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Passive Control of Axial Vibration of Fixed-Free Rods using Periodic Structures

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Abstract

Passive Control of Axial Vibration of Fixed-Free Rods using Periodic Structures" with consideration of four cases as mentioned earlier. The objective is to compare these cases from vibration point of view, analysis the best one and provide diameter, D, cells lengths, LA and LB which effects the rod with minimum vibration. These values were obtained using parametric analysis in order to reach optimal results. Therefore, the project was divided into two stages, each stage has its own modeling, analysis and results discussion. In conclusion, the recommended results of this study comes to be D = 11 mm, LA = 70 mm and LB = 45 mm. On the other hand, the team suggests other recommendations for further study such as that redesigning the portion of the bar using other materials which reduces vibration over millions of cycles without degrading such as Sorbothane® . Also, parametric study can be performed with a wider range of cells diameter values, D, cells lengths, LA and LB, in the purpose of having much more accurate results. This accuracy of results might affect the vibration significantly

Introduction and Background

Passive isolation:

"Passive vibration isolation" refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, as opposed to "active vibration isolation" or "electronic force cancellation" employing electric power, sensors, actuators, and control systems. Passive vibration isolation is a vast subject, since there are many types of passive vibration isolators used for many different applications. A few of these applications are for industrial equipment such as pumps, motors, HVAC systems, or washing machines; isolation of civil engineering structures from earthquakes (base isolation), [i]sensitive laboratory equipment, valuable statuary, and high-end audio.

Periodic Structures

The first question that anyone may ask is: what is a Periodic Structure? The definition of a periodic structure, according to Mead[ii], is that it is one that consists fundamentally of a number of identical substructure components that are joined together to form a continuous structure.

Periodic structures are seen in many engineering products, examples of periodic structures may include satellite solar panels, railway tracks, aircraft fuselage, multistory buildings, etc …

Following the above definition of periodic structure, there must be a distinction between different substructures that defines the individual unit, that distinction or boundary will introduce a sudden change in the properties of the structure. Two main types of discontinuities may be identifies, namely: geometric discontinuity and material discontinuity. Figure 1 shows a sketch of the two different types of periodicities.

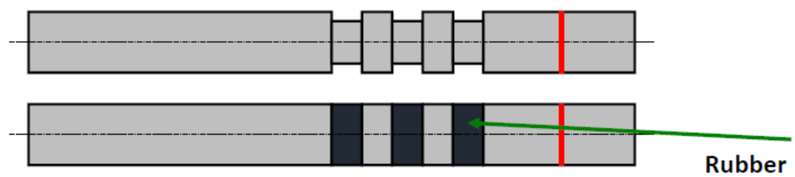

Figure 1, Geometric and Material Periodicity

Problem Definition and Assumptions

The project is mainly dealing with the problem of vibration with specified conditions such as: fixed-free circular cross-section rod, cantilever, which is subjected to an axial force with very small magnitude. Moreover, it aims to apply Passive Control, where feedback plays no role, to this system. The objective of this project is to localize the axial vibration acting on bar by redesigning the bar. A part of this rod is to be redesigned as a Periodic Structure which has two common types: geometric periodicity and material periodicity.

There are four cases provided to the team to work on, which are:

1. Plain Rod
2. Rod with Geometric Periodicity
3. Rod with Material Periodicity, and
4. Rod with Geometric and Material Periodicity.

- Finding the first three modes of vibration and the harmonic response at the sensor location for each of the four cases mentioned above, and
- Deciding the best case followed by finding the optimal design of the structure.

The procedure, in general, that team 2 will follow is divided into two stages which are:

Stage 1:

- ✓ Analyzing each case separately
- ✓ Determining the optimal diameter of segments for cases two and four
- ✓ Comparing these cases from vibration perspective
- ✓ Picking the best case with lowest vibration effects

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Stage 2:

- ✓ Applying parametric analysis to the chosen case with three different alternatives of two, three and four rubber cells as well as variable inputs of lengths versus vibration effects of each alternative, and
- ✓ Deciding the best alternative according to vibration analysis, discussing and presenting its results.

Assumptions, those which are not mentioned in problem file, can be summed up as following:

a) Material used for the bar is Structural Steel
b) Material used for the cells is Rubber
c) Bar diameter is 20 mm
d) Bar is to move only in x-direction, and
e) Axial force applied is in tension with magnitude of 1 N.

Stage 1:

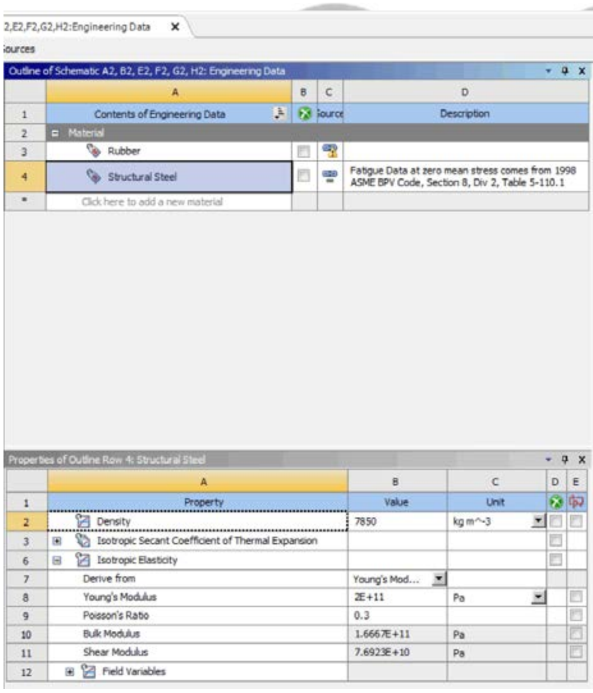

Figure 2: Material Assignment of Bar

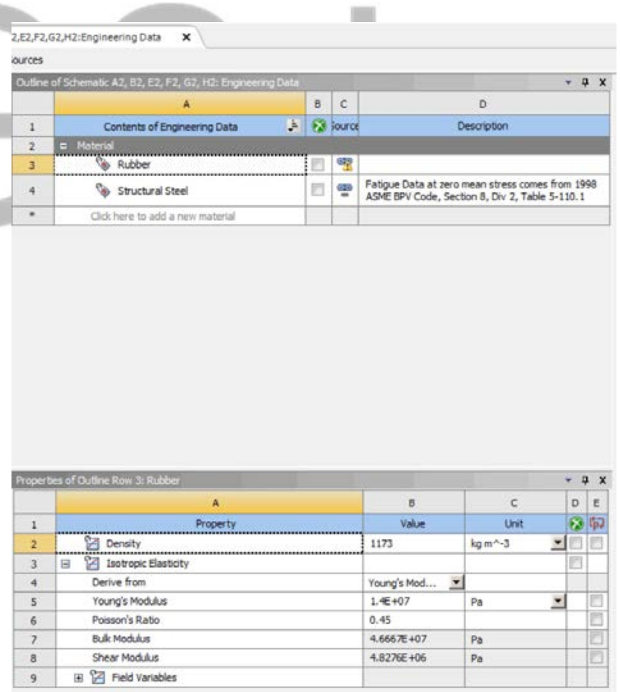

Figure 3: Material Assignment of Segments

Modeling

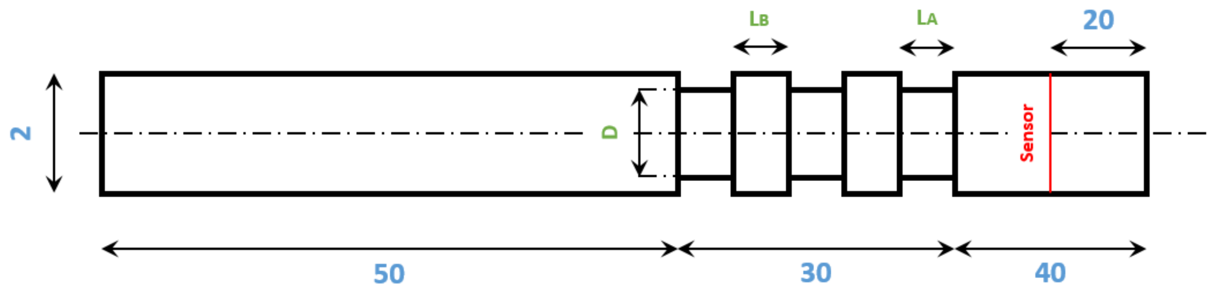

Figure 4: Illustration Sketch of The Geometry – all dimensions are in cm.

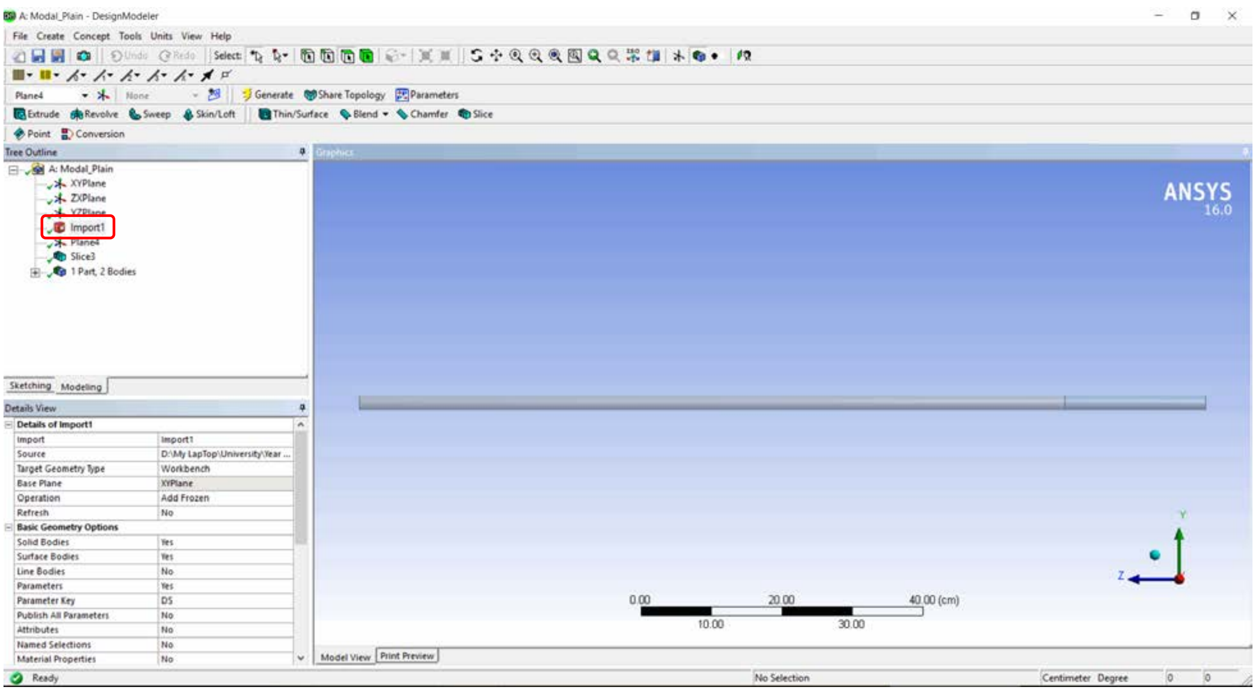

Figure 5: Case 1 Modeling using Solidworks, Imported to ANSYS

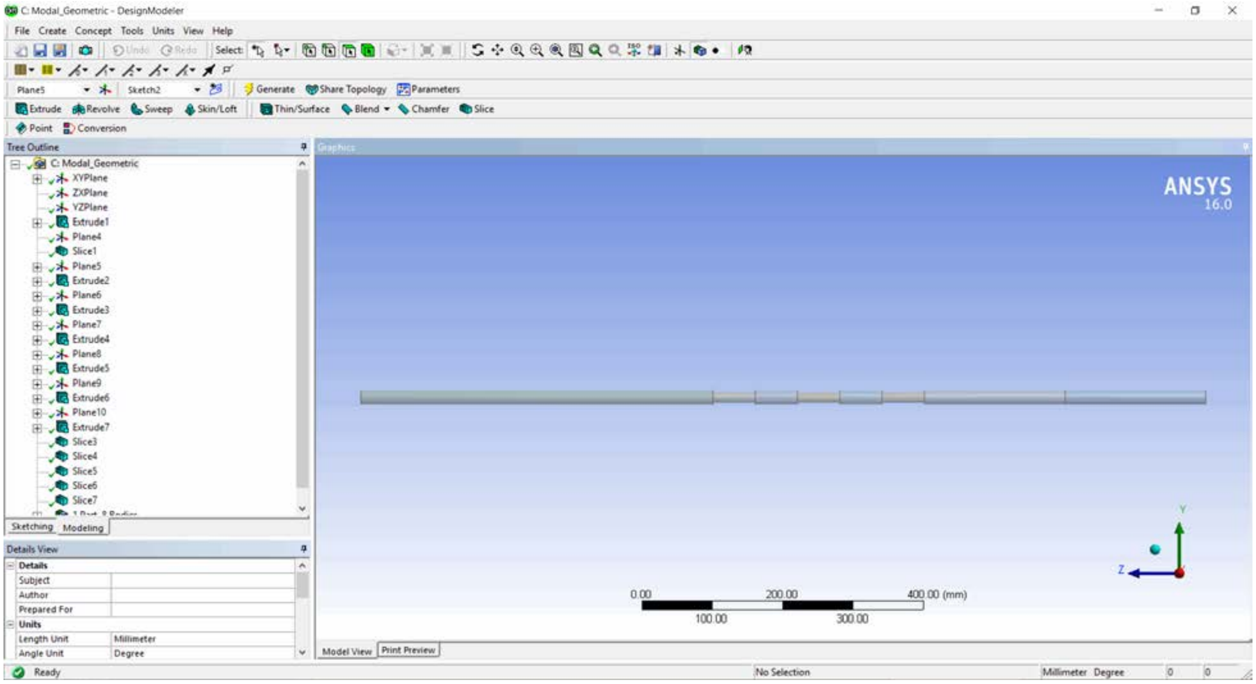

Figure 6: Case 2 Modeling using ANSYS

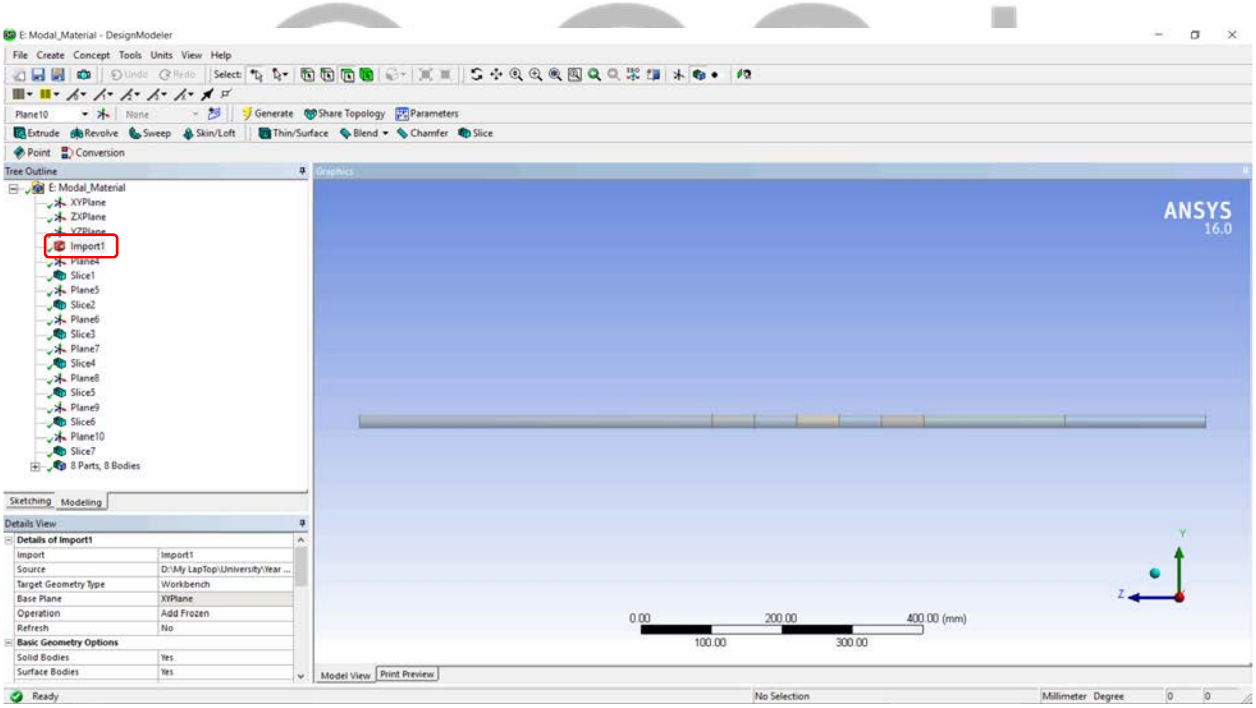

Figure 7: Case 3 Modeling using Solidworks, Imported to ANSYS

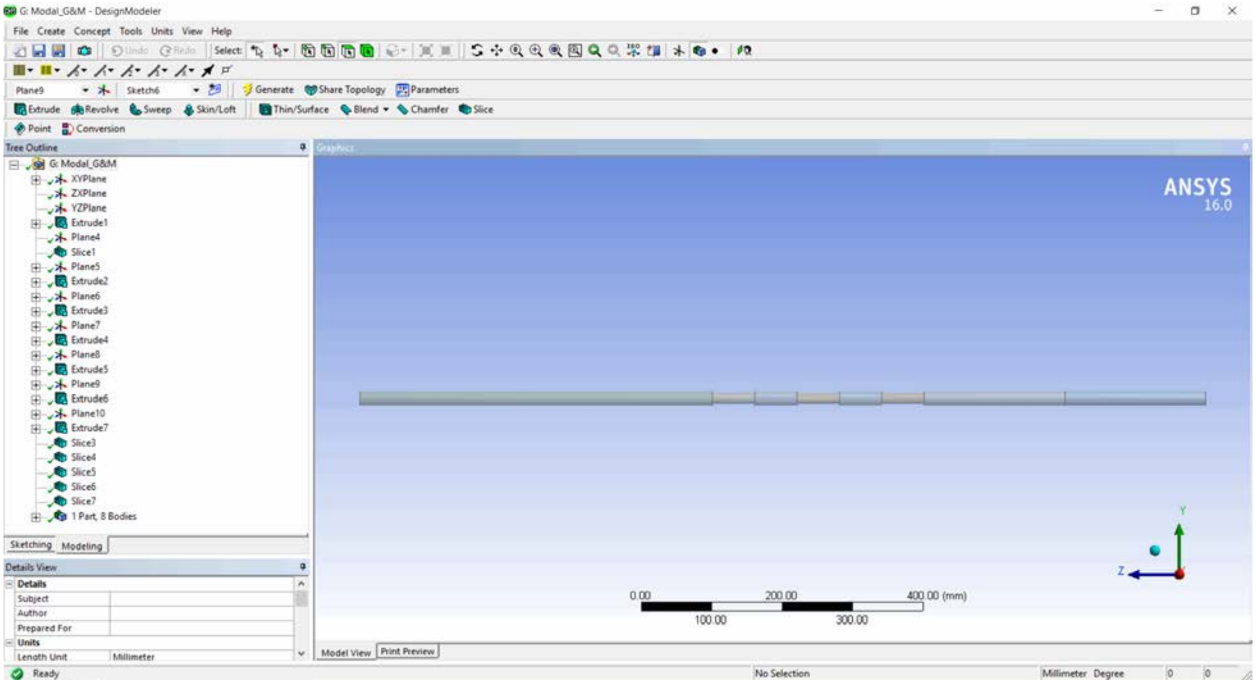

Figure 8: Case 4 Modeling using ANSYS

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Analysis Setup

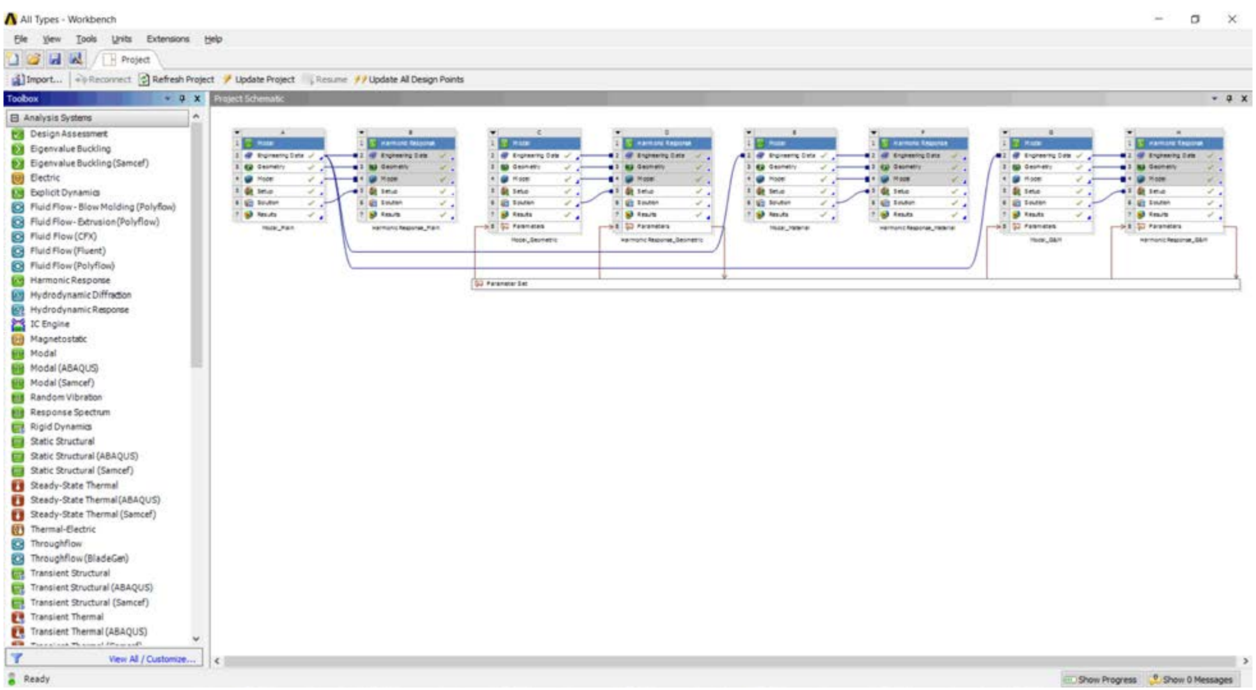


Figure 9: Overall Setup of Stage 1

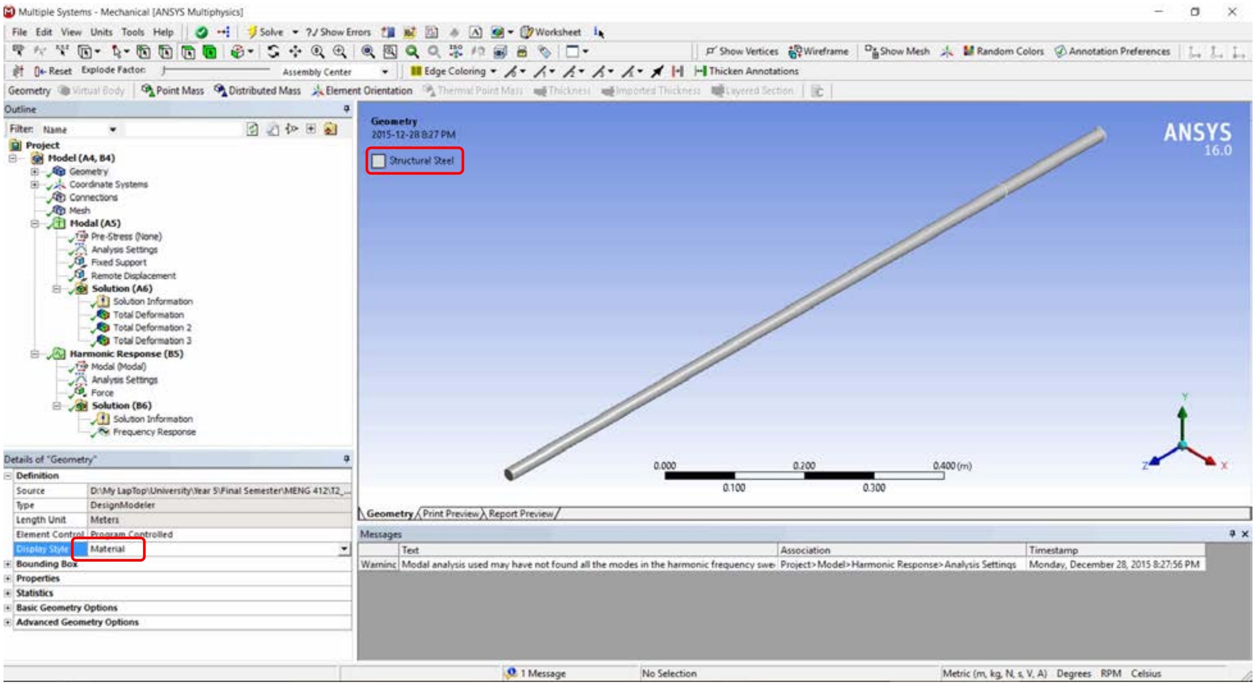


Figure 10: Case 1 Material Display

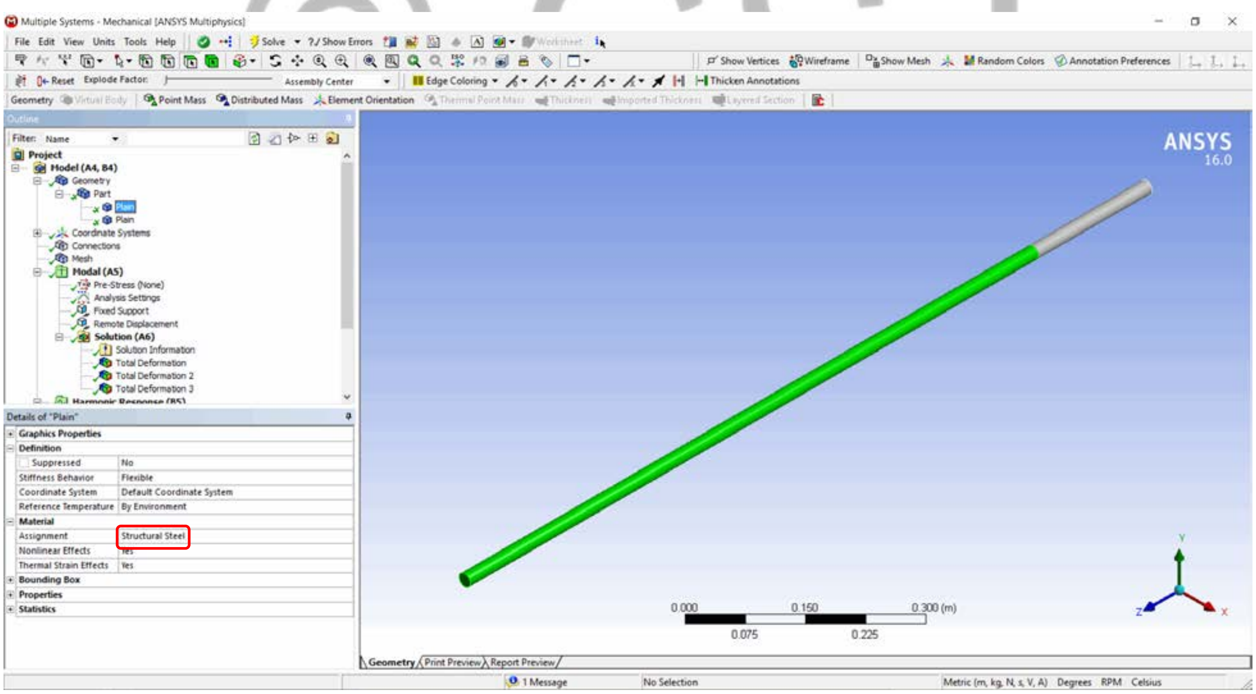


Figure 11: Case 1 Material Assignment and Part Forming for Mesh Continuity

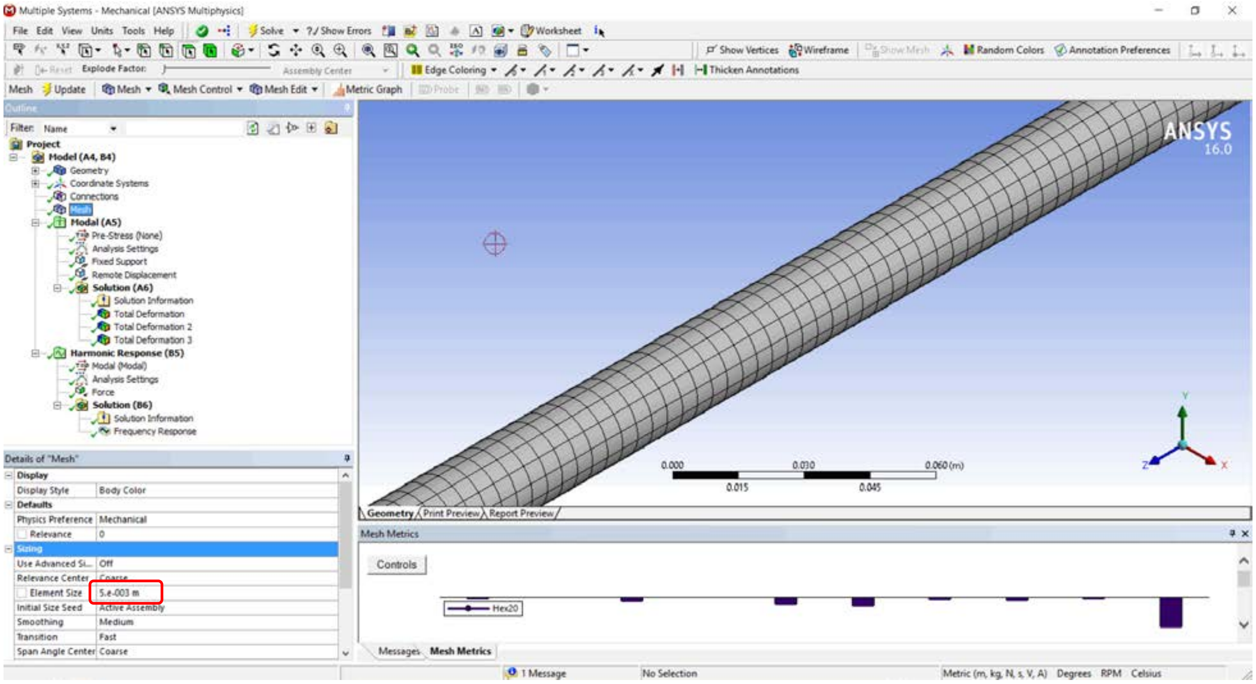


Figure 12: Case 1 Mesh Sizing

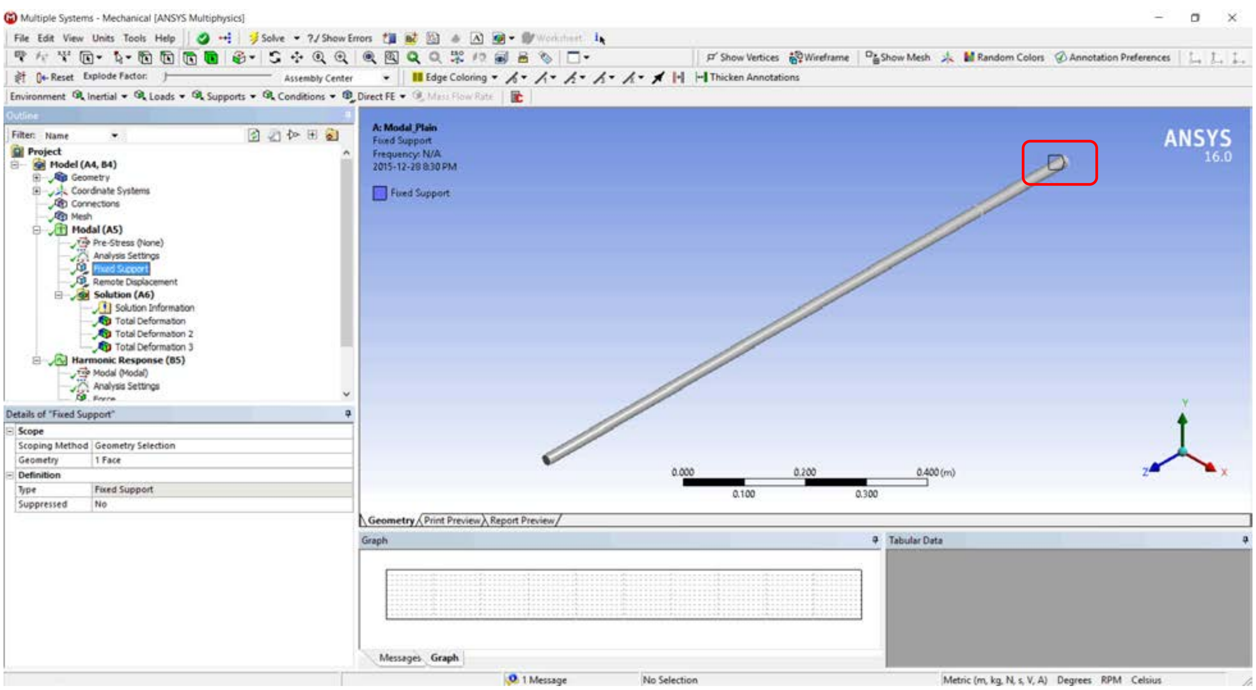


Figure 13: Case 1 Fixation

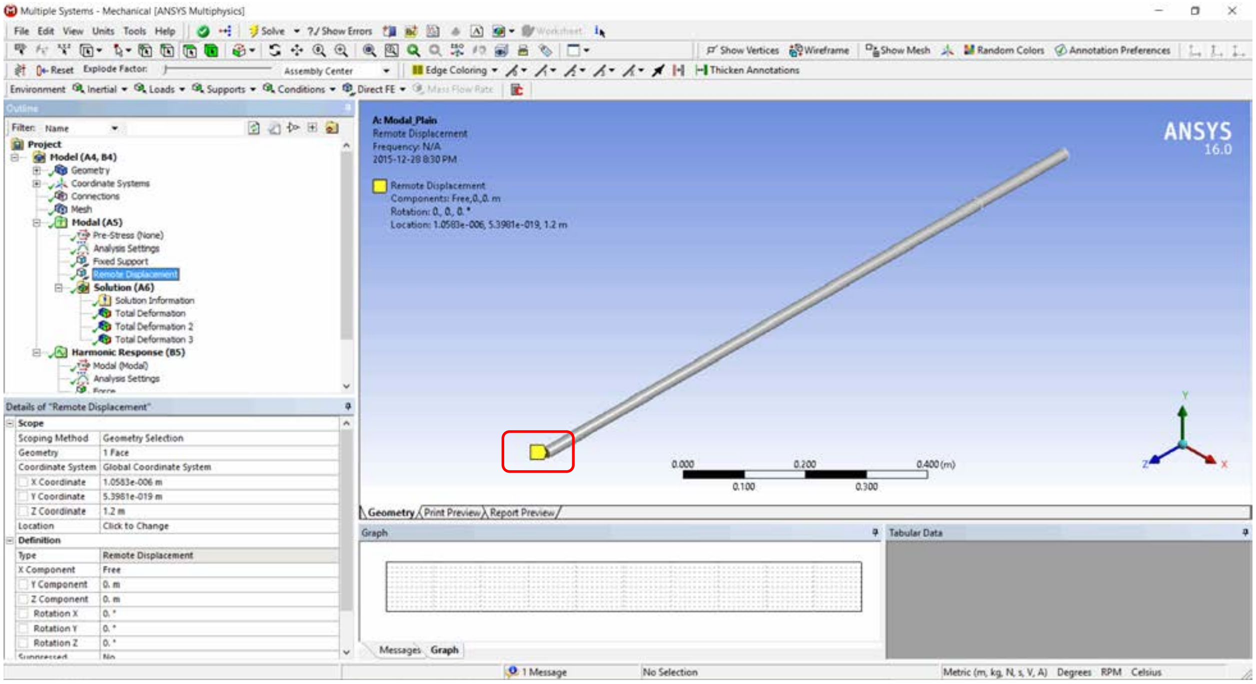


Figure 14: Case 1 Remote Displacement for x-direction Movement

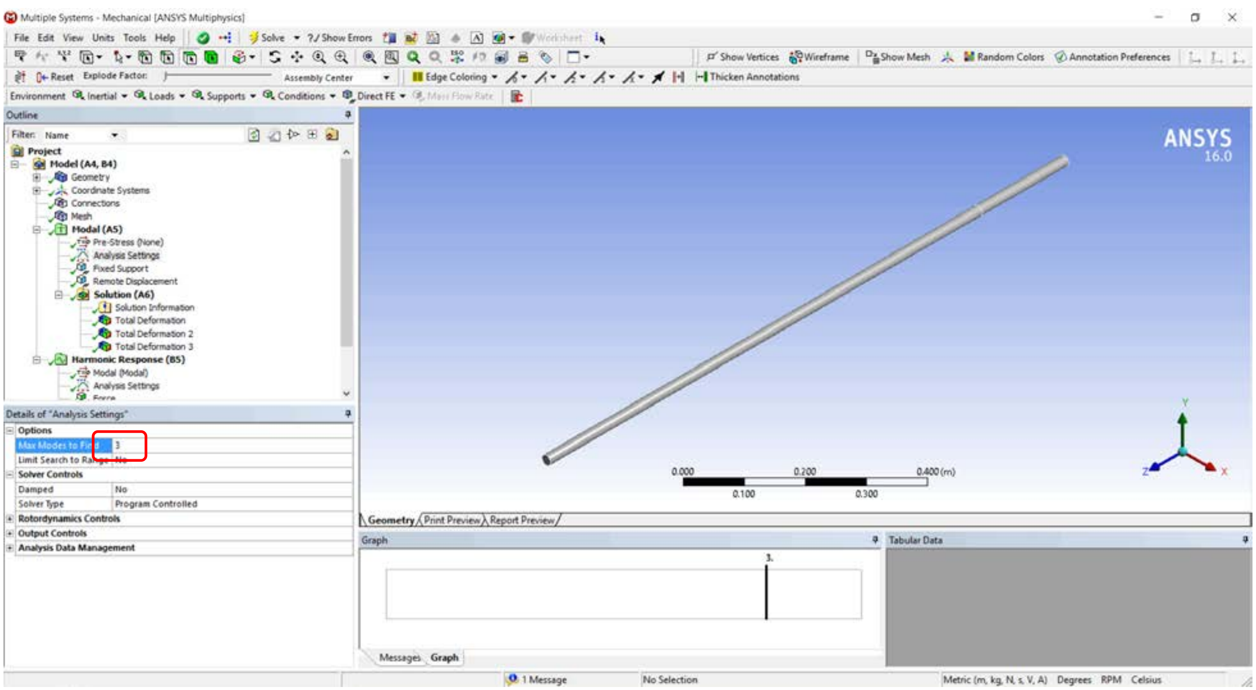


Figure 15: Case 1 Limitation Number of Mode Shapes (first three mode shapes as stated in the problem)

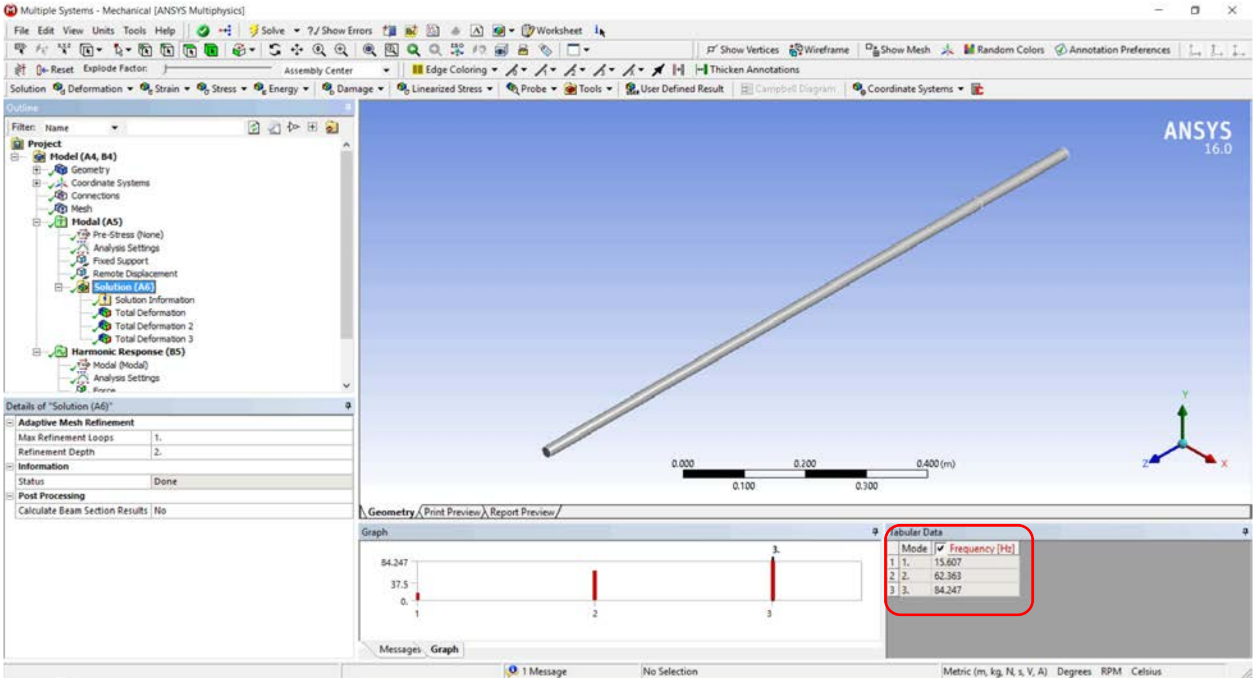


Figure 16: Case 1 First Three Natural Frequencies

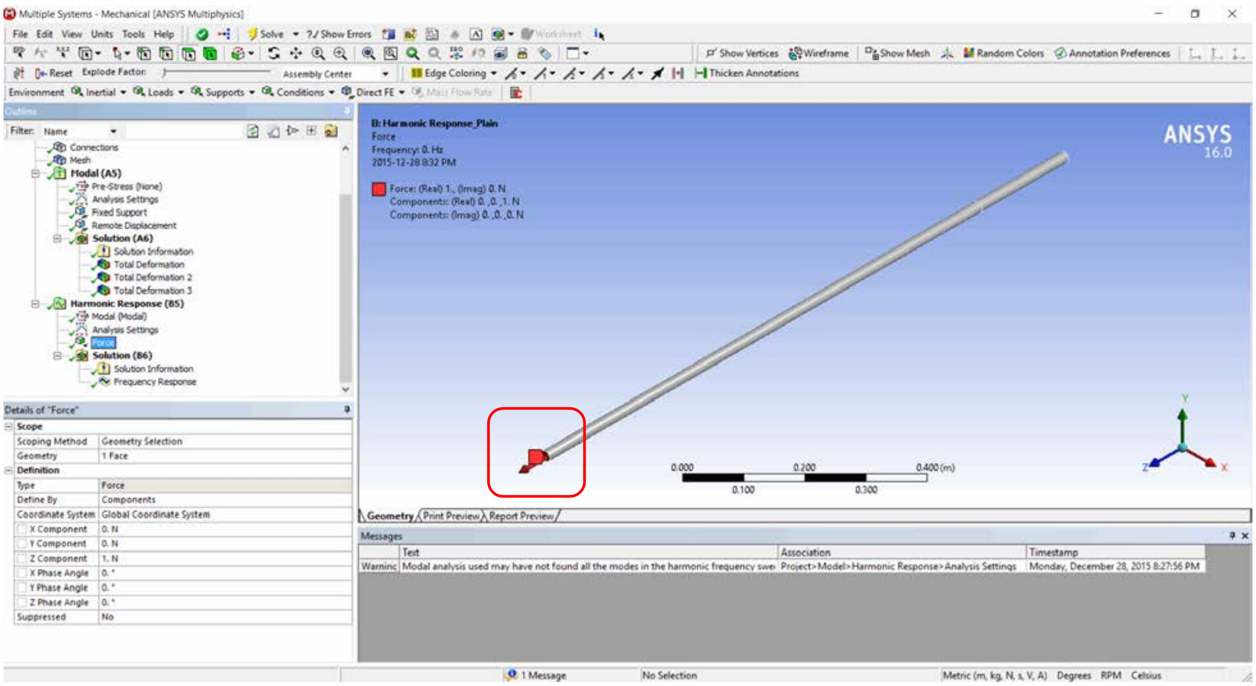


Figure 17: Case 1 Applied Axial Force on The Free End

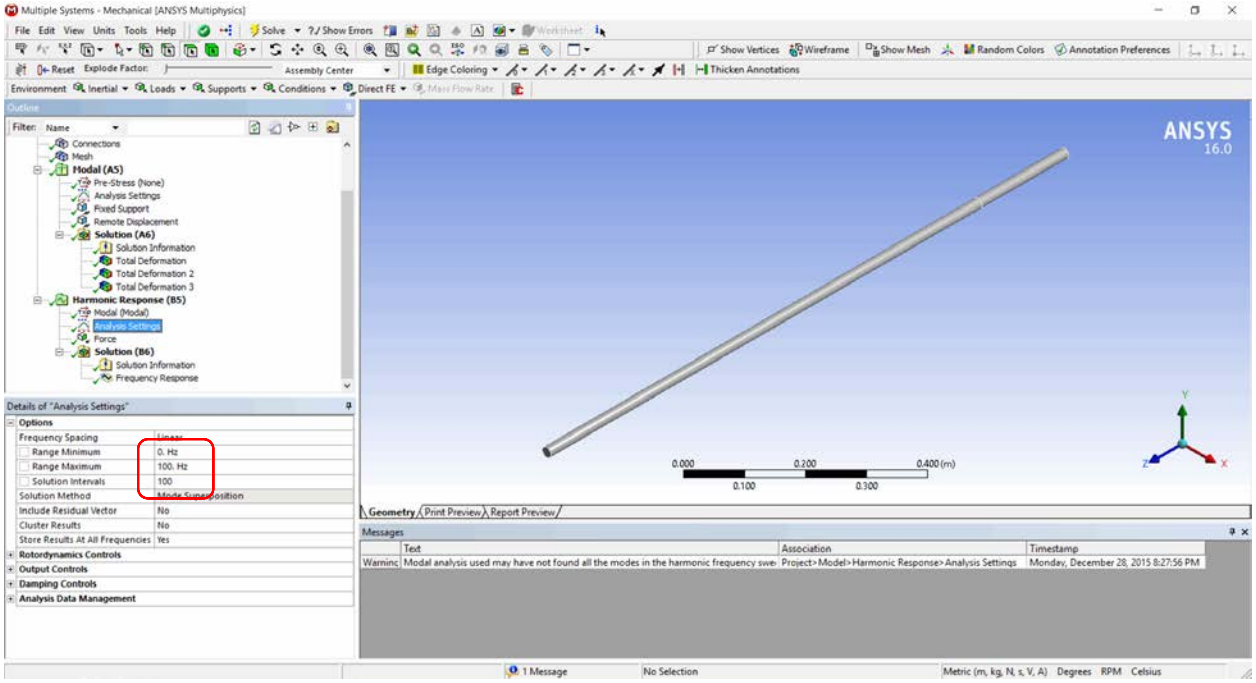


Figure 18: Case 1 Suitable Frequency Range Including First Three Mode Shapes

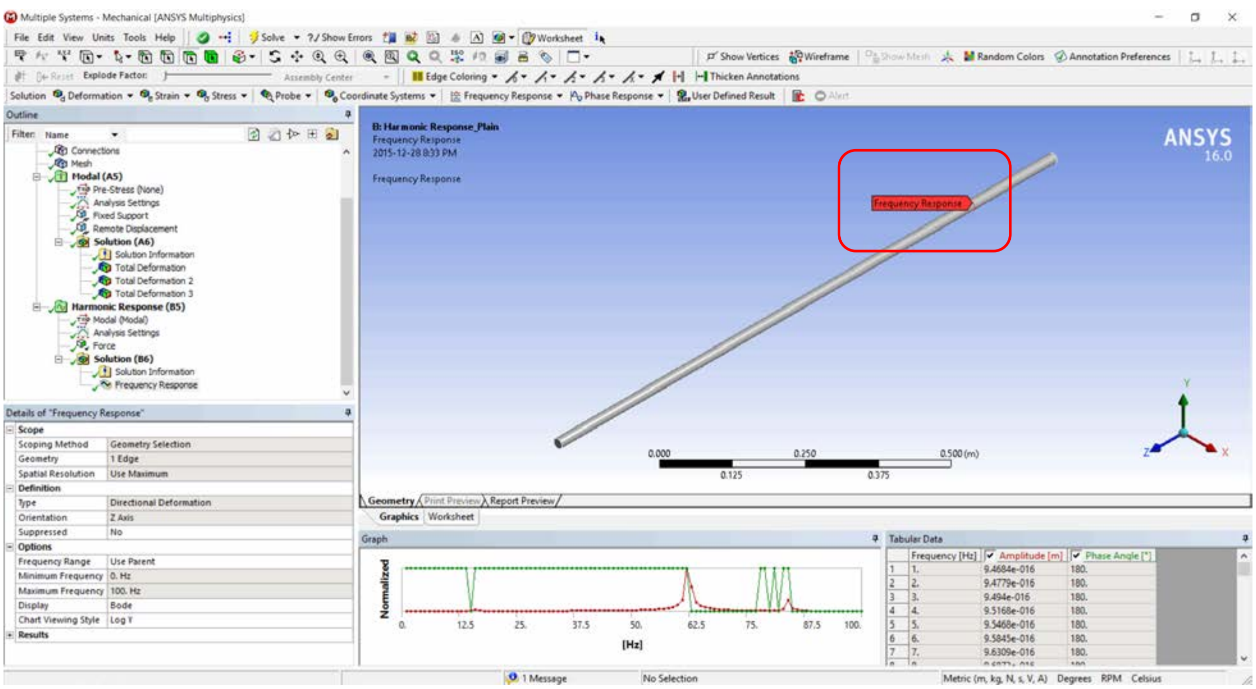


Figure 19: Case 1 Sensor Location for Studying Frequency Response

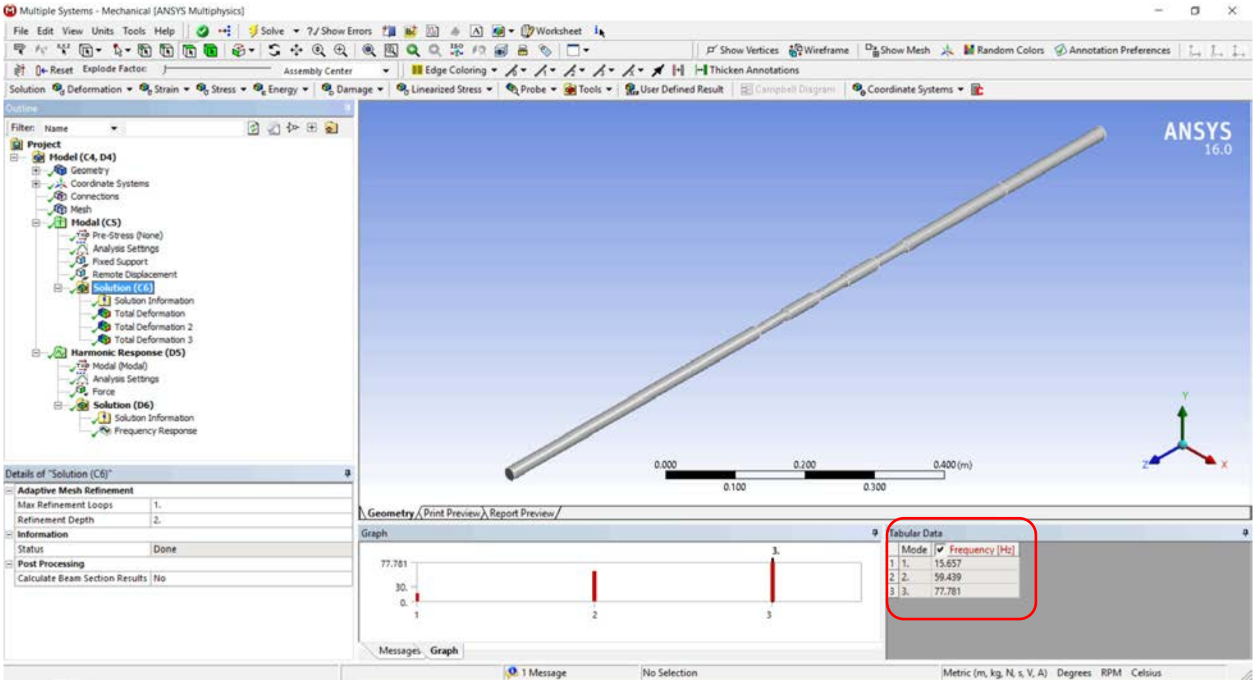


Figure 20: Case 2 Overall Analysis Showing First Three Natural Frequencies

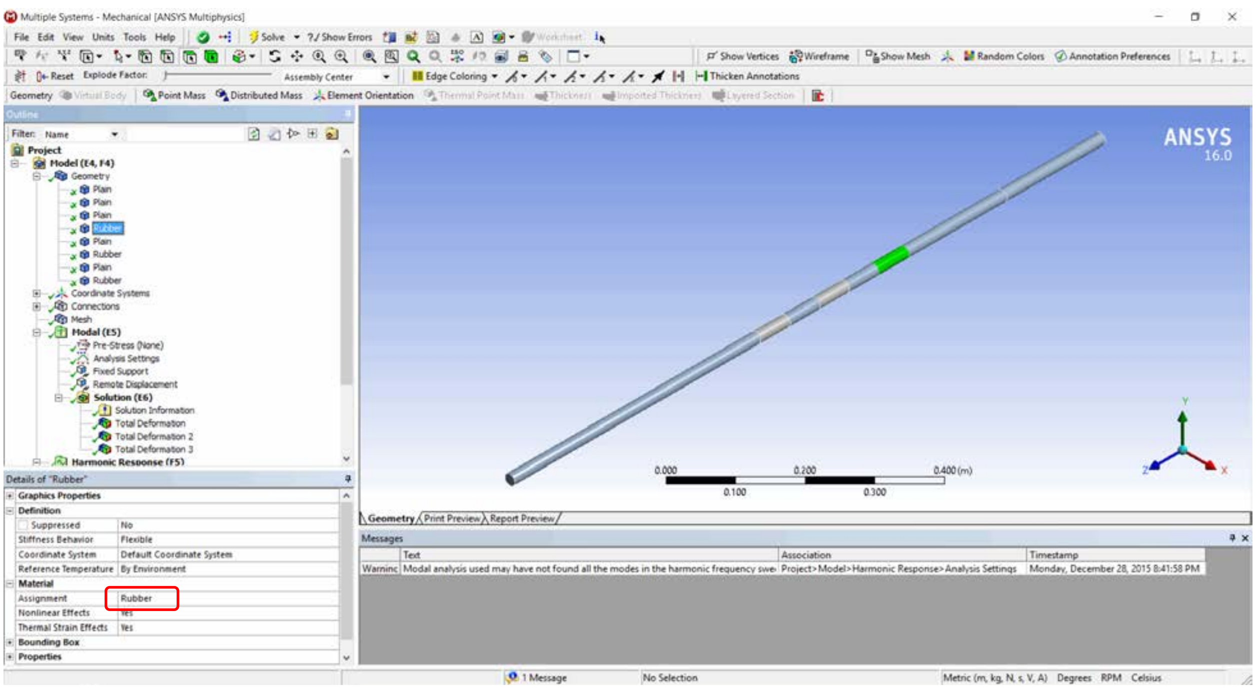


Figure 21: Case 3 Material Assignment of Segments

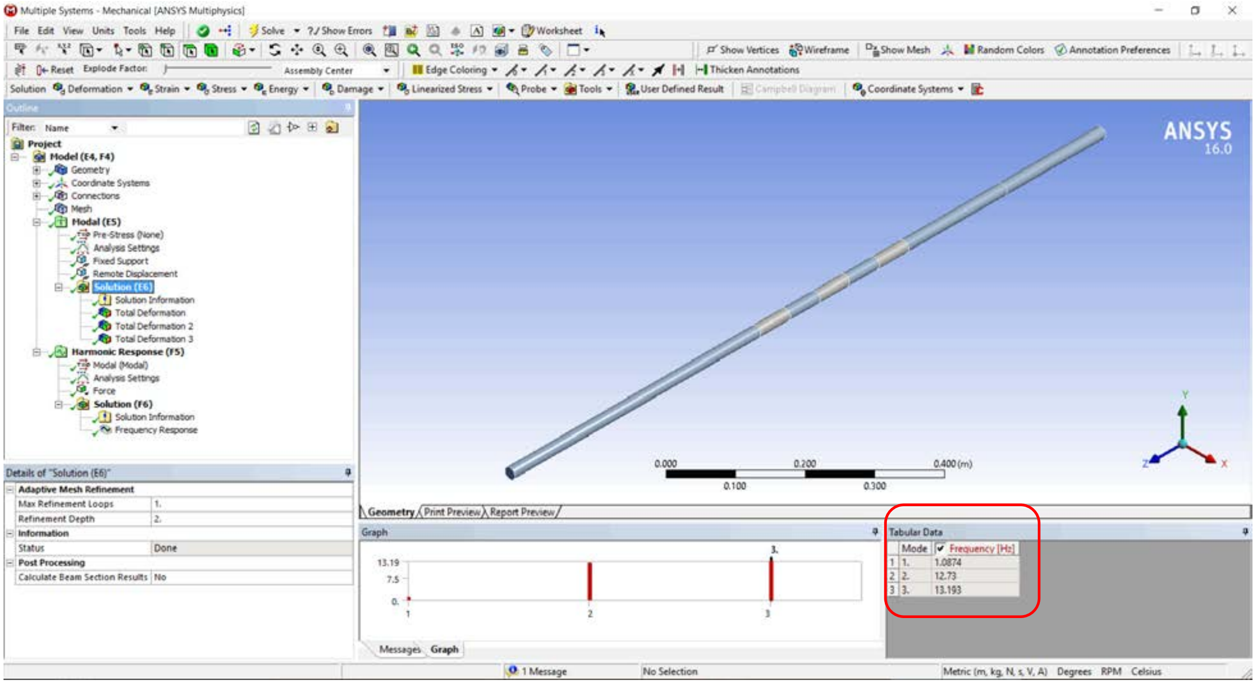


Figure 22: Case 3 Overall Analysis Showing First Three Natural Frequencies

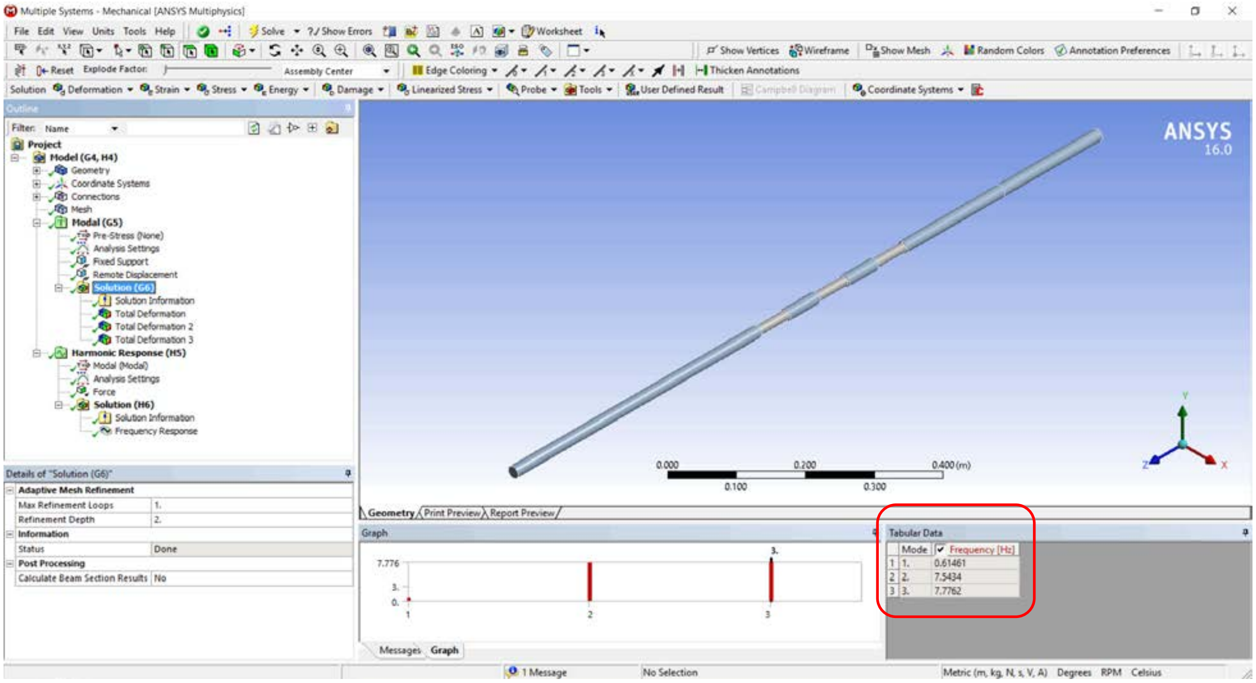


Figure 23: Case 4 Overall Analysis Showing First Three Natural Frequencies

Results and Discussion

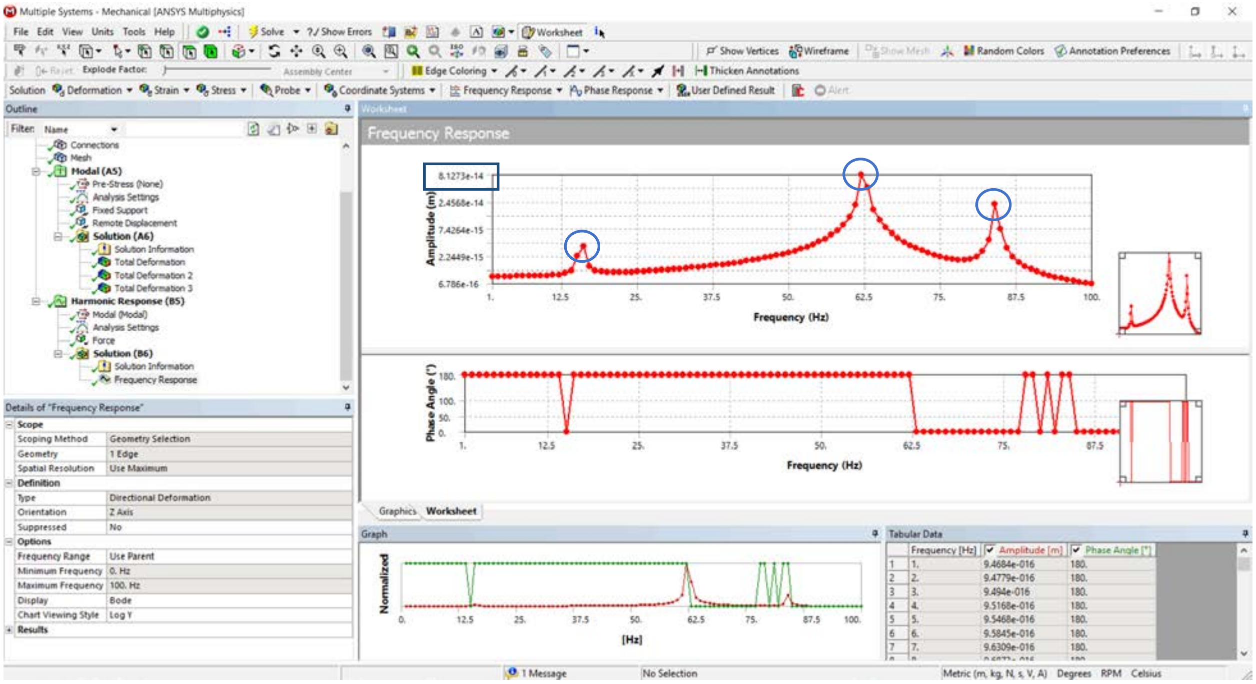


Figure 24: Case 1 Frequency Response

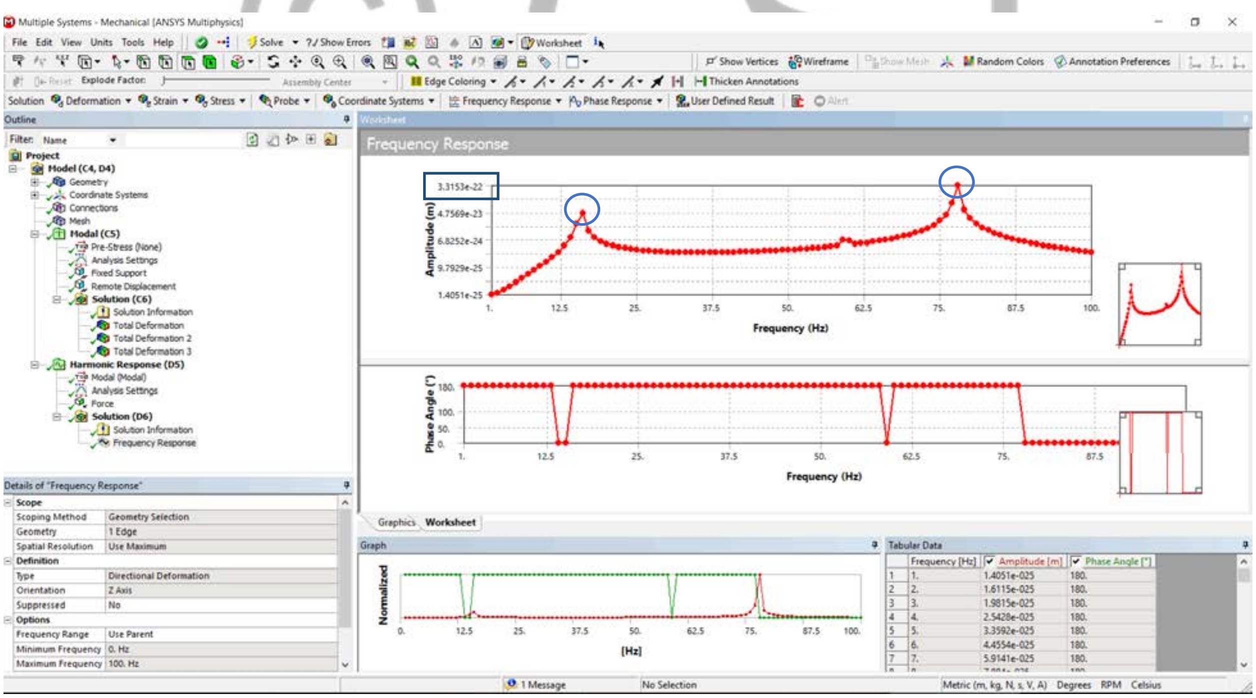


Figure 25: Case 2 Frequency Response

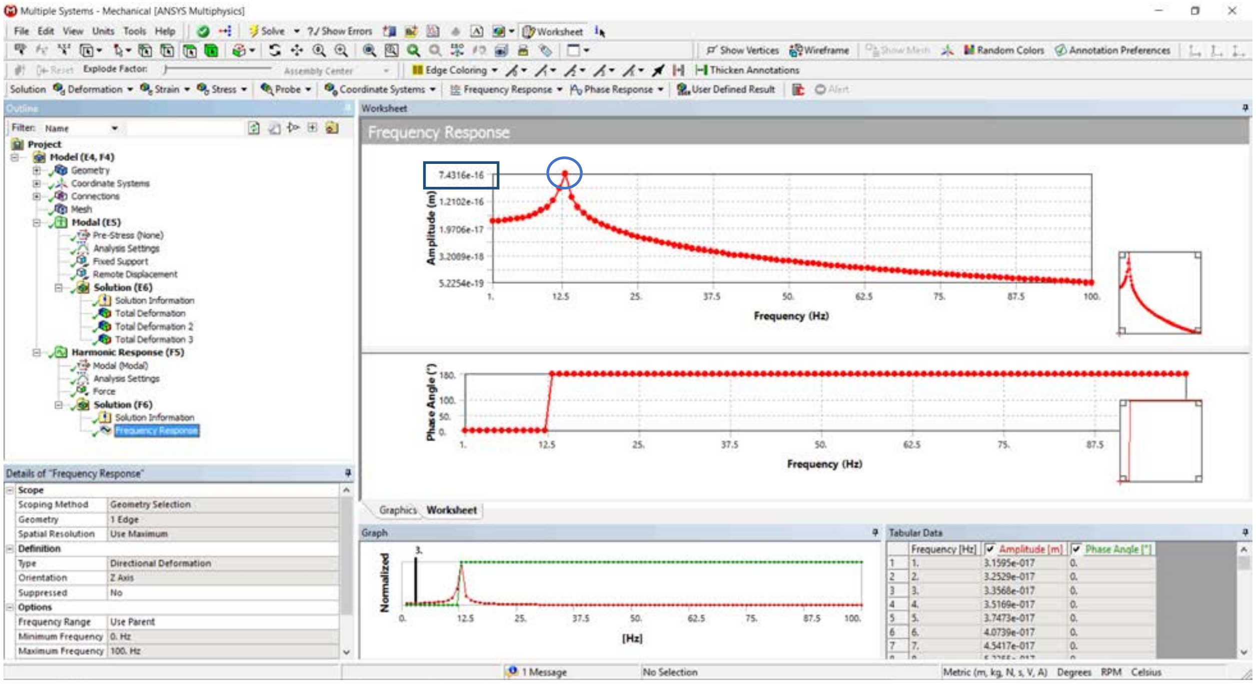


Figure 26: Case 3 Frequency Response

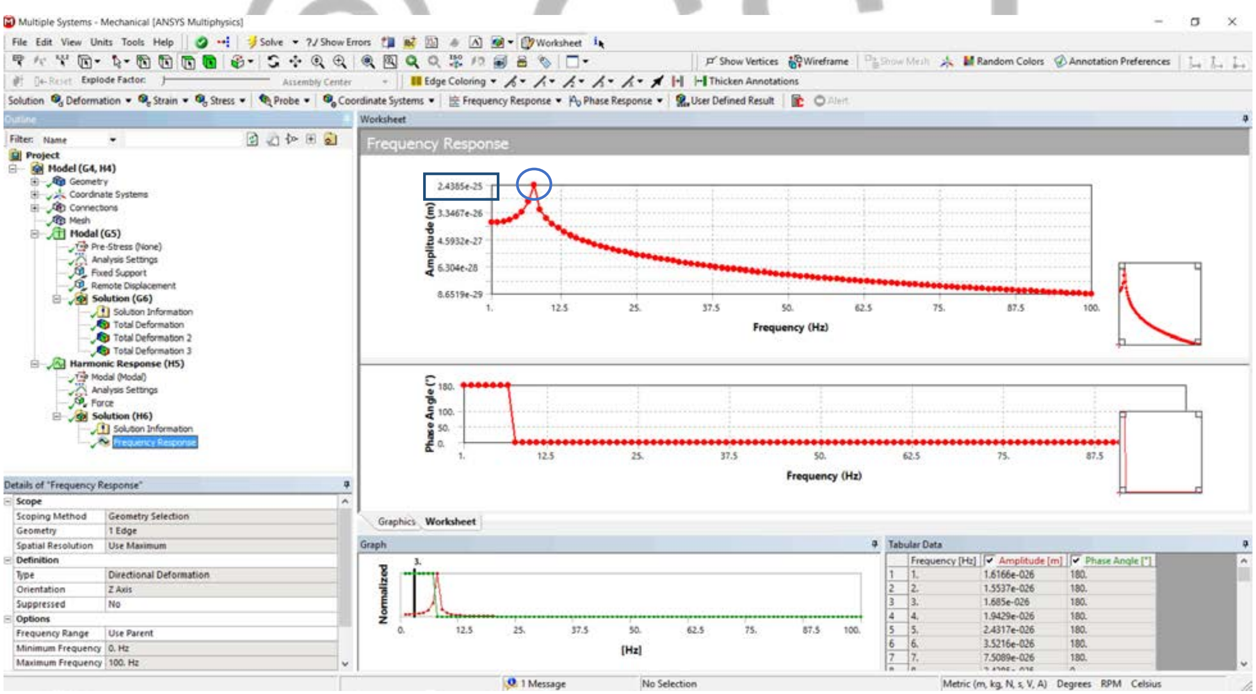


Figure 27: Case 4 Frequency Response

As can be seen from Figure 24, peaks occur in the natural frequencies with maximum amplitude of 8×10^{-14} m for Case 1 (Plain Structure) while Case 2 reduces the maximum amplitude to 3.3×10^{-22} m (Geometric Periodicity) as Figure 25 shows. Moreover, Figure 26 demonstrates Case 3 (Material Periodicity) with maximum amplitude of 7.4×10^{-16} m which is less in vibration than Case 1 but higher than Case 2. However, Case 4 (Geometric and Material Periodicity) has the lowest maximum amplitude of all previous cases with a value of 2.4×10^{-24} m as shown in Figure 27. From this we can conclude that Case 4 is what we are looking for in term of minimizing vibration effects.

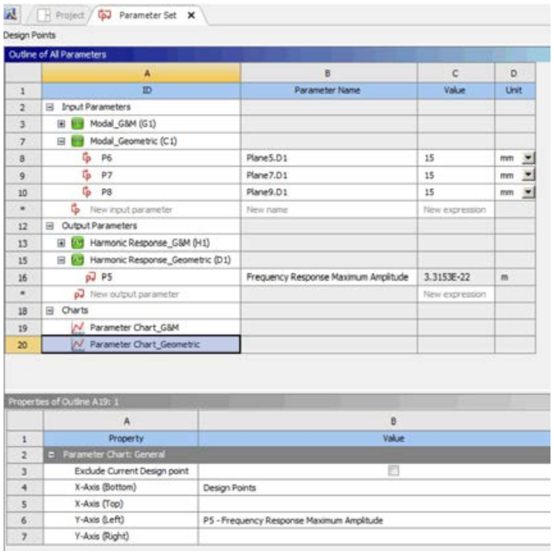


Figure 29: Case 2 Parametric Analysis to Obtain Optimal Segments Diameters

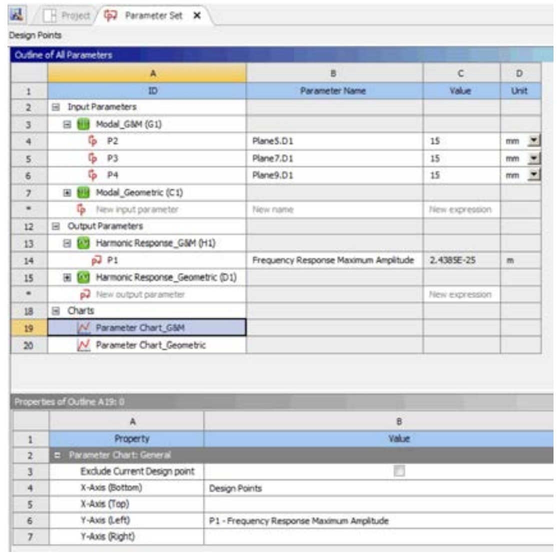


Figure 28: Case 4 Parametric Analysis to Obtain Optimal Segments Diameters

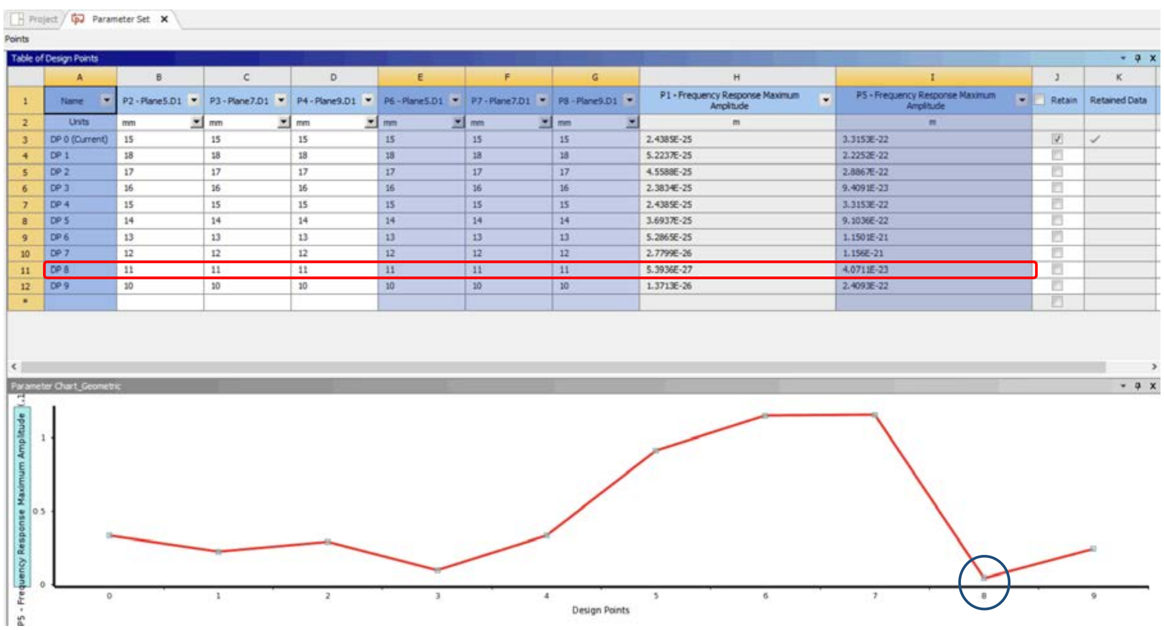
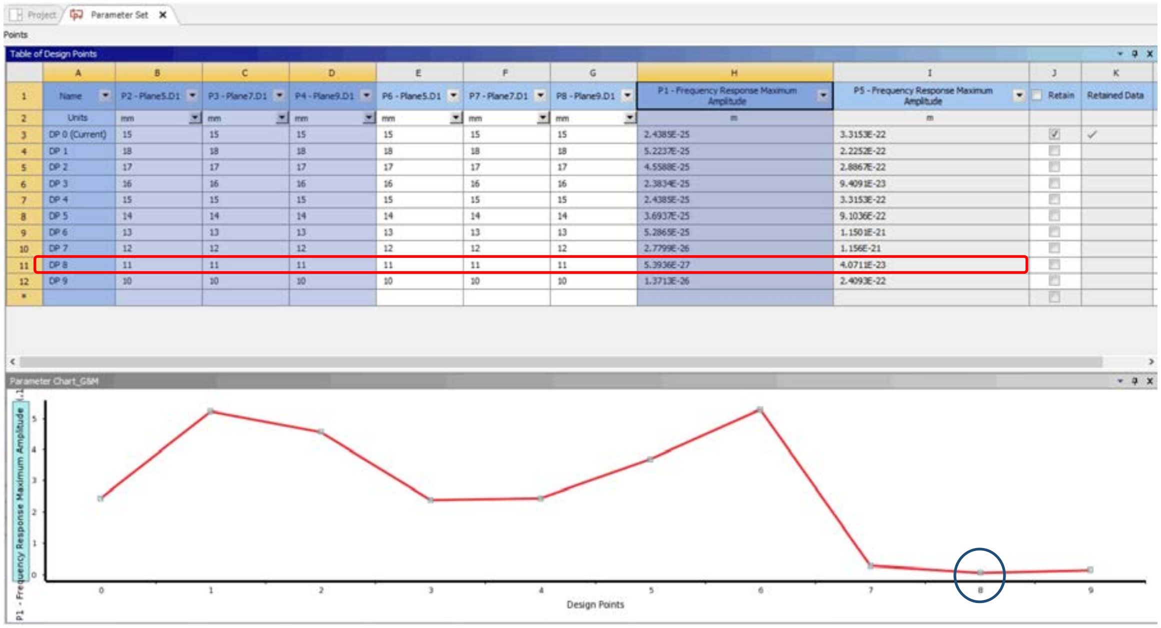


Figure 30: Case 2 Parametric Analysis Results



	A	B	C	D	E	F	G	H	I	J	K
1	Name	P2 - Plane5.D1	P3 - Plane7.D1	P4 - Plane9.D1	P6 - Plane5.D1	P7 - Plane7.D1	P8 - Plane9.D1	P1 - Frequency Response Maximum Amplitude	P5 - Frequency Response Maximum Amplitude	Retain	Retained Data
2	Units	mm	mm	mm	mm	mm	mm	m	m		
3	DP 0 (Current)	15	15	15	15	15	15	2.4385E-25	3.3153E-22	✓	✓
4	DP 1	18	18	18	18	18	18	5.2237E-25	2.2252E-22		
5	DP 2	17	17	17	17	17	17	4.5588E-25	2.8867E-22		
6	DP 3	16	16	16	16	16	16	2.3834E-25	9.4091E-23		
7	DP 4	15	15	15	15	15	15	2.4385E-25	3.3153E-22		
8	DP 5	14	14	14	14	14	14	3.6937E-25	9.1036E-22		
9	DP 6	13	13	13	13	13	13	5.2865E-25	1.1501E-21		
10	DP 7	12	12	12	12	12	12	2.7799E-26	1.156E-21		
11	DP 8	11	11	11	11	11	11	5.3936E-27	4.0711E-23		
12	DP 9	10	10	10	10	10	10	1.3713E-26	2.4093E-22		

Figure 31: Case 4 Parametric Analysis Results

For the necessity of determining the optimal segments diameters of Cases 2 and 4, which have geometric periodicity, parametric analysis is applied for both cases. Figures 28 and 29 show the settings of parametric analysis while Figures 30 and 31 demonstrate the results. The optimal segments diameter, D, of Case 2 is equal to 11 mm with the minimum amplitude represented by design point 8 as can be seen from Figure 30. On the other hand, Figure 31 shows clearly that design point 8 with optimal diameter of 11 mm has the lowest effect of vibration for Case 4.

Stage 2:

Modeling

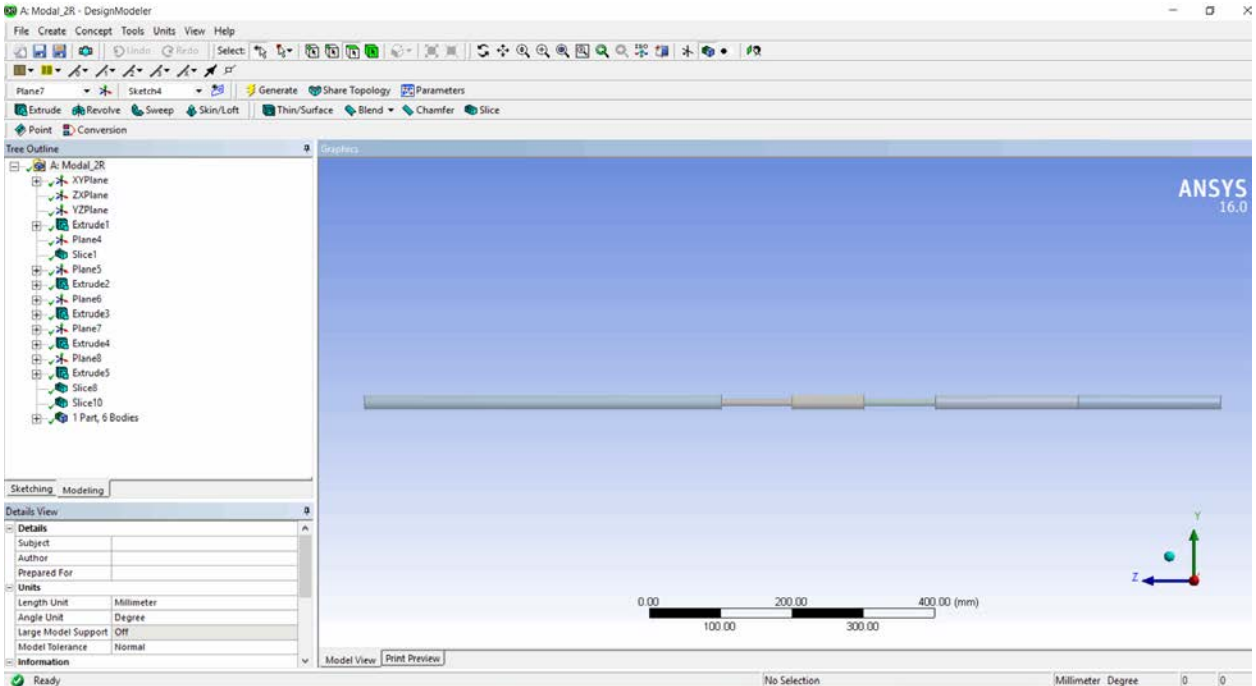


Figure 32: Alternative 1 Modeling, Two Rubber Segments

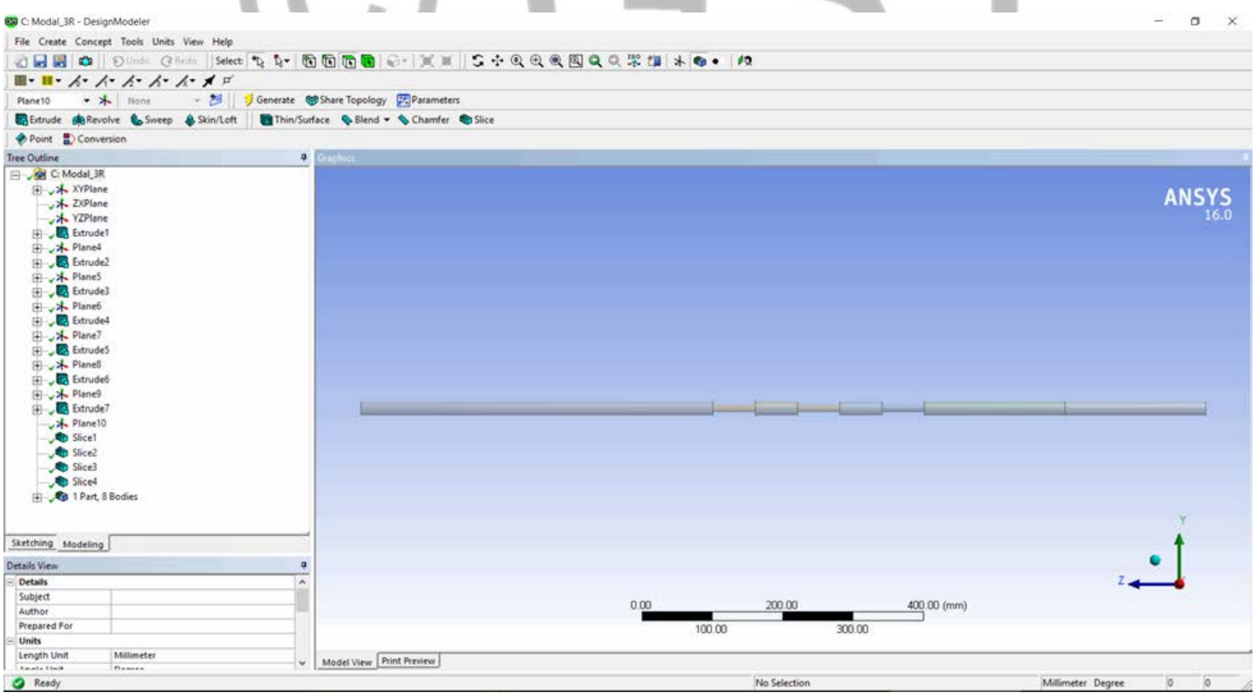


Figure 33: Alternative 2 Modeling, Three Rubber Segments

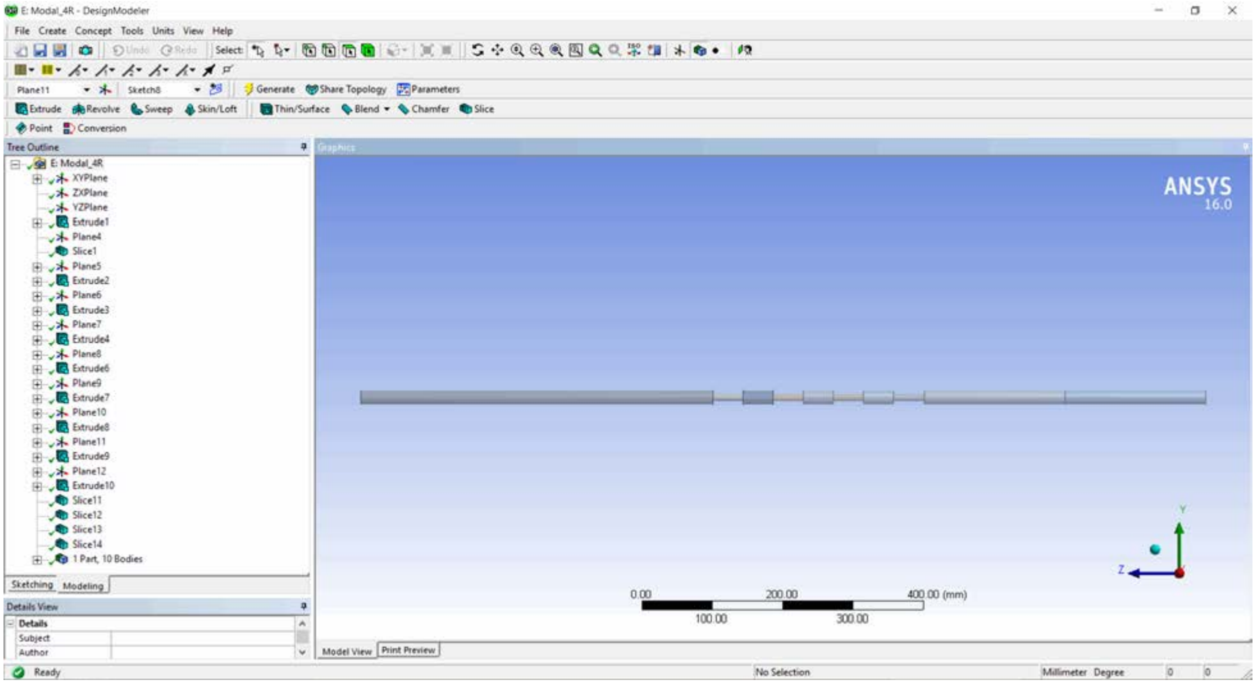


Figure 34: Alternative 3 Modeling, Four Rubber Segments

Analysis Setup

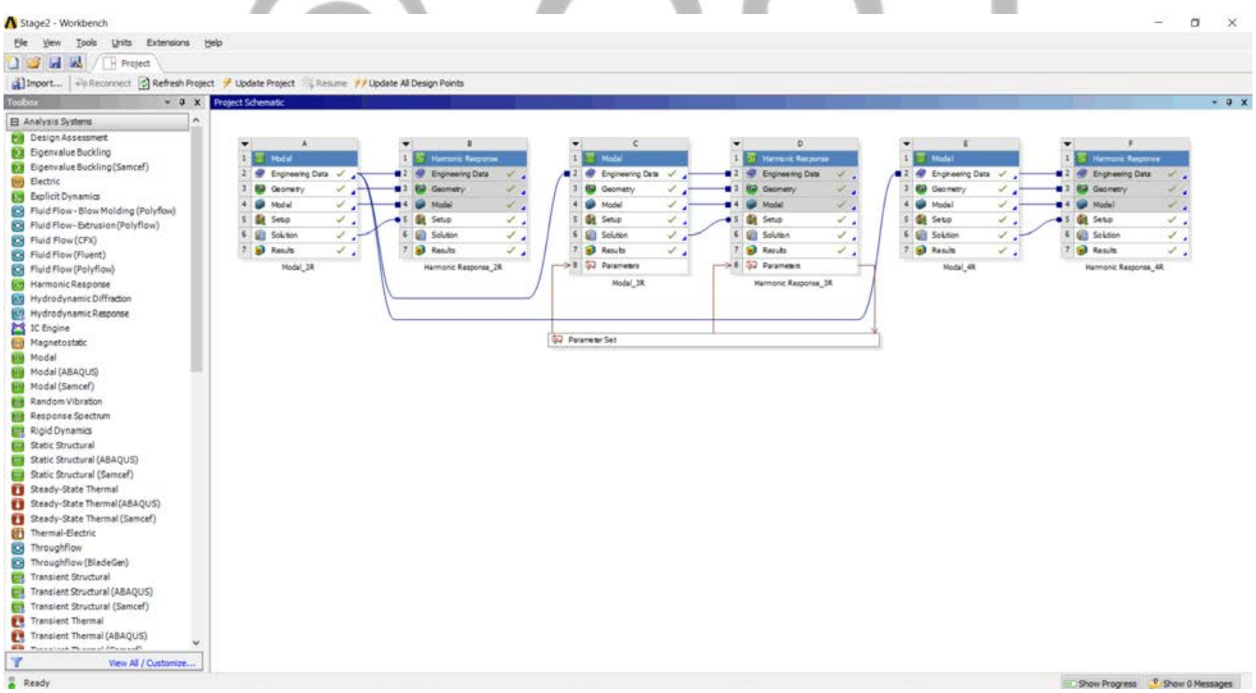


Figure 35: Overall Analysis Setup of Stage Two

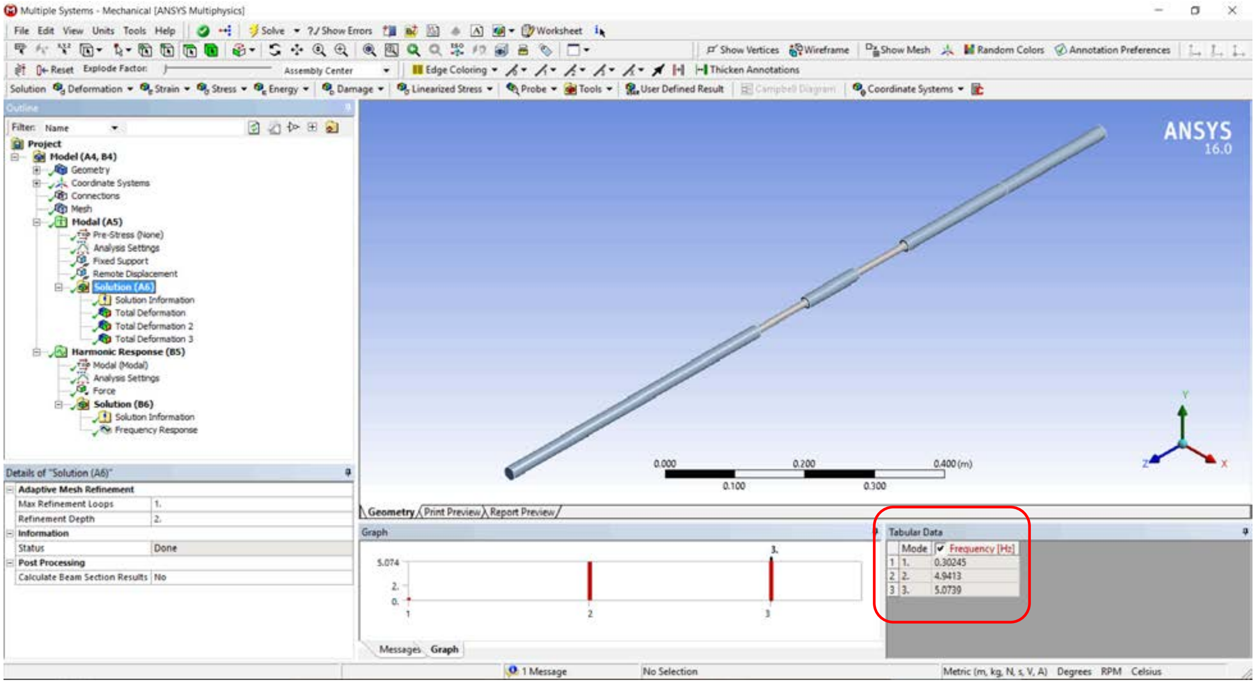


Figure 36: Alternative 1 Overall Analysis Showing First Three Natural Frequencies

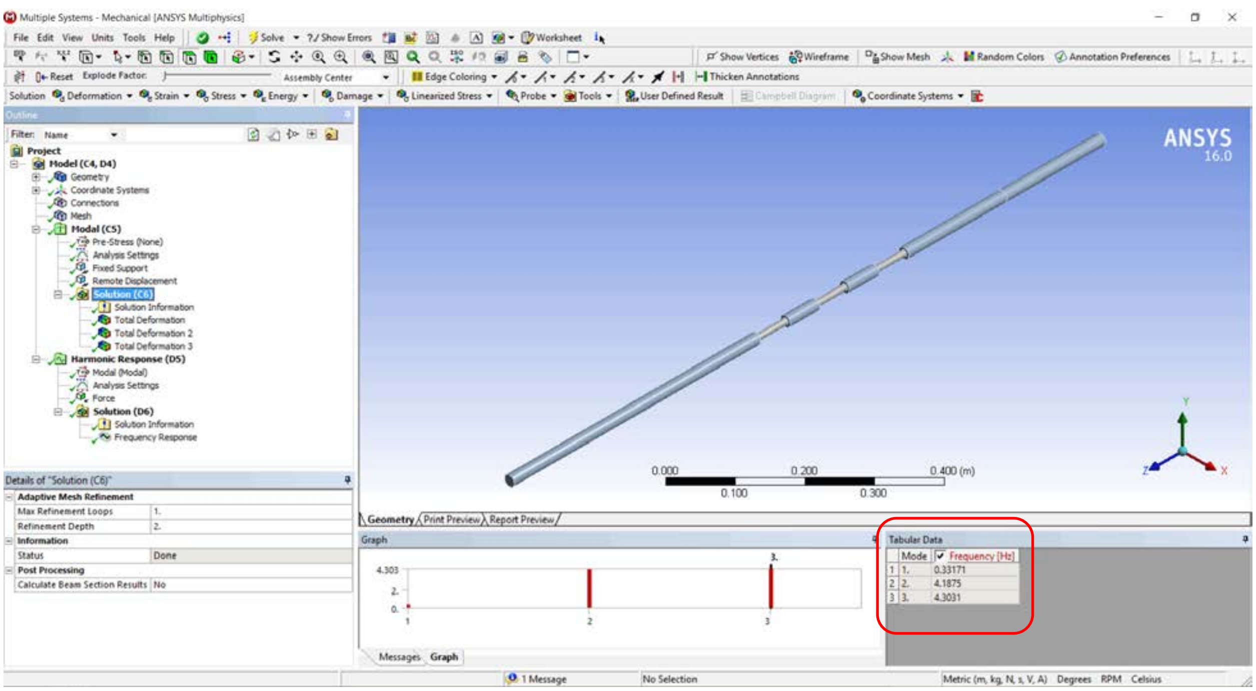


Figure 37: Alternative 2 Overall Analysis Showing First Three Natural Frequencies

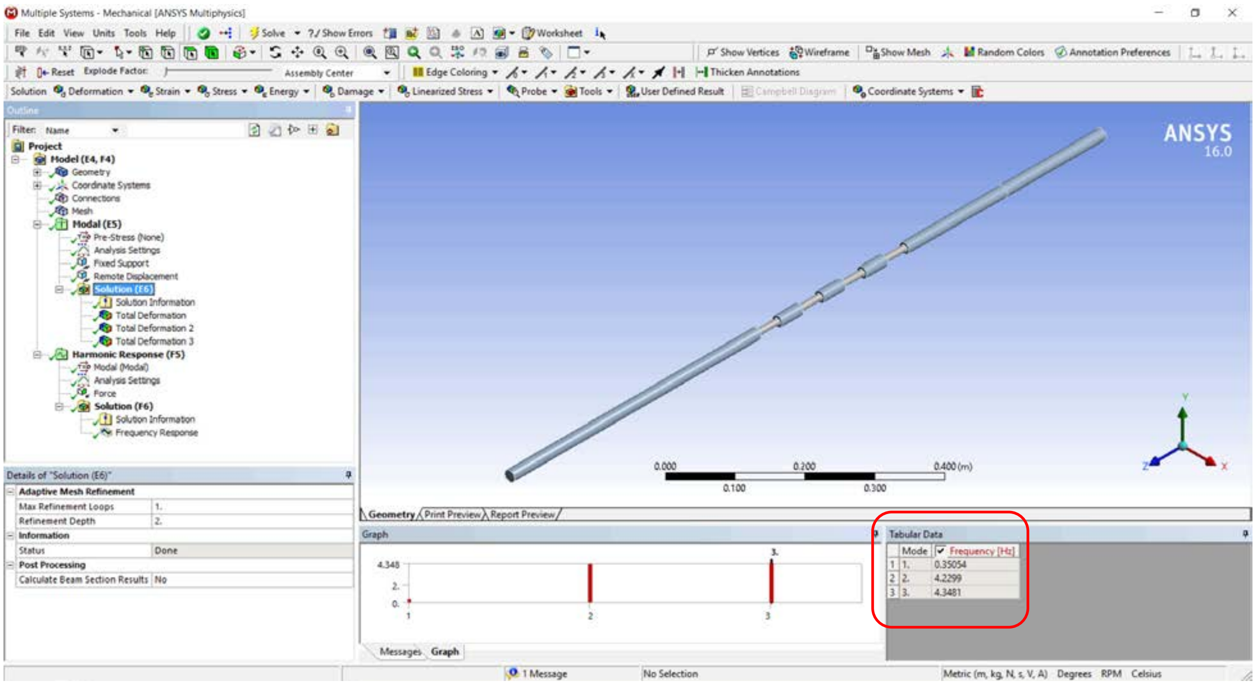


Figure 38: Alternative 3 Overall Analysis Showing First Three Natural Frequencies

Results and Discussion

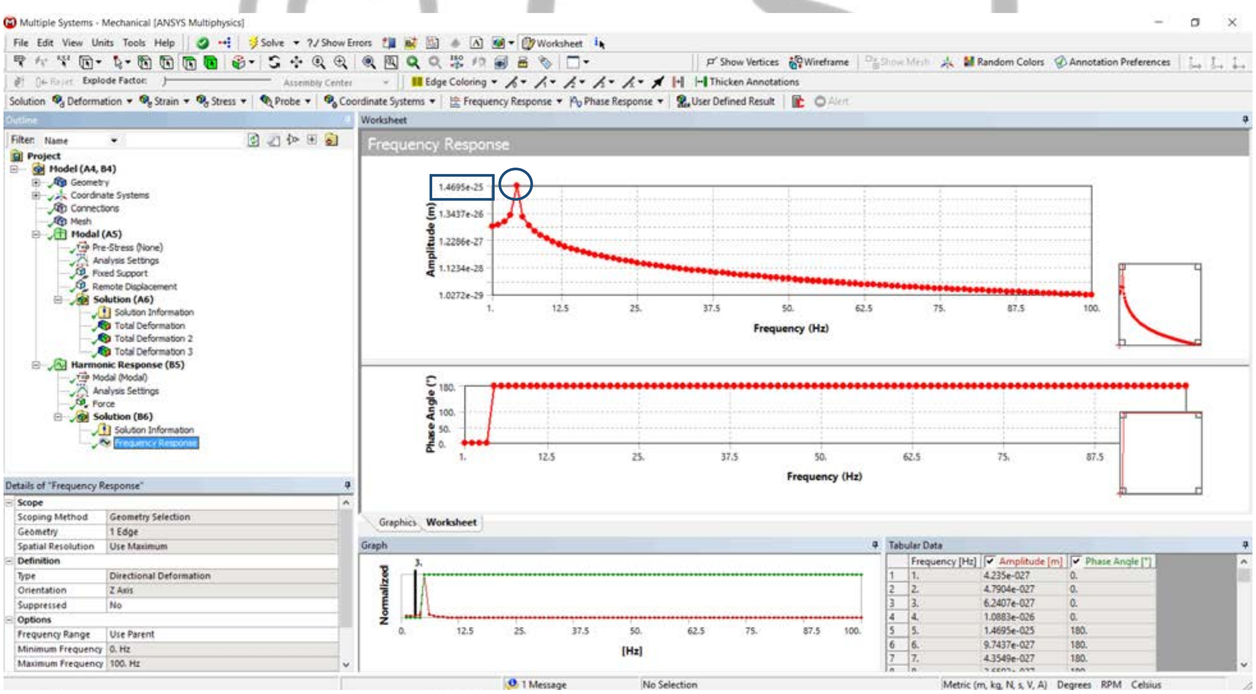


Figure 39: Alternative 1 Frequency Response

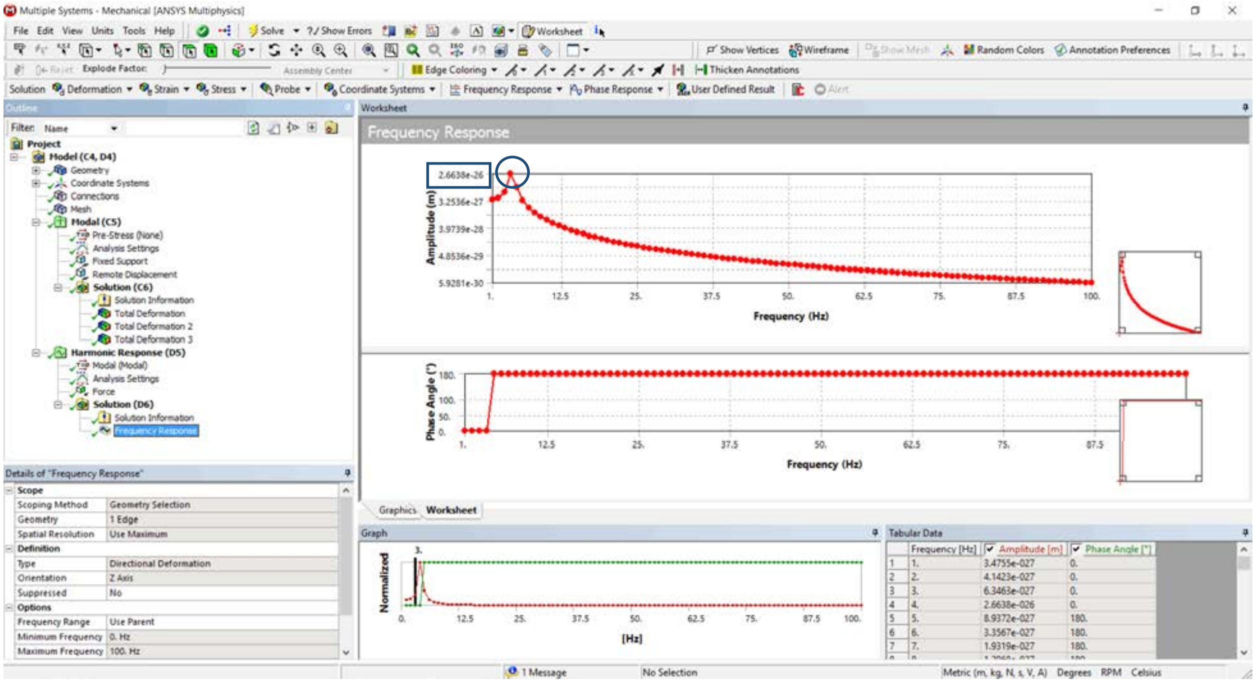


Figure 40: Alternative 2 Frequency Response

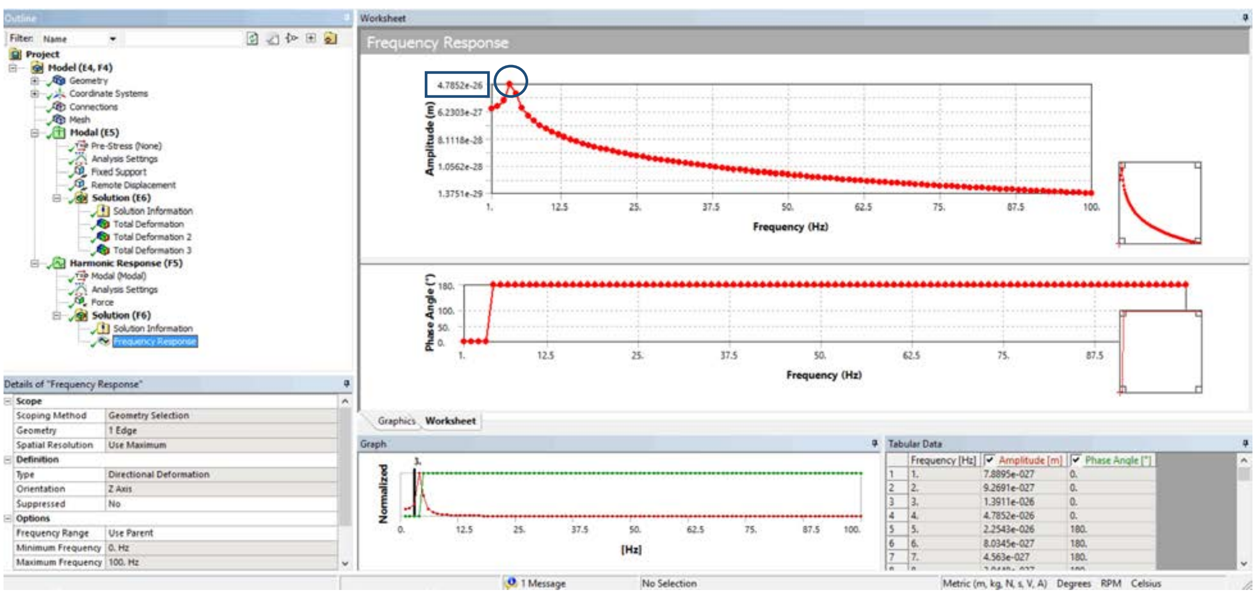


Figure 41: Alternative 3 Frequency Response

As Case 4 was chosen according to previous analysis, three alternatives are developed in order to obtain the optimal number of cells and their lengths. For alternative 1 with two rubber cells, as can be seen from Figure 39, the maximum amplitude is to be found as 1.47×10^{-25} m. For alternative 2 with three rubber cells, as can be seen from Figure 40, the 2.66×10^{-26} m is the maximum amplitude recorded. Alternative 3 with four rubber cells records maximum amplitude of 4.78×10^{-26} m as demonstrated in Figure 41. Thus, it can be concluded that alternative 2 is the best alternative from vibration perspective as its maximum amplitude in the frequency response is the lowest.
Note: in this study, two to four cells of rubbers are used which is recommended by the team for manufacturing purposes.

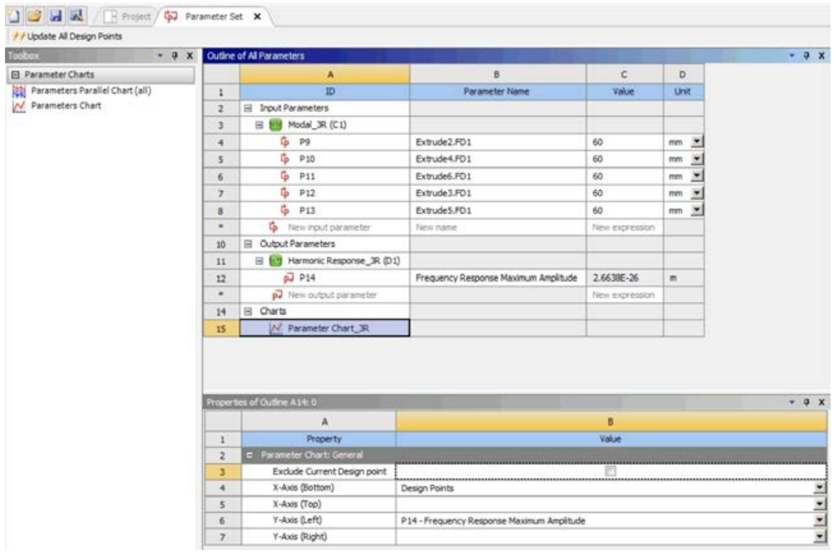


Figure 42: Alternative 2 Parametric Analysis to Obtain Optimal Segments Lengths

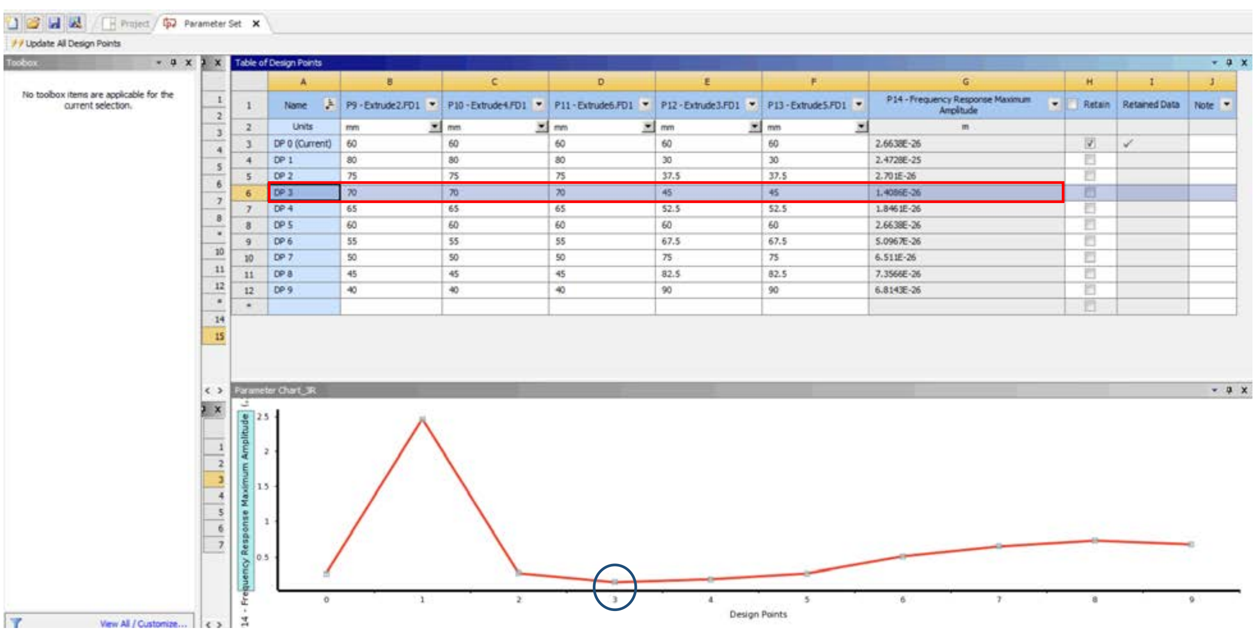


Figure 43: Alternative 2 Parametric Analysis Results

One of the aims of this study is to obtain the optimal lengths of cells called L_A, length of rubber segment, and L_B, length of structural steel segment. For that to be done, a parametric analysis is carried with various values. However, the setting is shown in Figure 42 while its results are demonstrated in Figure 43. Therefore, design point 3 has the lowest vibration effect with L_A = 70 mm and L_B = 45 mm.

Conclusion and Recommendations

Summing up everything has been done in this project is a necessity as it makes everything easy for the reader to go through. Therefore, the project from beginning to end is to be concluded in this section. Starting from providing a background of what is passive control and periodic structures, one can understand their concepts where passive control refers to vibration isolation using passive techniques explained above while periodic structures are divided into two types: geometric and material which have the ability to minimize vibration. Secondly, the project is titled as "Passive Control of Axial Vibration of Fixed-Free Rods using Periodic Structures" with consideration of four cases as mentioned earlier. The objective is to compare these cases from vibration point of view, analysis the best one and provide diameter, D, cells lengths, L_A and L_B which effects the rod with minimum vibration. These values were obtained using parametric analysis in order to reach optimal results. Therefore, the project was divided into two stages, each stage has its own modeling, analysis and results discussion. In conclusion, the recommended results of this study comes to be D = 11 mm, L_A = 70 mm and L_B = 45 mm. On the other hand, the team suggests other recommendations for further study such as that redesigning the portion of the bar using other materials which reduces vibration over millions of cycles without degrading such as Sorbothane®[iii]. Also, parametric study can be performed with a wider range of cells diameter values, D, cells lengths, L_A and L_B, in the purpose of having much more accurate results. This accuracy of results might affect the vibration significantly.

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[i] Reitherman, Robert (2012). Earthquakes and Engineers: An International History. Reston, VA: ASCE Press. ISBN 9780784410714.
[ii] Mead, D.J., "Wave Propagation in Continuous Periodic Structures: Research Contributions From Southampton, 1964-1995", Journal of Sound and Vibration, Vol. 190, No. 3, 1996, pp. 495-524
[iii] Sorbothane website, http://www.sorbothane.com/what-is-the-best-material-to-reduce-vibration.aspx, accessed on [26/12/2015 G]

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