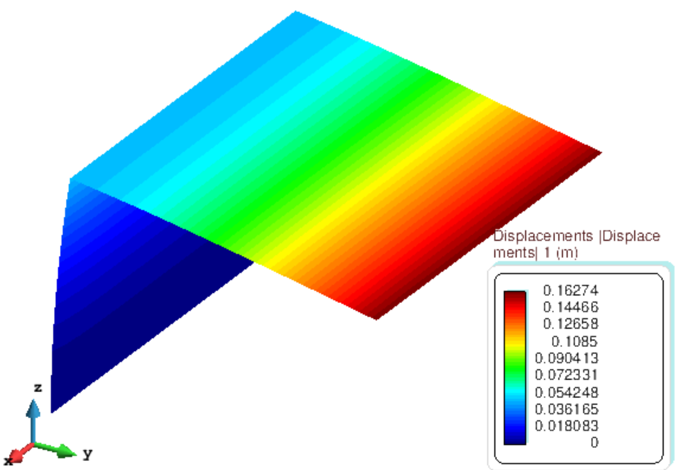
2.3.1 Post-processing: Dynamic response

The following figures present the post-processed results for the dynamic analysis by showing the vertical displacement vs time plots of the corner node 1 to represent the surface of load application and the deformation at total time as a representation.

Firstly, considering $\omega_p = 0.75\omega_1$, we have the results shown in Figure 38. The sinusoidal behaviour of the load applied is clearly seen in the results obtained. As the frequency is not equal to the natural frequency of the structure, the displacements seem to be within an acceptable range. This is an expected results since the load frequency is not close enough to the natural frequency of the structure.



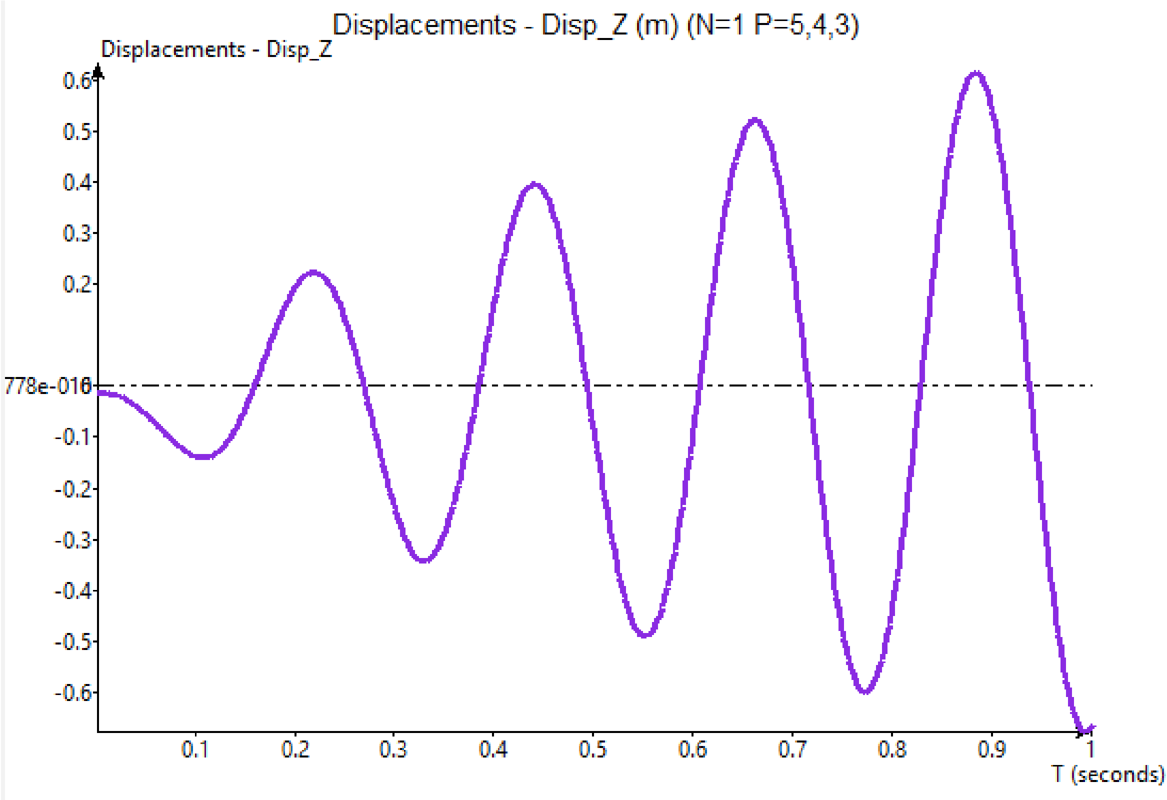
(a)



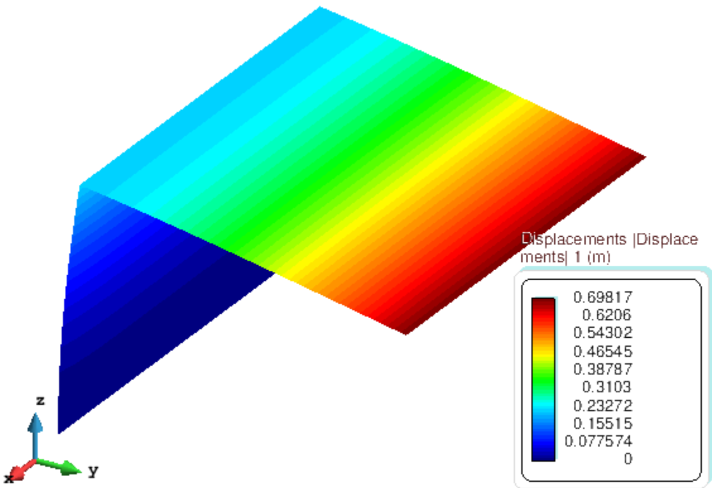
(b)

Figure 38: Result: z-displacement vs. time plot for $\omega_p = 0.75\ \omega_1 = 3.39$

Next, we consider the case of $\omega_p = \omega_1$, which is again an interesting case to analyse since the load frequency is exactly equal to the natural frequency of the structure. It is expected that the displacement in this case would drastically increase without control due to resonance. As seen earlier, in the resonance phenomenon, the external force drives the structure to oscillate with greater amplitude and could potentially lead to failure. This effect is clearly seen in the results obtained as shown in Figure 39.



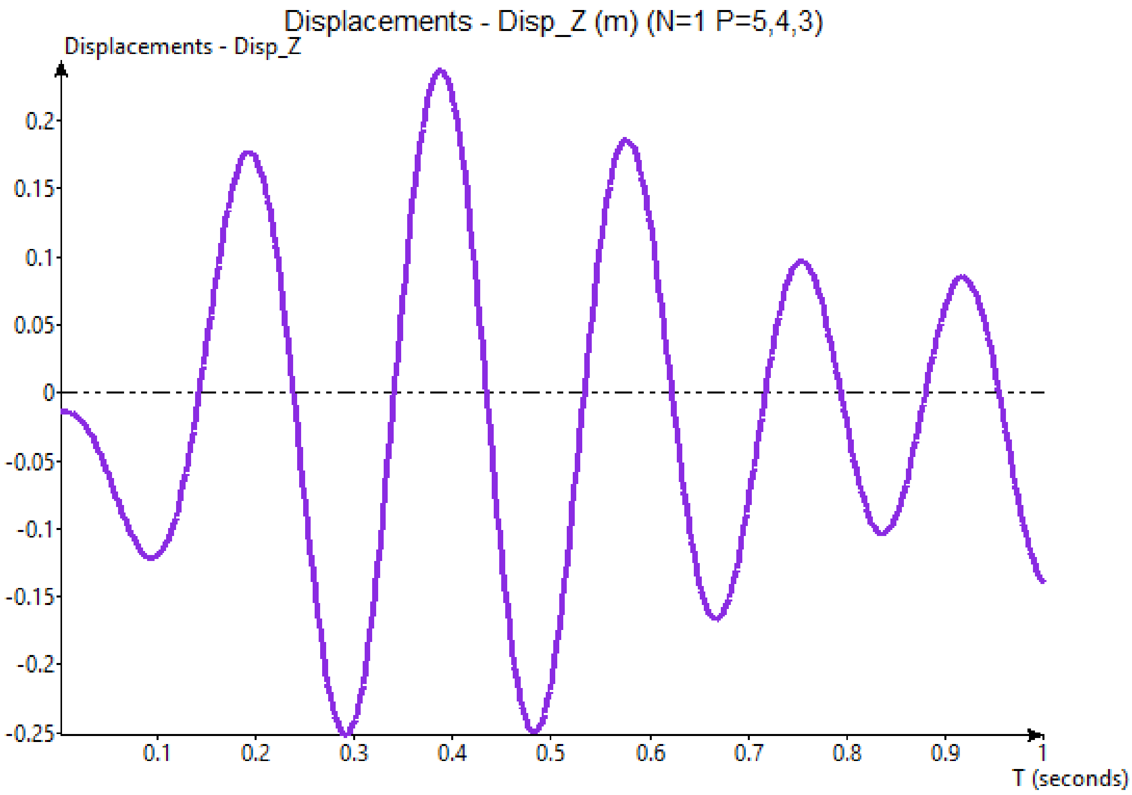
(a)



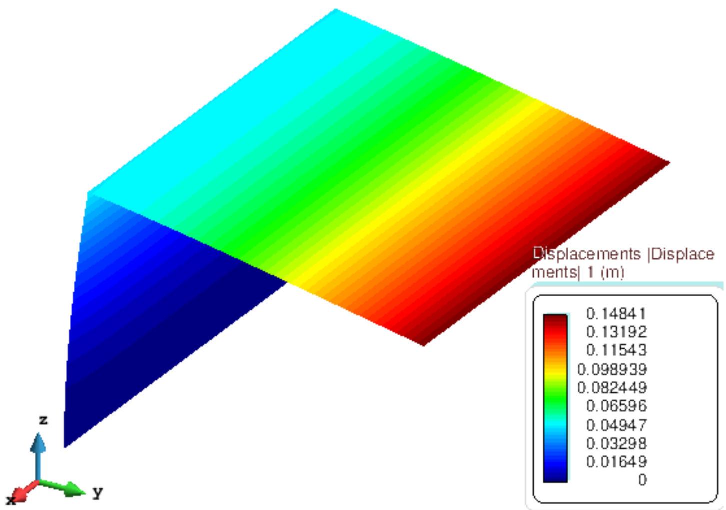
(b)

Figure 39: Result: z-displacement vs. time plot for $\omega_p = \omega_1 = 4.52$

Finally, we analyse the case with $\omega_p = 1.25\omega_1$. The oscillations in this case are not expected to increase drastically since the load frequency is not close to the natural frequency of the structure. As seen in Figure 40, the results show the expected behaviour and the oscillations are damped with time.



(a)



(b)

Figure 40: Result: z-displacement vs. time plot for $\omega_p = 1.25\ \omega_1 = 5.65$

3. Conclusion

In these set of exercises, we analysed the dynamic behaviour of the given structures by first calculating the natural frequencies and modes of the structures and then performing modal analysis. Use of dynamic load frequency with different values was understood by the results obtained where we could analyse the phenomenon of resonance in these structures. Understanding the importance of resonance is vital in the field of structural dynamics. It was evident from these examples that in day-to-day life, every component has to be designed such that it operates away from their natural frequency to avoid failure.