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Structural Health Assessment of the Bagmati Bridge

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Abstract

Bridges are one of the main components of any transportation infrastructure network which connects roads, villages, and cities. Bridge infrastructures when subjected to evolving patterns of operational loads, relaxation, deterioration and other actions such as natural or man-made disasters declines the condition of the structure. The main objective of the study is to assess the structural health of the superstructure of the Bagmati bridge and to detect damage if present any using sensors(Accelerometer and Geophone) and CSIBridge software. The changes in the structure's physical properties such as boundary conditions, stiffness,etc. show changes in the dynamic characteristics such as frequencies, mode shapes of the structure. CSiBridge was used to establish the finite element model of the superstructure of the bridge with simply supported boundary conditions. The time domain data were collected using an accelerometer and geophones and were transformed to the frequency domain using the Fast Fourier Transformation. Then the dynamic properties of the bridge obtained from sensor data and analytical method are compared to determine the damage or deterioration in the superstructure.

Keywords

Physical Properties, Dynamic Characteristics , Fast Fourier Transformation(FFT), Frequency

1. Introduction

Bridges are vital infrastructures in the development process of a country. Moreover, in a mountainous country like Nepal with many thousands of rivers and streams, hills, and valleys bridges are one of the main components of any transportation infrastructure network which connects roads, villages, and cities. In recent years, there is the rapid development in transportation construction in Nepal along with bridge construction. According to the Department of roads, Government of Nepal, by 2020 AD total number of registered bridges in Nepal was 2022, among which the construction status of 1797 bridges was completed and 225 bridges were under construction. Kathmandu-the capital city of Nepal has 50 bridges and the total length is 2289.52 m.

The Bagmati bridge is the longest bridge recorded in Kathmandu linking two metropolitan cities (Kathmandu and Lalitpur) with a length of 156.05 m which was constructed in 1967 AD and the bridge number is F103 according to the Department of Roads and Transportation. Due to the rapid increase of population and immigration, the population in the valley is 2,783,875 according to the national census 2021 which is about 5.8 times more population than the time bridge was built. This fact, along with the inadequate provision of urban infrastructure, has given rise to various problems including uncontrolled pollution, unmanaged wastes, traffic congestion on the city roads, and poor facilities for public transport. Due to heavy traffic congestion on the Bagmati bridge, to operate traffic flow and large numbers of pedestrians smoothly, the new Bagmati bridge was constructed in 1995.

Bridge infrastructures when subjected to evolving patterns of operational loads and other actions such as natural or man made disasters, several degradation processes such as creep, corrosion, and cyclic loading occur due to which condition of the structure declines. Often the intensity of load, nature, and magnitude of the load on these structures varies from the ones taken into account during its design. So, it is necessary to know the condition of the structure, whether to demolish and re-construct it or perform appropriate maintenance to increase its life span. Hence have brought attention to the importance of structural health assessment carrying out required periodic inspections, and developing damage detecting tools for such highly important structures to obtain sustainability and damage mitigation purposes.

Structural health monitoring (SHM) refers to the process of monitoring the structures, identifying damage, and implementing maintenance strategies to ensure structural integrity and safety of aerospace, civil, and mechanical engineering structures. SHM has gained significant interest over the years because of safety and economic concerns due to aging and degradation of infrastructure and also its abilities in reducing maintenance costs and extending life–cycles to both the existing and new structures with less involvement of human efforts. The main objectives of SHM are design validation, assessment of the structural performance, and improving asset management.

SHM integrates a comprehensive sensory system and a sophisticated data processing system implemented with advanced information technology and structural analysis algorithms. With the advancement in sensing technologies, developments in the fields of communication and computations, signal processing, and energy harvesting, an interesting development can be observed in SHM technologies for monitoring the behavior of structures and also for identification of potential damages. The ability to monitor the present and future behavior of structures and assessment of damage and its evolution at the earliest possible stage results in efficient maintenance strategies and provides an accurate life of a structure under certain loading conditions.

2. Literature Review

D. Bacinskas, 2013 [1] collected the acceleration-time record using accelerometer and then filtered with a 30 Hz low-pass filter and transferred into the PULSE Lapshop software, where Fast Fourier Transform was done. Resonant frequencies are directly obtained using pick picking method. The natural frequency of bridge for different modes of vibration was obtained from STAAD Pro. The results of natural frequency upto third modes were comparable and finally it was concluded that the combination of both experimental in-situ testing with relatively small number of vibration sensors and numerical simulation has been proven to be reliable and inexpensive methodology for identification of modal vibration properties of the bridge.

Steliana Stanciu, 2019 [2] has determined the influence of mass loss and stiffness loss of beam due to corrosion, on the natural frequencies and shape of natural modes of beam. ANSYS software was used for analytical values and was compared with the value obtained from numerical approach, which were similar. The natural frequencies of the beam were found to decreases with the increase in corrosion thickness for each modes.

Xueyan Zhao, 2019 [3] has studied the effect of crack on dynamic characteristics of simple supported beam by establishing the model of simple supported steel beam with V-crack damage in ANSYS software. Then, effect of crack location and crack depth on dynamic characteristics of the simple supported beam is studied by comparison with the case when no crack occurs. Whatever the crack depth or the crack position is, it was obtained that the natural frequencies decrease for the presence of crack in simply supported steel beam.

Swapnil Dokhe, 2015 [4] performed experiment on mild steel beam for cantilever boundary conditions with crack of different depths at different locations. Using the accelerometer and impact hammer, frequency response function was captured for uncrack beam. Then the frequencies for different depth of crack were captured. The frequency of cracked and un-cracked solid cantilever beam of same dimension and property and for similar conditions were obtained using ANSYS 14.5. The results were close to the experimental findings. The natural frequency of the of cracked beam decreases as the crack depth increases for the constant crack location and also the natural frequency of the cracked beam increases as the crack location increases from fixed end for constant crack depth. It was also observed that the sensitivity of the natural frequencies decreases with crack depth ratio for mild steel cantilever beam.

Nimisha K P, 2017 [5] modelled the reinforced concrete beams with inclined symmetric crack on the bottom surface of the beam near the supports in ANSYS 17. Different boundary conditions, different crack inclination and different crack depth were applied to the beam and free vibrational analysis was done. It was found that the natural frequency for both fixed and simply supported reinforced concrete beam with inclined symmetric crack, decreases as the crack depth increases and also it was found that the variation in natural frequency in cracked fixed beam was more than in cracked simply supported beam.

3. Objective

The main objectives of this research are:

- To assess the structural health of the superstructure of the bridge
- To evaluate the dynamic properties of the Bagmati bridge

4. Modeling of the Bridge

4.1 Bridge Description

The Bagmati bridge is the composite bridge having 5 number of span, each of 30m length. There are 4 steel girders in each span, each resting on rocker bearing on one side and rocker cum roller bearing on other side. For steel girder, the height of web is measured to be 1.717m and the width of top and bottom flange to be 0.61m. The thickness of both web and flange was measured to be 14 mm. The angle of 80*80*10 mm is used for cross bracing. The concrete deck is of 0.34 m consisting of a two-traffic lane with 7.25 m wide carriageway, and 1.5 m and 13.8m wide walkway on the left and right sides of carriageway. The parapet walls of 1.14 m high has been built on both side of the road. Expansion joints of 6 cm are used to accommodate the movement at the interval of 30 m. The running surface over the Reinforced concrete deck is Bituminous.

4.2 Bridge Modeling and Modal Parameters Computation

The superstructure of the bridge was modeled and analyzed with simply supported boundary conditions using finite element software, CsiBridge V20. CSiBridge is one of the most versatile and productive software program for modeling, analysis and design of bridge structures. The data required were measured using a measuring tape and Vernier caliper. Using the compressive strength as 20 MPa, modulus of elasticity as 22360.68 MPa, unit weight as 25 kN/m3 and poison’s ratio as 0.2 for the property of concrete and material grade as Fe250, modulus of elasticity as 210000 MPa, unit weight as 76.97 kN/m3 and poison’s ratio as 0.3 for the property of steel, the bridge was modeled and analyzed for the measured data. The frequency for different modes of vibration were obtained from the software. The modes with the lowest frequencies are most desired as the object will vibrate in these modes prominently, dominating all the higher frequency modes.

The accelerometers, which are used to measure the acceleration of motion of a structure, were installed at the girder of the bridge and the data were collected on the local server. The data recorded were in the time domain. The data recorded at the time when no vehicles were moving over the bridge, were transformed in the frequency domain using Fast Fourier Transform in MATLAB R22019b and the power spectral density graph was plotted. The first peak picking from the graph was done to obtain the fundamental frequency of the bridge.

4.5Hz Geophone of sensitivity of 28.8V/m/s was kept on the deck of the bridge when no vehicles were running and the vibration of the structure was measured. A geophone is a device that converts ground movement (velocity) into voltage. The vibration thus measured (velocity vs time) was converted to the frequency domain using Fast Fourier Transform in Geopsy software and the fundamental frequency was obtained from the power spectral density vs frequency graph. The frequency thus obtained also gives the validation for the frequency obtained from the accelerometer or vice-versa.

5. Results and Discussions

Using the measured data of the bridge, the model was analyzed in CSiBridge and the frequency of 3.458 Hz was obtained for the first mode. From the data obtained from the acclerometer the graph was plotted which is shown in figure 1 and the data were transformed to frequency and plotted as shown in Figure 2, from which the fundamental frequency was obtained as 4.138 Hz. Also, a similar value of frequency i.e 4.4 Hz was obtained for different samples of Geophone data as shown in figure 3.

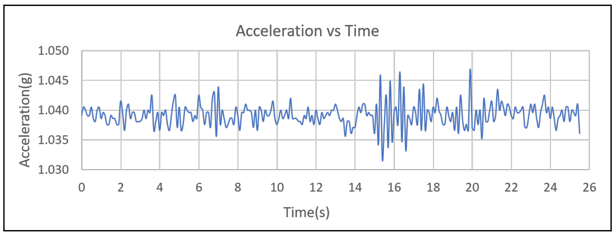

Figure 1: Plot of Raw Acceleration vs Time

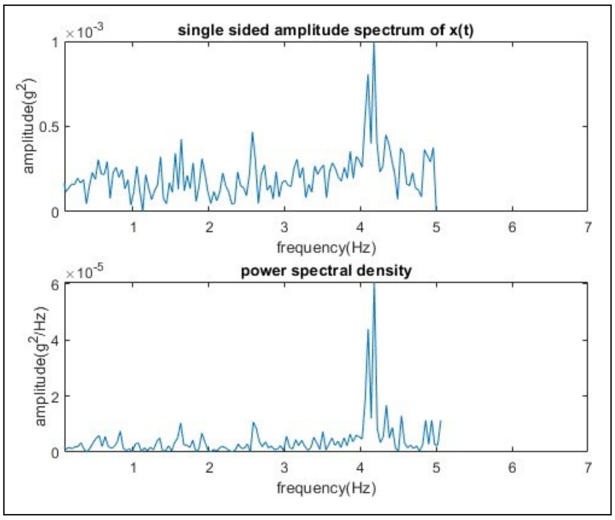

Figure 2: Plot of Power Spectral Density vs Frequency of the Accelerometer data for different samples of data

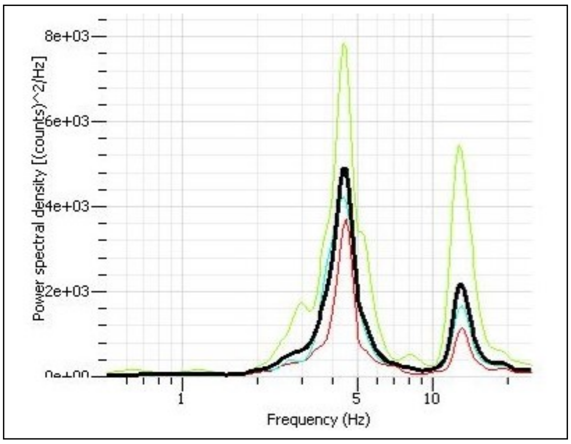

Figure 3: Plot of Power Spectral Density VS Frequency of Geophone data for vertical direction for different samples of data

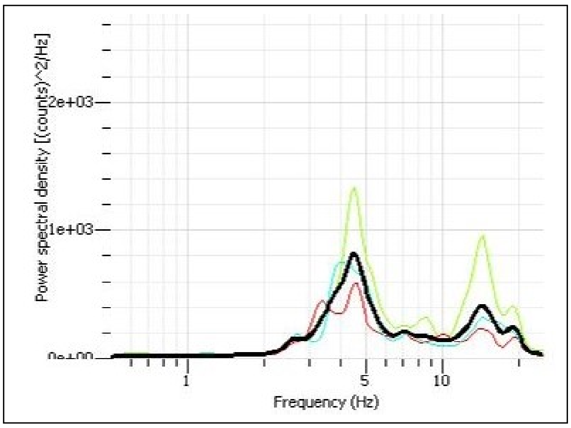

Figure 4: Plot of Power Spectral Density VS Frequency of Geophone data for northing for different samples of data

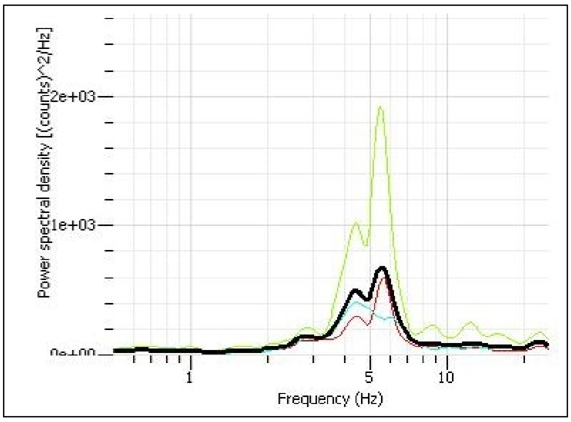

Figure 5: Plot of Power Spectral Density VS Frequency of Geophone data for easting for different samples of data

Table 1: Frequencies of the bridge using different methods

Methods	Frequency(Hz)	% difference
CSiBridge V20	3.458	
Accelerometer	4.183	17.33
Geophone	4.400	4.93

The natural frequency of the bridge as obtained from the CSiBridge and those obtained from the sensor data should have been the same or nearly the same but the value of frequency obtained from sensors was higher (17.33 %) than that obtained from the analysis in CSiBridge. This shows that there is no crack in the concrete slab and/or steel girder as crack reduces the frequency of the bridge [3][4][5]. The common problem seen on steel girders is corrosion when maintenance is not done timely and properly. Due to corrosion, there is mass loss as well as stiffness loss which also reduces the frequency of the bridge [2]. The reason for the increase in frequency could be the change in boundary conditions that we assumed. From the visual inspection, it can be seen that there is residue present around the rocker and roller support. As no crack was seen in between the support and the residue there is the possibility that some fixity on the boundary condition has developed. Table 1 shows the possible boundary condition of the bridge and it is seen that the possible boundary condition of the bridge may have changed from roller support to in between the roller and pinned support and the pinned support to in between pinned and fix support.

Table 2: Frequencies of the bridge for different boundary condition

Boundary condition	Frequency(Hz)
Roller and Pinned	3.458
Roller and Fixed	3.510
Pinned and Pinned	4.268
Pinned and Fixed	4.528

Figure 6: Roller Cum Rocker Bearing of the Bagmati Bridge

Figure 7: Rocker Bearing of the Bagmati Bridge

The iterative process of applying fixity in the roller support and the pinned support was done for a different condition to get the frequency of 4.183 Hz which obtained from the accelerometer data.

Case 1: The partial fixity was given only for the translation along the layout line (U3) for roller support and the stiffness for that was found to be 479167.701 N/mm.

Case 2: The partial fixity was given only for the rotation about normal to layout line (R2) for roller support. The stiffness was set to 10^{11}N/mm, which is the highest possible value but the frequency obtained for that is 3.461 Hz showing very less effect of fixity in rotation compared to translation along the layout line.

Case 3: The partial fixity was given only for the rotation about normal to layout line (R2) for rocker support. The stiffness was set to 10^{11} N/mm, which is the highest possible value but the frequency obtained for that is 3.510 Hz showing very less effect of fixity in rotation compared to translation along the layout line.

6. Conclusion

From this research work, the following conclusions are drawn:

1. The natural frequency of the bridge observed is found 17.33% higher than that obtained from the FE model.
2. No any significant effect of corrosion or presence of crack in deck or girder is found.
3. Increase in the frequency of the superstructure should be due to the generation of fixity at the bearings.
4. Bearings have to be changed or maintained for the relative movements between superstructure and substructure.

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