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AN INVESTIGATION OF THE BEHAVIOR OF MECHANICAL STRUCTURES DUE TO VIBRATION USING ANSYS

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Abstract--*The paper exhibits the modal analysis and harmonic response of the model of a simply supported steel truss bridge as a mechanical structure. The geometric modeling and the simulations were done by using ANSYS Workbench 15.0. The natural frequencies were determined by means of modal analysis for the first fifteen modes whereas the harmonic response was observed by subjecting the bridge to an excitation sinusoidal force of 100N distributed over the deck of the bridge with an analysis range of 0-1000Hz. The bridge-load interactions are graphically and analytically portrayed in terms of total deformations and equivalent stresses with respect to the variation of frequencies. All these analytical and graphical results reflect the possibilities of multiple degrees of vibrations and provide a comprehensive geometric optimization to prevent potential resonance to the model of the steel truss bridge which would lead to a practical implementation of such a steel truss bridge.*

Keywords: Modal Analysis, Harmonic Response, ANSYS, Steel Truss Bridge

1. INTRODUCTION

Bridges tend to use high strength materials. Therefore, their structure is very slender. Specifically, the steel truss bridges, which have a mechanical structure, are very sensitive to dynamic loadings such as wind, earthquake and vehicle movement [1]. As bridge span gets longer, they become more flexible and prone to vibrate. The geometry and the materials used for such a bridge play crucial roles in the possible occurrence of resonance-which is due to the superposition of the frequency of the external sinusoidal forces acted upon it and the structures' own natural frequencies [2]. Vibration can have several levels of consequences; from a potentially hazardous effects(causing immediate structural failure) to a more extended effect like structural fatigue [7]. In addition, vibrations affect safety as well as comfort of users and limit service ability of the bridge. Therefore, extensive studies have been carried out to understand mechanisms behind bridge vibrations and to reduce this undesirable vibration effect.

2. THEORETICAL DESCRIPTIONS

Modes are intrinsic features of a structure, and are defined by the mass, damping, stiffness and boundary conditions of the structure [9]. Each mode is characterized by natural frequencies, modal damping and a mode shapes. Modal analysis is essentially concerned with the determination of mode shapes (eigenvectors), modes (eigen values), natural frequencies and to some extent, the damping ratios of a system subjected to vibration [14]. The determination of the aforementioned properties is essential in order to prevent the destructive impacts caused by possible resonant vibrations [13] and to observe the response of various dynamic loads imposed on the system [6]. The harmonic response refers to the response of a system to sinusoidal external force of a specified frequency imposed on the system. When the frequency of the harmonic excitation has the same frequency as any of the natural frequencies of the vibratory system, resonance occurs which subjects the system to a possible structural failure.

3. GEOMETRIC AND MECHANICAL PROPERTIES OF THE STEELTRUSS BRIDGE

The model of the steel truss bridge had the following dimensions and specifications as shown in Table 1.

Table 1: Dimensions and specifications of the steel truss bridge model

Parameters	Specification
Length	8.0 m
Width	2.0 m
Thickness	0.5 m
Volume	8.1394 m³
Mass	63895 kg
Nodes	317
Elements	184

The material selected for the model of the steel truss bridge subjected to modal analysis and harmonic response observation was structural steel [10][16]. The mechanical properties of structural steel are shown in Table 2.

Table 2: The mechanical properties of structural steel

Parameters	Specification
Density	7850 kg/m^3
Young's Modulus	2.e+005
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+011 Pa
Shear Modulus	76923e+006 Pa
Yield Strength	250e+006 Pa
Ultimate Strength	460e+006 Pa

3.1 Mesh Specifications

The solid model of the steel truss bridge was imported to ANSYS workbench and the volume of the model was meshed into individual elements [11]. The properties of generated mesh of solid model are shown in Table 3 and the generated mesh of solid model is shown in Fig. 1.

Table 3: Properties of generated mesh

Parameter	Specification
Relevance Center	Fine
Young's Modulus	Medium
Angle Center	Coarse
Minimum Size	Default (100.0 mm)
Maximum Face Size	Default (500.0 mm)
Minimum Edge Length	2000.0 mm

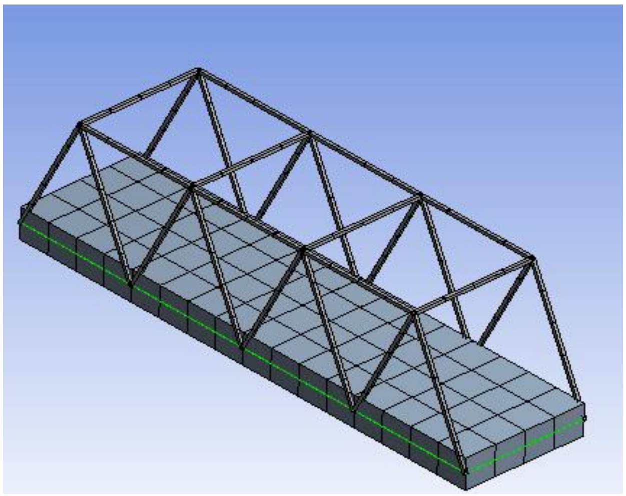


Fig. 1: Generated Mesh of the Solid Model

4. MODAL ANALYSIS OF THE STEEL TRUSS BRIDGE

The modal analysis was carried out for two conditions. The analysis settings used, along with the descriptions and 3D pictorial illustrations of both of the analytical cases are provided in the following discussions. The two cases are considered for analyzing the model. They are without supports and with supports at the end faces of the deck of the bridge. The analysis settings used in modal analysis for both cases are shown in Table 4.

Table 4: Analysis settings used in modal analysis

Analysis Settings	Value
Physics Type	Structural
Solver Target	Mechanical APDL
Environment Temperature	22 °C
Initial Condition	*Pre-Stress (None)*
State	Fully Defined
Maximum Modes to Find	15

Case 1: With no supports provided

In this case, there were no supports provided to the at the end faces of the deck of the bridge model [15]. The modal analysis was carried away for fifteen modes. The modes and corresponding frequencies for case 1 are shown in Table 5 and the representations of mode shapes of the steel truss bridge model are shown in Fig. 2.

Table 5: Modes and corresponding frequencies

Mode	Frequency [Hz]
1	0
2	0
3	0
4	0
5	0.00001312
6	0.000060062
7	7.2378
8	8.4092
9	11.397
10	15.061
11	31.533
12	33.345
13	33.977
14	34.489
15	34.677

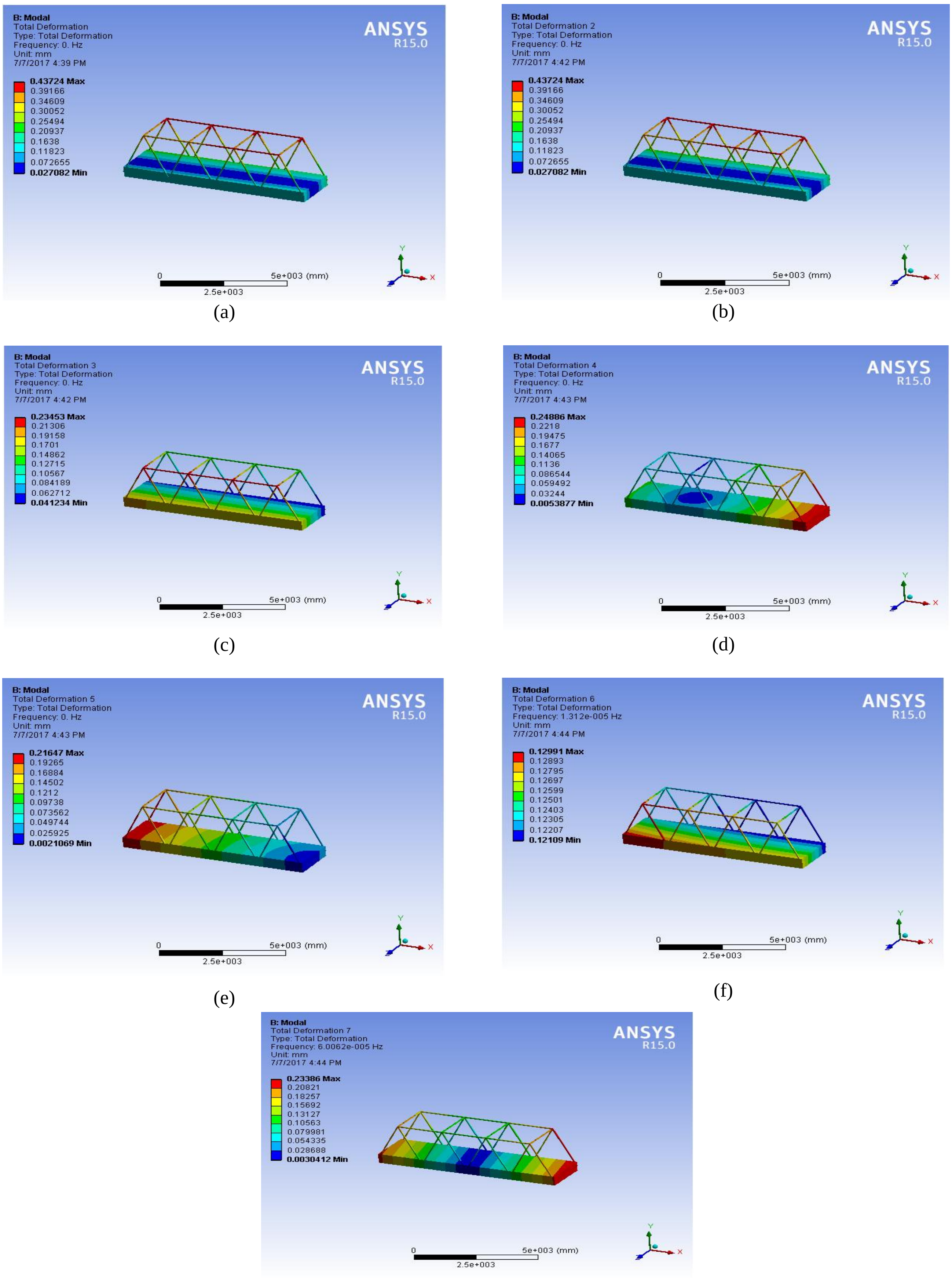


Fig. 2: Mode shapes for no supports at the end faces of the deck of the bridge model (a) mode shape 1 (b) mode shape 2 (c) mode shape 3 (d) mode shape 4 (e) mode shape 5 (f) mode shape 6 (g) mode shape 7.

Case 2: With fixed supports provided:

In this case, two fixed supports were provided. The end faces of the deck of the bridge were subjected to these supports [3]. The modal analysis was carried away for fifteen modes in this case as well. The modes and corresponding frequencies for case 2 are shown in Table 6 and the mode shapes for supports provided to the at the end faces of the deck of the bridge model are shown in Fig. 4 and graphical representation of variation of modes vs frequency where x-axis indicates the number of modes and y-axis indicates the frequencies of modes are shown in Fig. 3.

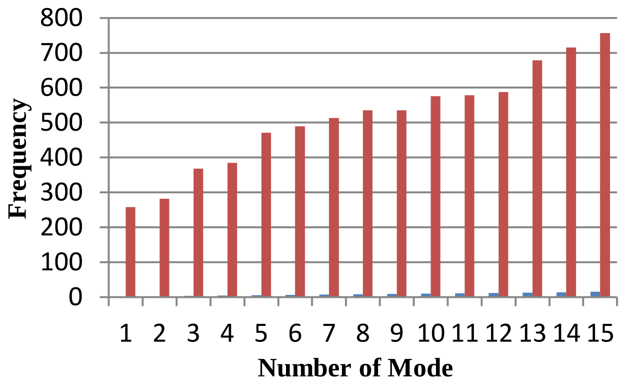
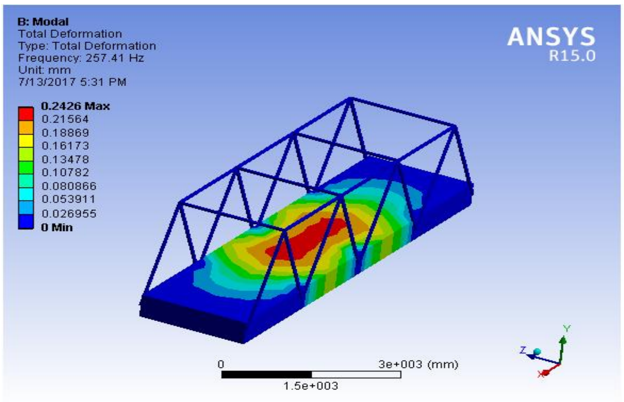
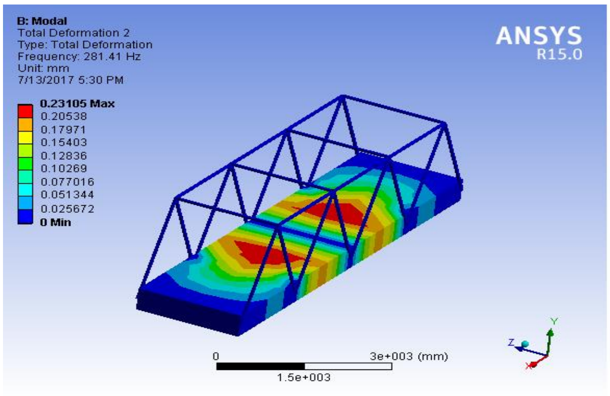


Fig. 3: Variation of modes vs frequency



(a)



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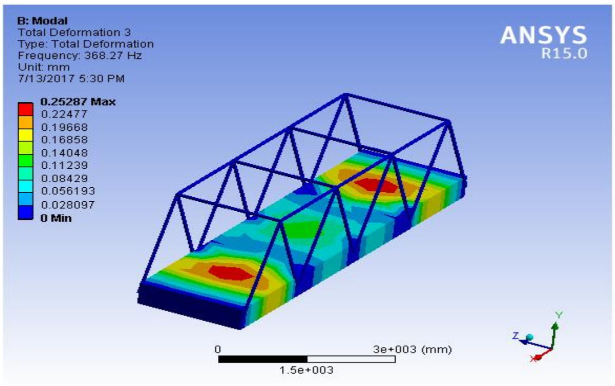

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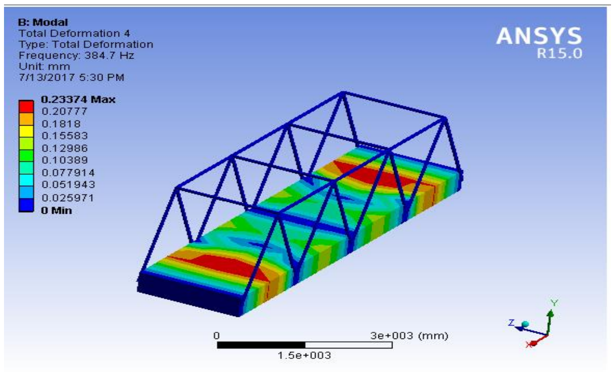

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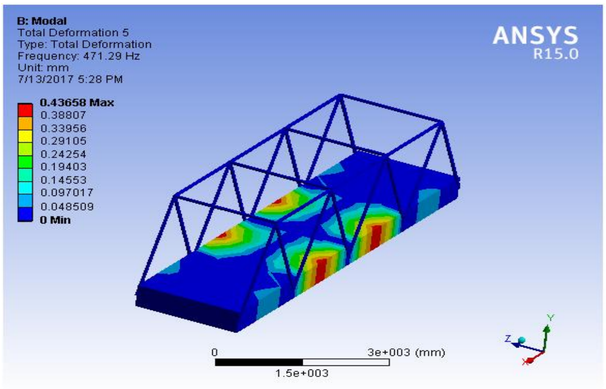

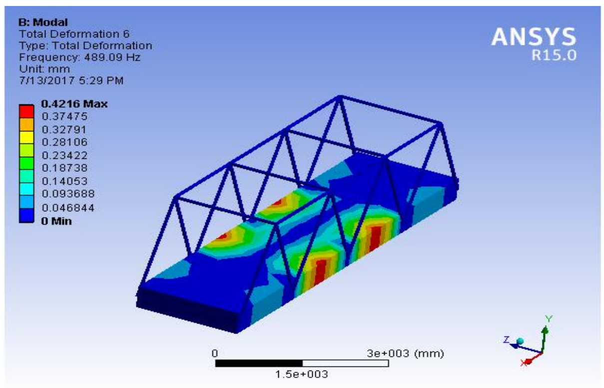

(f)

(e)

Fig. 4: Mode shapes for supports at the end faces of the deck of the bridge model.(a) mode shape 1 (Bending) (b) mode shape 2 (Bending) (c) mode shape 3 (Double Bending) (d) mode shape 4 (Twisting) (e) mode shape 5 (Twisting), (f) mode shape 6 (Twisting & Bending).

Table 6: Modes and corresponding frequencies

Mode	Frequency [Hz]
1	257.41
2	281.41
3	368.27
4	384.70
5	471.29
6	489.09
7	512.88
8	535.22
9	535.49
10	575.68
11	578.55
12	587.63
13	678.44
14	715.41
15	756.73

5. HARMONIC RESPONSE ANALYSIS OF THE STEEL TRUSS BRIDGE

The mode superposition method adopted in the harmonic analysis automatically executed a modal analysis. This determined the natural frequencies of the system when subjected to the fixed supports provided in the second case of the modal analysis procedure [1]. An external sinusoidal excitation force of 100N was then applied, which was equally distributed over the upper surface of the deck of the bridge where vehicles have to travel.

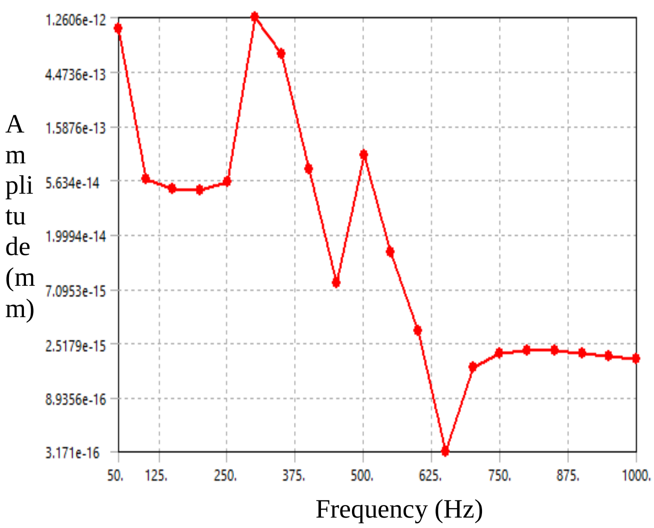

Fig.5: Variation of displacement amplitude with different exciting frequencies.

The analytical settings of the harmonic response along with the obtained 3D pictorial illustrations are provided in Table 6. The variations of displacement amplitude with different exciting frequencies are shown in Fig. 5. The variations of stress amplitude with different exciting frequencies are shown in Fig. 6.

Table 7: Analysis settings used in harmonic analysis

State	Fully Defined
Range Minimum	0. Hz
Range Maximum	1000. Hz
Solution Intervals	20
Solution Method	Mode Superposition
Cluster Results	No

6. RESULTS AND DISCUSSION

In case of the free-free vibration condition where no supports at ends of the deck, there should have been no vibrations present. But it was observed that vibrations were generated for some period of time in the structure as shown in Fig. 2. The displays of the mode shapes under such conditions reflect such deformations resulting from the generated vibrations. This is due to the self-weight of the steel truss bridge. In the second case, where two fixed supports were applied at the end faces of the deck of the

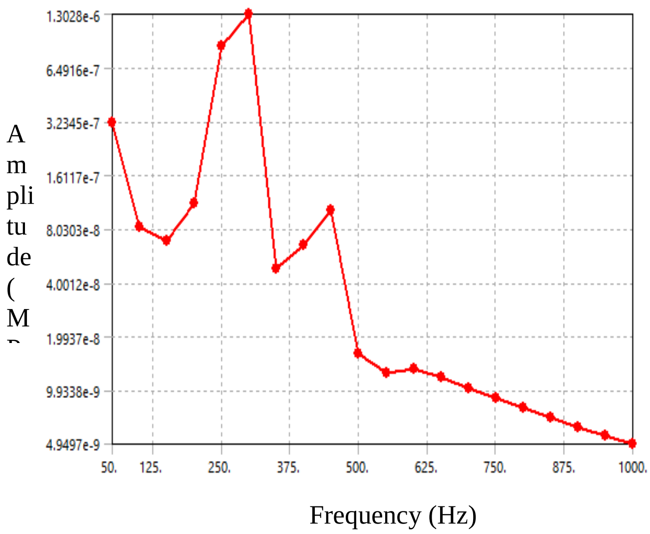

Fig.6: Variation of stress amplitude with different exciting frequencies.

bridge, the mode shapes obtained in Fig. 4 display higher frequencies than the analysis of the structure without any fixed supports. The mode shapes were displayed till bending-torsion couplings as later mode shapes are more complex to show.

In the harmonic response analysis, after applying the 100N force which was distributed uniformly over the upper surface of the deck and providing the fixed supports on both of the end faces of the deck, the graphs display the possibilities of resonance. The range of the external sinusoidal force was kept within 0-1000 Hz and the peaks obtained from the figures correspond to the resonance conditions. The displacement from Fig. 5 and stress from Fig. 6 amplitudes at the resonant conditions are observed to be significantly larger than the nearby conditions. Although these observed displacement are rather diminutive to actually cause a significant damage to the structure which results in a desirable reliability and stability of structure of the steel truss bridge.

7. CONCLUSIONS

The steel truss bridge as a mechanical structure can be subjected to a significant intensity of vibration if the design is not analyzed and optimized properly. The modal analysis and harmonic response analysis provided in this paper were performed accurately. It displayed the resultant displacement and equivalent stresses developed in the structure. Additionally, these simulations notably rendered the possibilities of resonance and whether the steel truss bridge requires geometrical optimization or not. The results demonstrate that for the design provided and under the conditions adopted, the reliability and stability of the steel truss bridge is ensured. Moreover, the analysis specifies the circumstances when the steel truss bridge requires modifications.

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