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Modal and Vibration Analysis on Railway Viaduct Structure

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Abstract: This paper investigates the vibration modes, boundary conditions, natural frequency, and harmonic response of the viaduct structure. By using ANSYS software, two different analysis need to be measured which are modal analysis and vibration analysis. Finite Element Analysis is used to verify natural frequencies and boundary conditions for the vibration of the bridge. Modal analysis is used to determine the meshing of the geometry, material properties (structural steel and concrete) and natural frequency, and mode shape of the viaduct. The twenty-mode shape are deformed as results from the natural frequency. The vibration analysis is used to measure the harmonic response and boundary conditions including fixed support and forces on the railway viaduct. The frequency range that acting on the viaduct is between 0 Hz to 50 Hz for five intervals. At 50 Hz, the deformation of the bridge is appeared after solving in the simulation software.

Keywords: Modal Analysis, Vibration Analysis, Viaduct Structure

1. Introduction

The transportation sector has adopted larger vehicles with heavier axle loads to keep up with fast development. This includes reconstruction of the public transport infrastructure of light rail transit system (LRT). The existence of viaduct and bridges made the routes easier for this LRT to reach their destinations. A viaduct is a system of linked bridges that spans low ground, like a valley or wetland, and often takes the form of a series of arches. When a train passes through the viaduct, the vibration produced by high-speed trains is studied and investigated. In this study, the vibration structure analysis, natural frequency of the bridge is examined from the measurement results. Finite Element Method and ANSYS software are used to verify the natural frequencies for vibration. (Gu et al., 2022).

A completely enclosed sound barrier has gradually been added to high-speed rail systems. Its main function is to reduce railway traffic noise. However, wheel-rail interactions, train pulsation pressure, and the force of the wind all cause a fully enclosed sound barrier to vibrate violently, which can cause deformation, destruction, plate shedding, and structural member fatigue. Because of the secondary structure- borne noise that vibrations cause them to produce, it has turned into a source of noise. (Zheng et al., 2022).

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The objectives of this study are to determine the vibration modes and vibration responses to wheels rail vibration forcing. Next, to differentiate the modal and vibration analysis for the viaduct structure. This study will investigate the characteristics of modal and vibration analysis in terms of material properties, meshing, boundary conditions, natural frequency, and total deformation.

2. Materials and Methods

2.1 Materials properties

The viaduct structure that modelled by the SOLIDWORKS Software for the modal and vibration analysis was referred to the data from the Institute of Noise and Vibration, Universiti Teknologi Malaysia (UTM), Skudai, Johor. The material that is used in this geometry is structural steel and concrete. These two materials were chosen because of coefficient in thermal expansion, and it is possible to connect the steel rods and concrete in a way that is suitable. Additionally concrete shields the reinforcing steel from corrosion and flames. Besides of the material, the density, Young's Modulus, Poisson Ratio, Bulk and Shear Modulus also included in the material properties. Table 1 shows the material properties of concrete while Table 2 shows the material properties of structural steel.

Table 1: The material properties of concrete

No	Property	Value	Unit
1	Density	2300	kgm^{-3}
2	Coefficient of thermal expansion	1.4E-05	C^{-1}
3	Reference temperature	22	C
4	Young's Modulus	3E+10	Pa
5	Poisson Ratio	0.18	
6	Bulk Modulus	1.5625E+10	Pa
7	Shear Modulus	1.2712E+10	Pa

Table 2: The material properties of structural steel

No	Property	Value	Unit
1	Density	7850	kgm^{-3}
2	Coefficient of thermal expansion	1.2E-05	C^{-1}
3	Reference temperature	22	C
4	Young's Modulus	2E+11	Pa
5	Poisson Ratio	0.3	
6	Bulk Modulus	1.6667E+11	Pa
7	Shear Modulus	7.6923E+10	Pa

2.2 Designing the viaduct structure.

The design of the viaduct structure started with designing and sketching in SOLIDWORKS software. The sketching includes the assembly, part, and drawing. Figure 1 shows the isometric view of the viaduct structure.

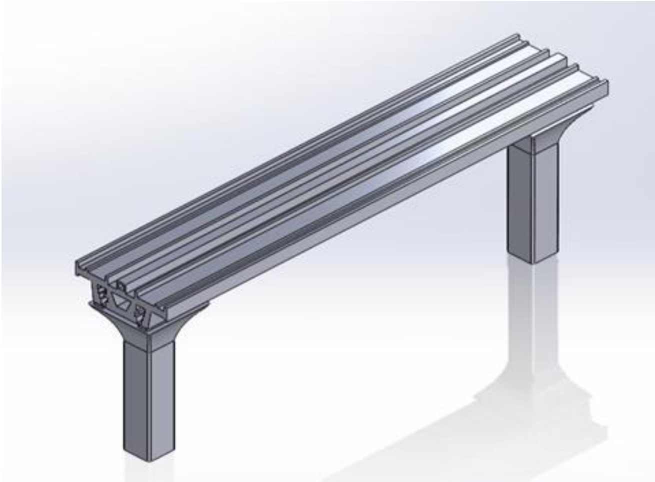


Figure 1: The isometric view of the viaduct structure.

After the designing bridge has been completed, the SOLIDWORKS file must be saved in STP format to import the geometry into the ANSYS software. Figure 2 shows the bridge structure that has been imported in the ANSYS Software.

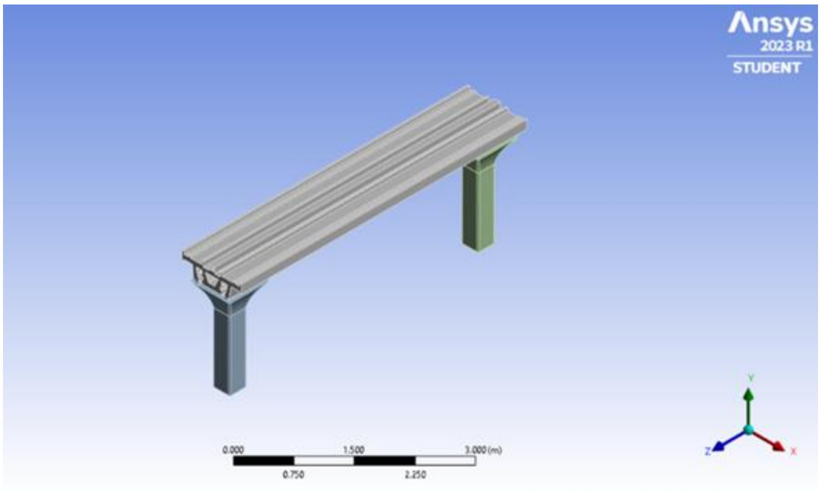


Figure 2: The bridge structure that has been imported in the ANSYS Software.

2.3 Meshing

In ANSYS Software, the function of the meshing is to lessen the time to get the accurate results. This is because to obtain the simulation results, it is usually taking a long time to solve it. The element size for this meshing is 0.05 m. Table 3 shows the value of nodes and element after the mesh has been generated.

Table 3: The nodes and element value after the mesh has been generated.

Statistics	Values
Nodes	122 647
Elements	45 122

After the mesh has been generated, the fixed support is added and generated, the natural frequency appears in 20 modes.

2.4 Harmonic Response

In the harmonic response, there are analysis settings that had minimum and maximum range for the natural frequency. The range for the bridge to deform is between 0 Hz to 50 Hz and has 5 solution intervals. After the analysis has been set up, the boundary conditions which is fixed support and force are added to the viaduct structure. Figure 3 shows the boundary conditions that are applied in the ANSYS Software.

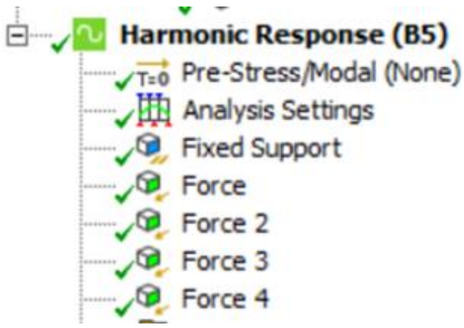


Figure 3: The boundary conditions in the ANSYS Software

3. Results and Discussion

For the results, modal analysis and vibration analysis will be discussed based on the simulation software. The harmonic response, boundary condition, and total deformation of the data from UTM and data from the software simulation will be deliberate and compared.

3.1 Modal Analysis

The objective of the modal analysis is to helps engineers understand the dynamic behavior of the viaduct under various loading conditions, identify its natural frequencies and mode shapes and evaluate its response to dynamic loads. From the geometry, there is a difference between the actual data and the simulation data. Since the dimension for the actual data has not given, so the assumed dimension for the viaduct structure is constructed by SOLIDWORK Software. Figure 4 (a) shows the actual geometry for the actual data while Figure 4 (b) shows the geometry that was designed from SOLIDWORKS. For the meshing analysis, the element size that applied is 0.05m. The value is chosen because to get the value that is nearest with the actual data. After the mesh has been generated, there is a slightly different value for the nodes and element. Figure 4 (a) shows the meshing from the actual data while Figure 4 (b) shows the meshing from the simulation data. Table 4 shows the comparison between actual data and simulation data.

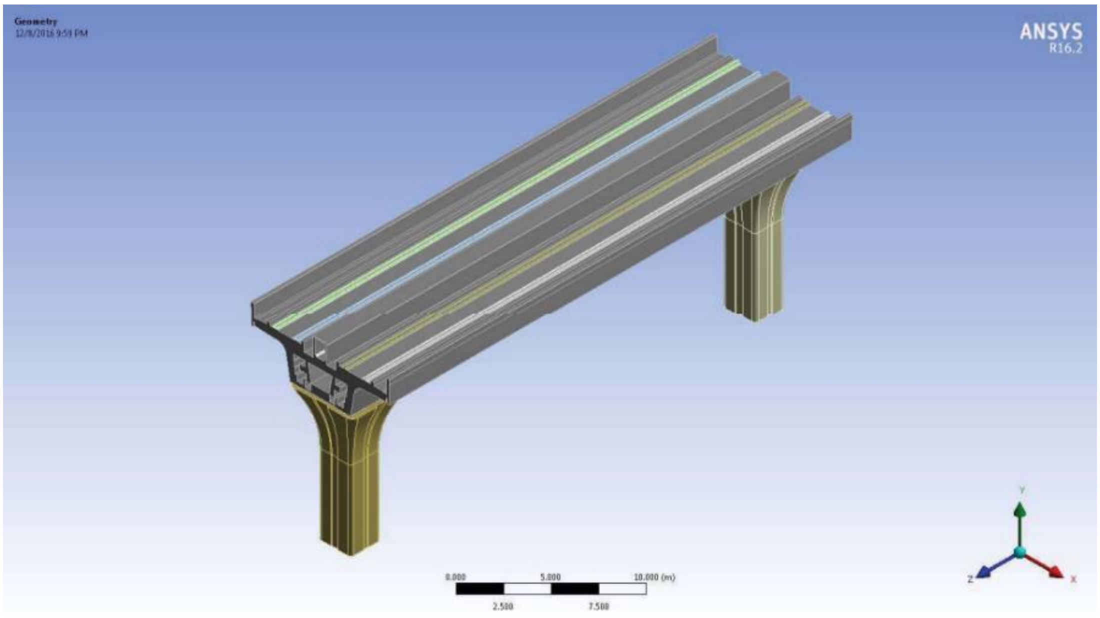


Figure 4 (a): The actual geometry of bridge structure.

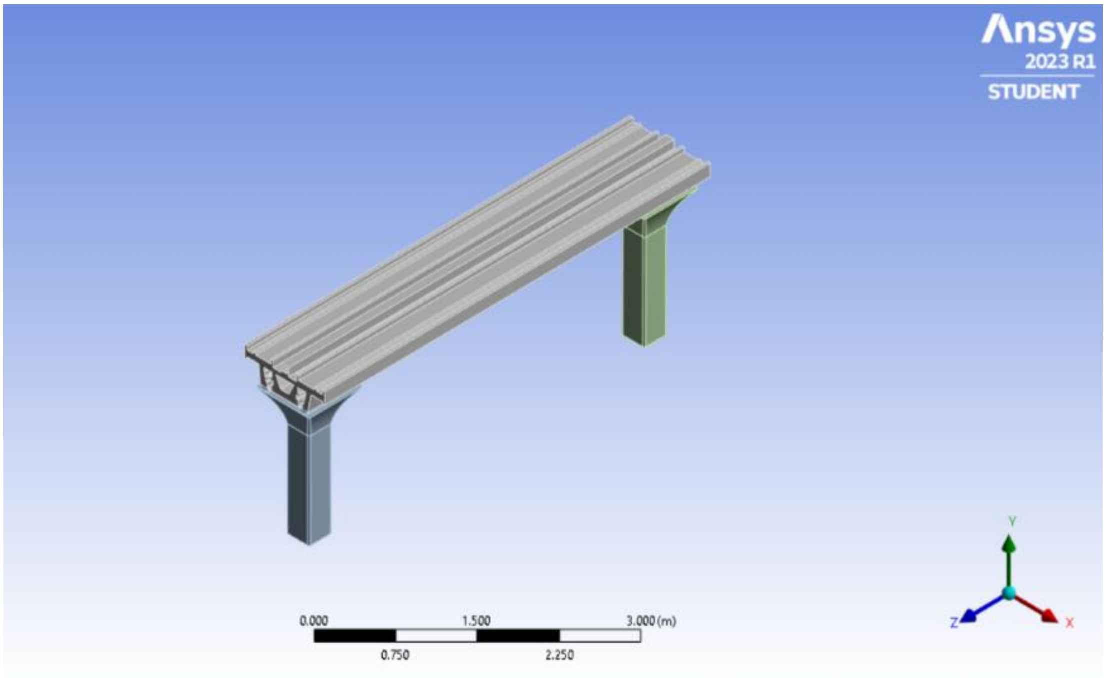


Figure 4 (b): Bridge structure design imported from SOLIDWORKS file.

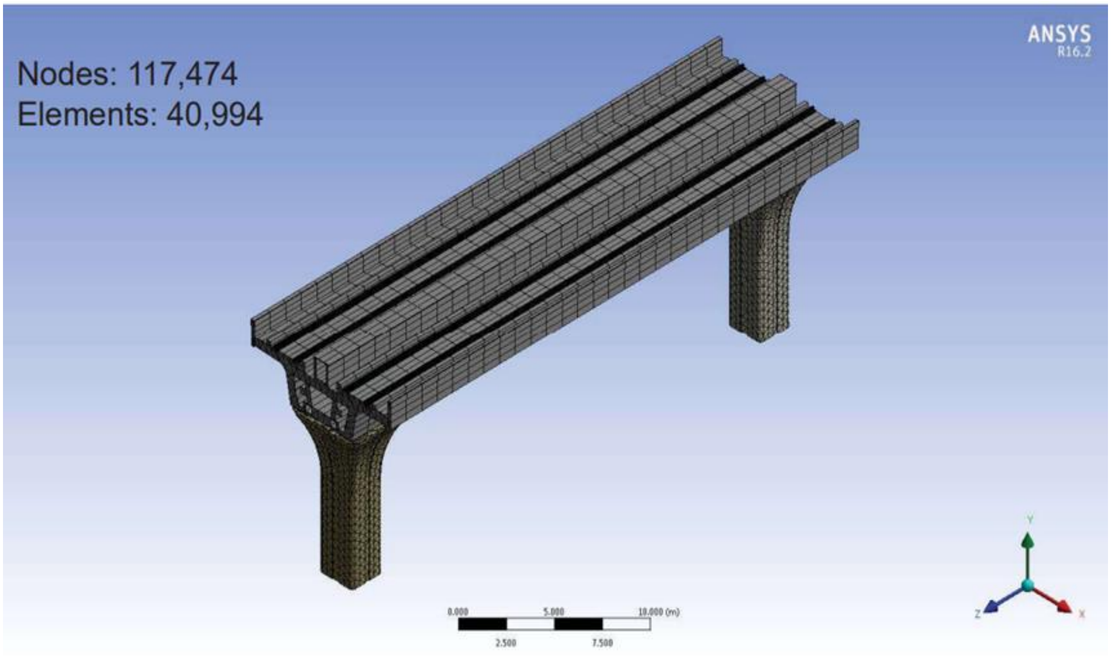


Figure 4 (a) Meshing from actual data.

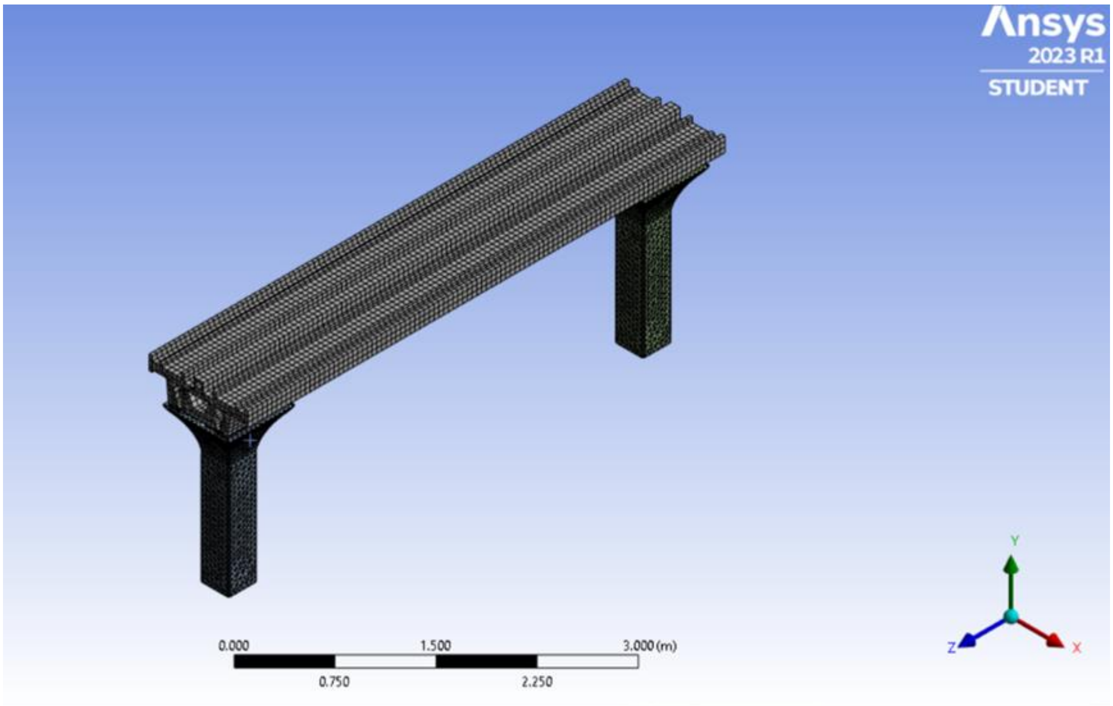


Figure 4 (b): Meshing data from ANSYS Software

Table 4: Comparison between actual data and simulation data

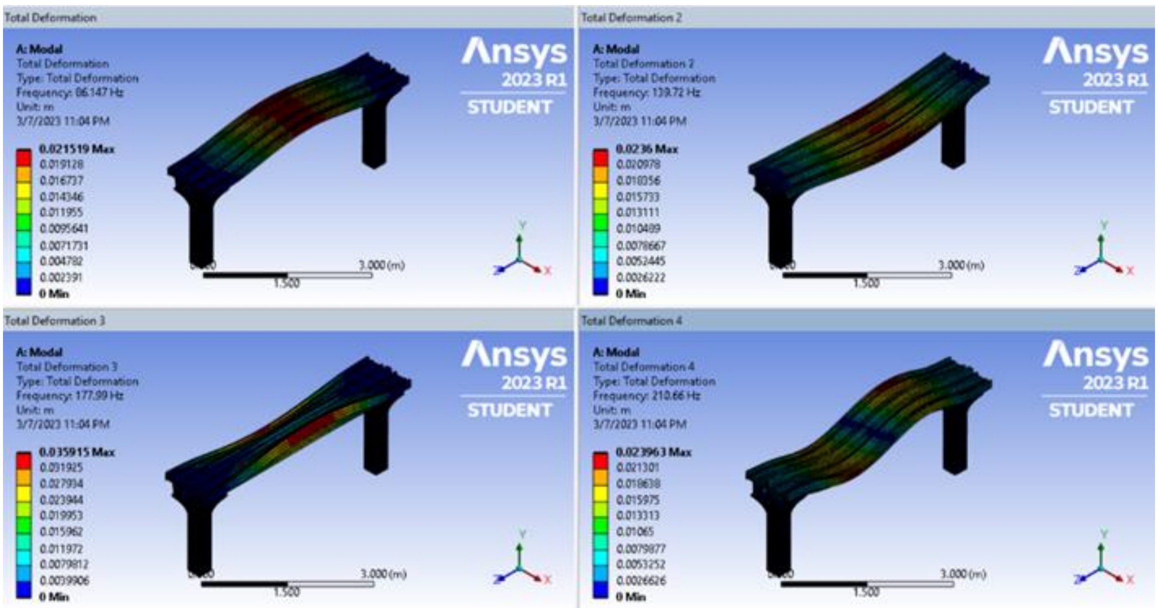
	Actual Data	Simulation Data
Nodes	117 474	122 647
Element	40 994	45 122

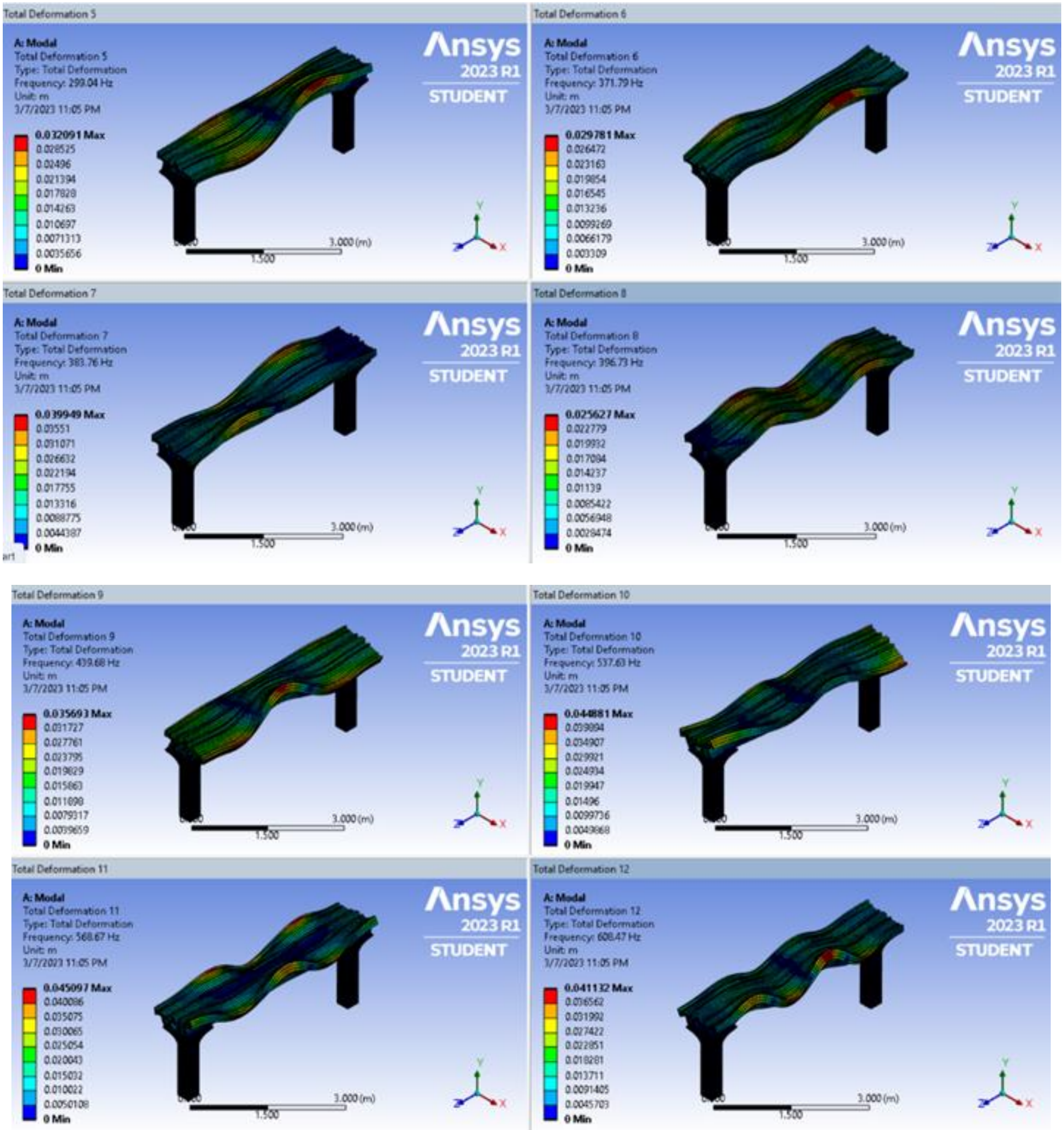
For the boundary conditions, fixed support is applied to both bridge structures. In terms of mode shape and natural frequency, the actual data had a range between 0 Hz to 50 Hz while the simulation data had a frequency range between 80 Hz to 900 Hz. Mode shape refers to the deformation of the bridge when it vibrates at natural frequency. From the frequency, mode shape can be created at the software. Table 5 shows the different values of frequency for twenty modes.

Table 5: Number of frequencies of actual data and simulation data based on 20 modes.

No of modes	Actual Data (Hz)	Simulation Data (Hz)
1	2.3	86.15
2	4.7	139.72
3	5.0	177.72
4	8.4	210.66
5	13.5	299.04
6	21.0	371.79
7	21.0	383.76
8	22.3	396.73
9	28.7	439.68
10	31.8	537.63
11	35.9	568.67
12	36.0	608.47
13	37.3	666.92
14	39.3	688.85
15	41.2	700.74
16	43.9	711.39
17	45.5	723.36
18	46.0	734.08
19	46.1	773.25
20	47.8	814.52

In the software simulation, the natural frequency needs to be selected to achieve the results of mode shape. Figure 4 below shows the results of total deformation of bridge structure for 20 modes.




Total Deformation 5
A: Modal
Total Deformation 5
Type: Total Deformation
Frequency: 299.04 Hz
Unit: m
3/7/2023 11:05 PM
0.032091 Max
0 Min
Ansys
2023 R1
STUDENT
Total Deformation 6
A: Modal
Total Deformation 6
Type: Total Deformation
Frequency: 371.79 Hz
Unit: m
3/7/2023 11:05 PM
0.029781 Max
0 Min
Total Deformation 7
A: Modal
Total Deformation 7
Type: Total Deformation
Frequency: 383.76 Hz
Unit: m
3/7/2023 11:05 PM
0.039949 Max
0 Min
Total Deformation 8
A: Modal
Total Deformation 8
Type: Total Deformation
Frequency: 396.73 Hz
Unit: m
3/7/2023 11:05 PM
0.025627 Max
0 Min
Total Deformation 9
A: Modal
Total Deformation 9
Type: Total Deformation
Frequency: 439.68 Hz
Unit: m
3/7/2023 11:05 PM
0.035693 Max
0 Min
Total Deformation 10
A: Modal
Total Deformation 10
Type: Total Deformation
Frequency: 537.63 Hz
Unit: m
3/7/2023 11:05 PM
0.044881 Max
0 Min
Total Deformation 11
A: Modal
Total Deformation 11
Type: Total Deformation
Frequency: 568.67 Hz
Unit: m
3/7/2023 11:05 PM
0.045097 Max
0 Min
Total Deformation 12
A: Modal
Total Deformation 12
Type: Total Deformation
Frequency: 608.47 Hz
Unit: m
3/7/2023 11:05 PM
0.041132 Max
0 Min
3.000 (m)
1.500

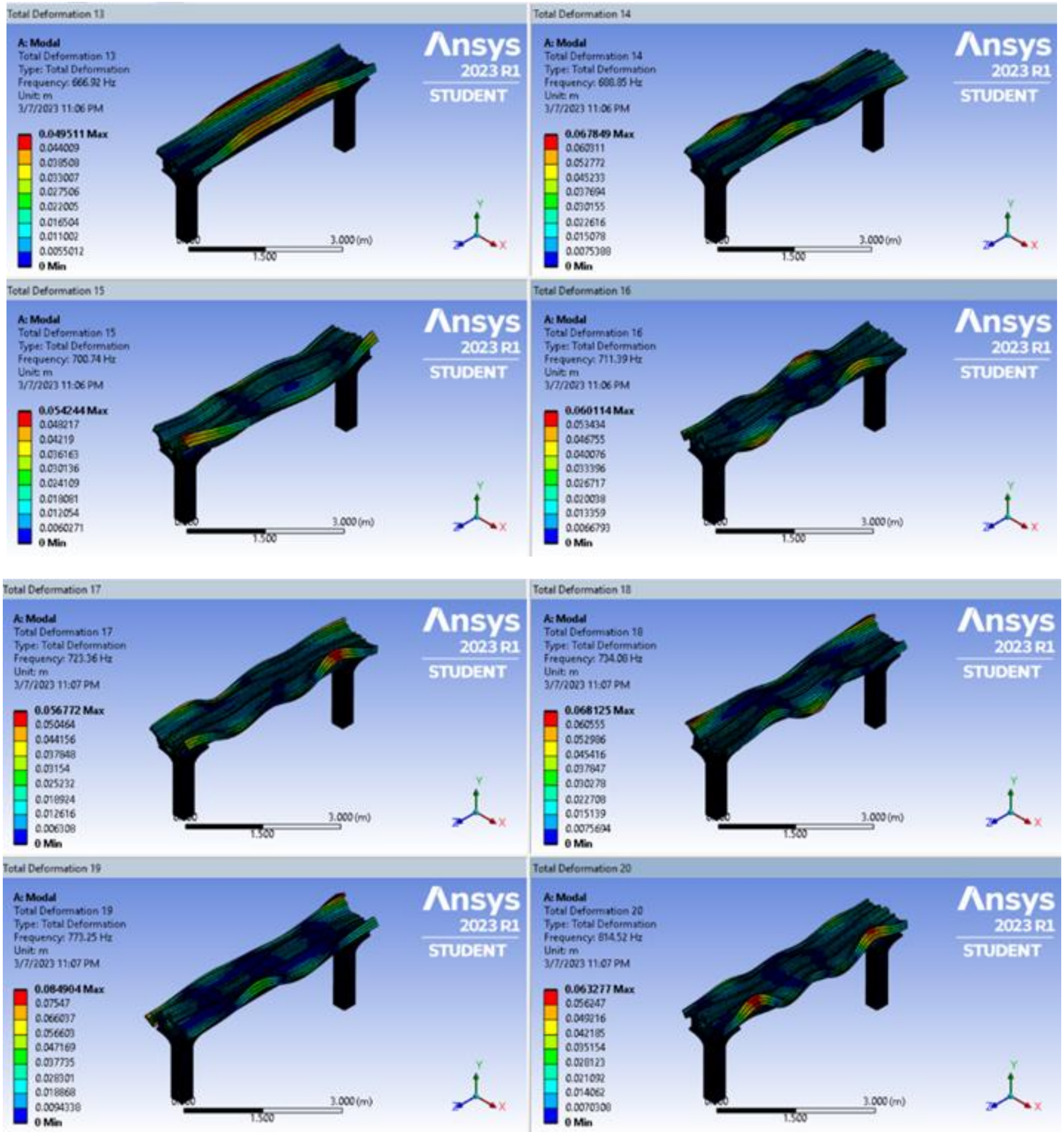


Figure 4: Total deformation of bridge structure for 20 modes

From the diagram above, the mode shape results show the system's motion at various resonance frequencies. The displacement patterns of the system's parts during vibration are represented by mode shape. each of the mode shapes from the first until the last has a different value. The most deform bridge is at the nineteen modes where the value is 0.084904 at the maximum while the least deform is at the first modes where the value is 0.021519 at the maximum point. At the 19th mode shape, the maximum point is at the end of the bridge while for the 1st mode, the maximum point is at the center of the bridge. The energy that exchanges back and forth between kinetic and potential energy to produce vibration can influence vibration behavior. The result of this vibration behavior may cause an initial excitation and a forcing periodic motion.

3.2 Vibration Analysis

For the vibration analysis, harmonic response will be discussed. A structure's response to dynamic loading with sinusoidal repetition is predicted using harmonic response analysis. This analysis will discuss the concepts such as natural frequency, mode shapes and resonance when the force is applied to the structure. In the ANSYS Software, the boundary conditions are applied to the structure including fixed support and four forces which is the value for each of the force is 4.75e+005 kN. The value for the forces is based on the boundary condition in the actual data of UTM. Figure 5 (a) shows the boundary condition from the actual data while Figure 5 (b) shows the force that applied to the viaduct structure.

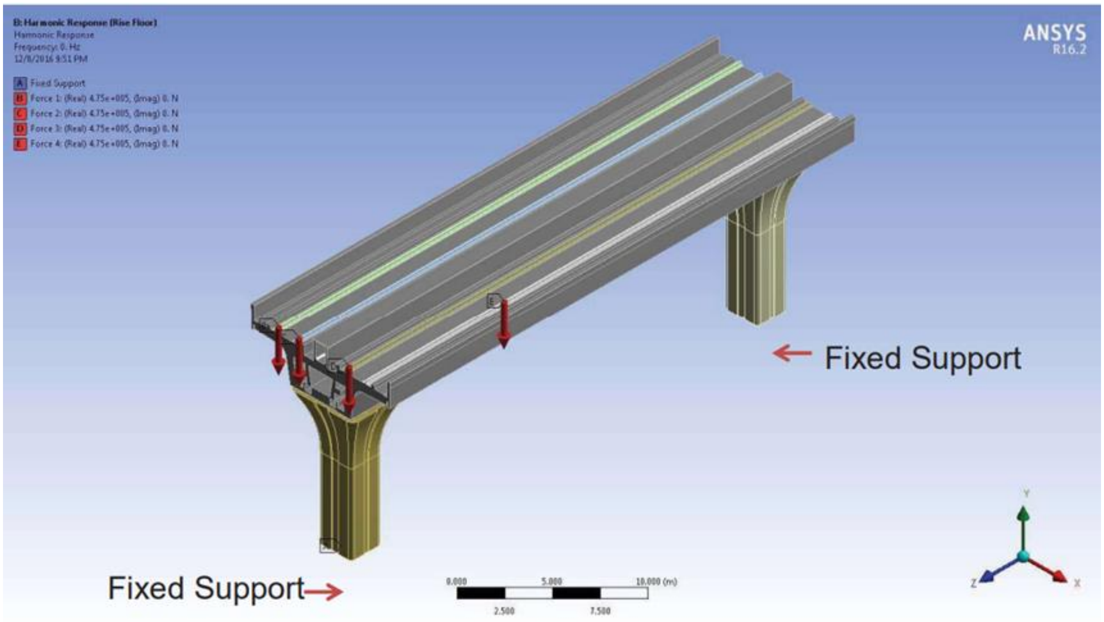


Figure 5(a): The boundary condition from the actual data.

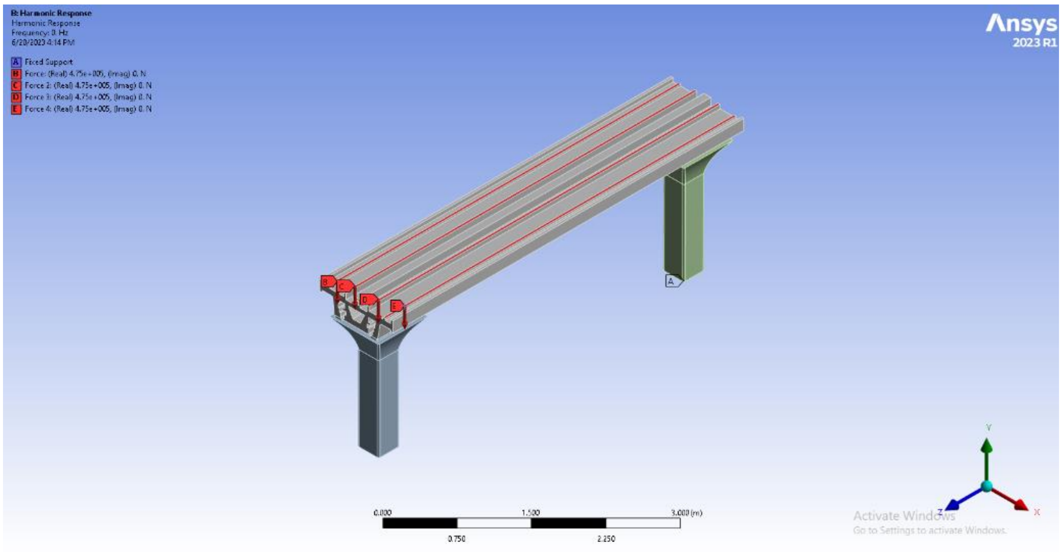


Figure 5(b): Fixed support and force applied to the structure.

After the boundary conditions have been applied to the bridge structure, the simulation software will calculate the total deformation for the bridge for 50 Hz. Total deformation refers to the overall displacement and distortion of a structure due to applied loads or constraints. It represents the cumulative effect of all displacements and deformations that occur in the structure during the analysis. The software calculates the resulting displacement and deformations for the model. Figure 6 (a) shows the total deformation from the actual data. while figure 6 (b) shows the total deformation of the viaduct structure that has been solved.

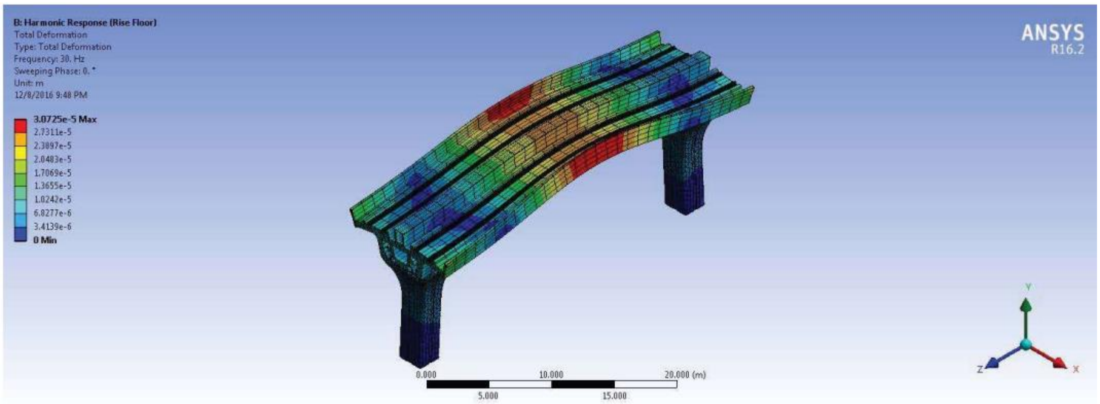


Figure 6 (a): Total deformation at 30 Hz from the actual data.

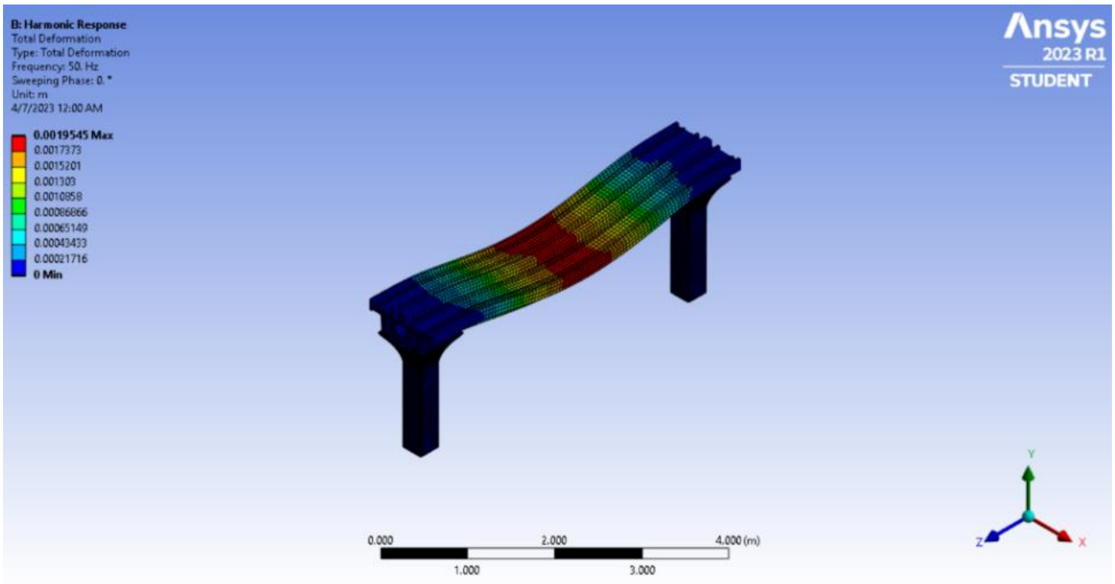


Figure 6 (b): Total deformation of the viaduct structure from the simulation software

From the diagram above, the maximum point is at the center of the bridge with the value of 0.0019545. The maximum point at the center shows that the bridge structure has the maximum deflection and the bending moment of a bridge and has a highest point.

4. Conclusion

The bridge structure is designed from SOLIDWORK software based on the actual data from UTM and the dimension was assumed since the actual dimension is not given. From SOLIDWORKS, the design is imported to the ANSYS software to analyze the modal and vibration analysis. Based on the result at chapter 4, the data from the simulation software and the actual data is slightly different due to the geometry design, dimensions, and others. The analysis setting is set up from 0 Hz to 50 Hz to define and control the parameters such as material properties and boundary conditions. Fixed support and forces are included in the boundary conditions. Since the simulation gives different data from the actual data, the result which is total deformation is also different. From the simulation software, the shape of the viaduct is suspended while the shape of the viaduct for the actual data is arch bridge.

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