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System Identification of Typical RC Bridges Using Smart Device

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Abstract
Recent structural collapse and current state of the aging bridge infrastructure in Nepal are driving the development of monitoring techniques for structural integrity assessment. In this study operational modal analysis using frequency domain method are used to determine dynamic characteristics of the bridge model. It shows an experimental phase with use of mobile phones to obtain acceleration response from two concrete bridge, from these records to obtain natural frequency using FFT. The natural frequencies determined from the numerical model which uses Finite Element Model are compared with experimental phase. The final result shows, the vibration answer can be extracted from mobile phones and structural behavior can be defined from natural frequency.

Keywords
System Identification, Operational Modal Analysis, Smartphones

1. Introduction

Determination of dynamic response of bridges under static and dynamic loads, is very complex and requires special studies. Static, dynamic, linear, and nonlinear behavior can be obtained and illustrated by using finite element modeling. Technical design data and engineering judgments based on finite element modeling are expected to yield reliable simulation [1]. However, required level of accuracy in predicting dynamic characteristics cannot be obtained because of modeling uncertainties. This step-up the need for verification of finite element model. Presence of structural damage in an engineering system leads to alteration of the vibration modes [2]. These modifications are demonstrated as changes in the modal parameters (natural frequencies, mode shapes and modal damping values) which can be obtained from results of dynamic (vibration) testing. Nature, location and severity of damage effect the change in modal parameters. The advantage of measuring vibration response is the global nature of derived natural frequency. Vibration response can be easily and cheaply used to obtain modal parameter. Some form of transducer are used to monitor the structural response from ambient forces [3].

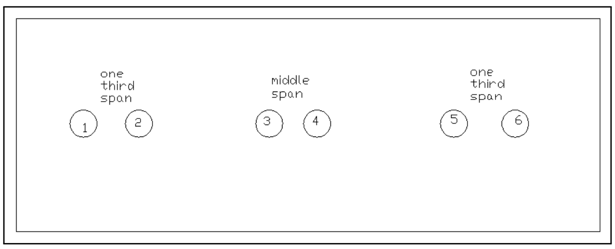

Figure 1: Sensor Instrumentation Plan

2. Description and Instrumentation of Tested Bridge

2.1 Mahadev Khola Bridge

The first bridge used for collecting data is Mahadev Khola bridge. It is a single-span simply-supported bridge located at Banepa, Kavrepalanchowk (chainage:20+290) in Arniko highway. The total span

Figure 2: Mahadev Khola Bridge

of bridge is 11 m and total width 7.9 m, and consists of four longitudinal girders and four cross girder. The longitudinal girder has depth of 0.9 m and width of 0.3 m and cross girder 0.75 m depth and 0.2 m width. The ambient vibration testing of the bridge is conducted in this study. The dynamic bridge assessment procedure involves the attachment of Samsung s6 on the deck of the span of the bridge at 6 measurement points.

2.2 Jagati Bridge

The second bridge used for collecting data is Jagati bridge. It is a single-span simply-supported bridge located at Jagati, Bhaktapur (chainage 13+590) in Arniko highway. The total span of bridge is 8.6 m and total width 7 m, and consists of four longitudinal girders and three cross girder. The longitudinal girder has depth of 0.7 m and width of 0.3 m and cross girder 0.4 m depth and 0.2 m width. The ambient vibration testing of the bridge is conducted in this study. The dynamic bridge assessment procedure involves the attachment of Samsung s6 on the deck of the span of the bridge at 6 measurement points.

Figure 3: Jagati Bridge

3. Data Collection Using Smartphone

The vibsensor app was installed and recording interval of six minute was set prior to data acquisition. Then the deck surface was cleaned and the Smartphone was attached firmly to the deck with the help of tape. The main objective was to obtain bridge vibration data. The sampling rate of 100 Hz was used for data acquisition. The collected data was stored for future retrieval and then this raw data was extracted for further analysis.

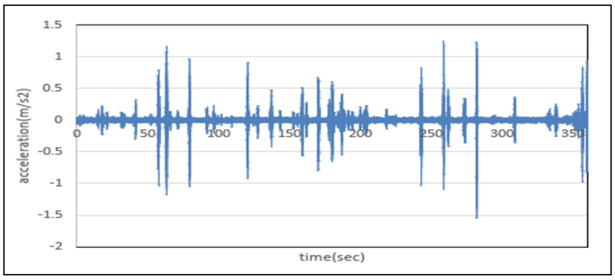

Figure 4: Raw Acceleration Data for Mahadev Khola Bridge (Sensor Position at 1)

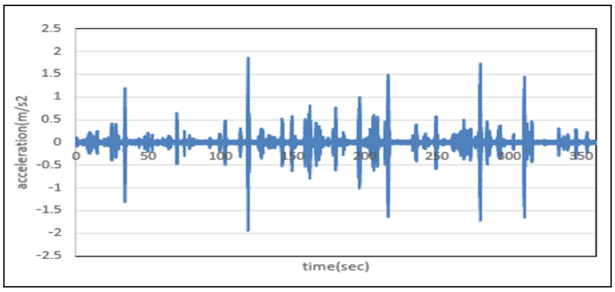

Figure 5: Raw Acceleration Data for Mahadev Khola Bridge (Sensor Position at 2)

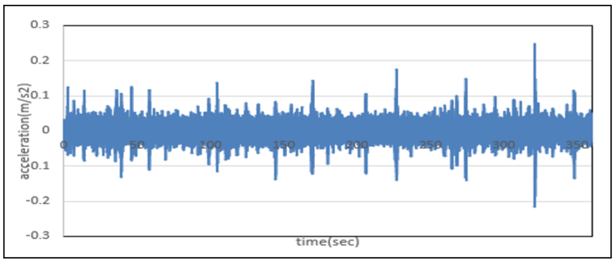

Figure 6: Raw Acceleration Data for Jagati Bridge (Sensor Position at 1)

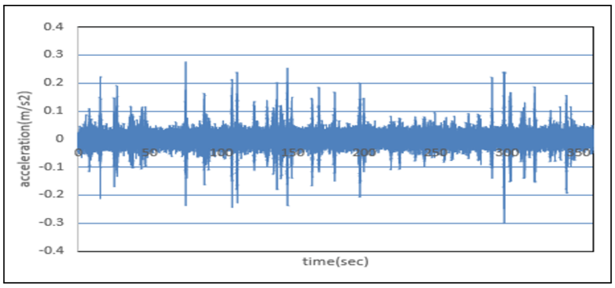

Figure 7: Raw Acceleration Data for Jagati Bridge (Sensor Position at 2)

4. Data Analysis

The measurement data which is recorded in the time domain, needs a transformation of the signal, to obtain a representation of the signal in a frequency domain. The measurement data in the time domain is transformed into the frequency domain by FFT. For the transformation of data, the code in MATLAB is used, where the data first is imported and then by Fast Fourier Transformation the data is transformed into the frequency domain. The data has much noise which makes it difficult to read the graphs. To reduce the noise and obtain a smoother curve in the frequency domain, a code named "pwelch" is used in MATLAB, which returns a clearer and smoother curve that is easier to read by splitting the signal into segments which are multiplied by Hamming windows.

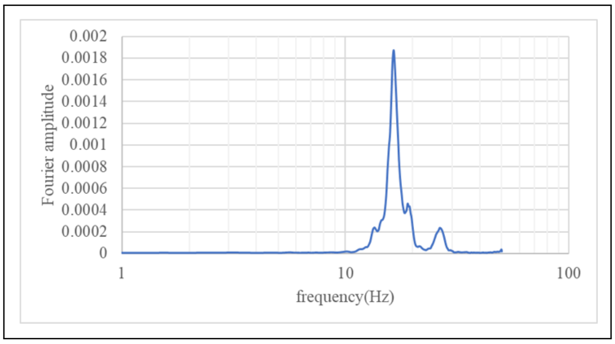

Figure 8: Fourier Amplitude vs Frequency (Sensor at Position 1 of Mahadev Khola Bridge)

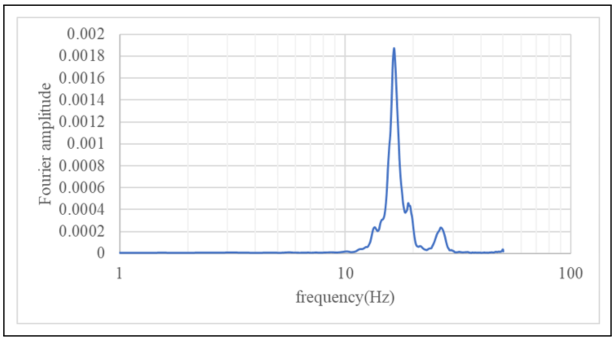

Figure 9: Fourier Amplitude vs Frequency (Sensor at Position 2 of Mahadev Khola Bridge)

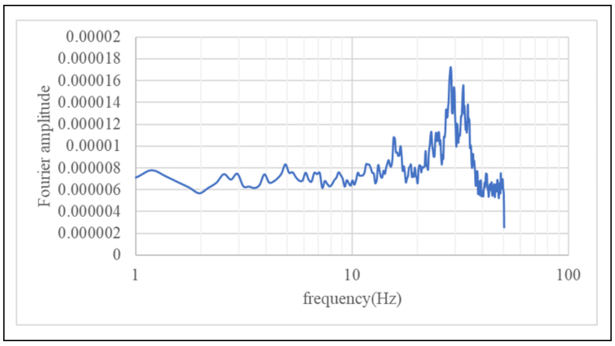

Figure 10: Fourier Amplitude vs Frequency (Sensor at Position 1 of Jagati Bridge)

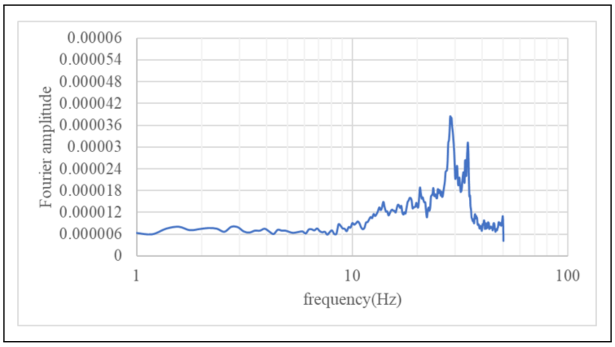

Figure 11: Fourier Amplitude vs Frequency (Sensor at Position 2 of Jagati Bridge)

5. Finite Element Modeling

Finite Element Analysis (FEA) was performed to obtain modal frequency and its corresponding mode shapes on Mahadev Khola and Jagati bridge model using the software SAP 2000. In these bridge model, girders were represented by line elements while concrete deck was represented by shell element. To allow comparison, this bridge model has the same boundary conditions as on respective bridge.

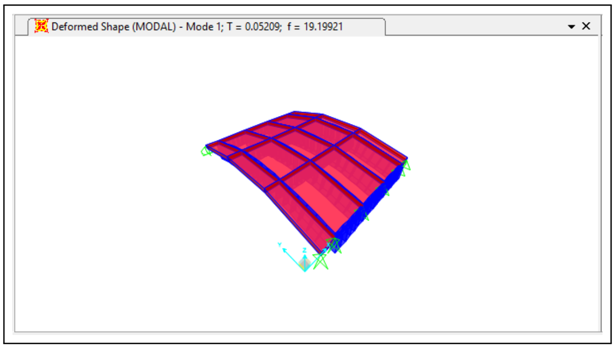

Figure 12: Mode 1 (Mahadev Khola Bridge)

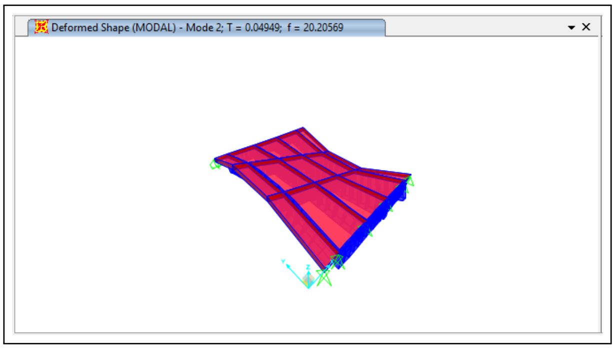

Figure 13: Mode 2 (Mahadev Khola Bridge)

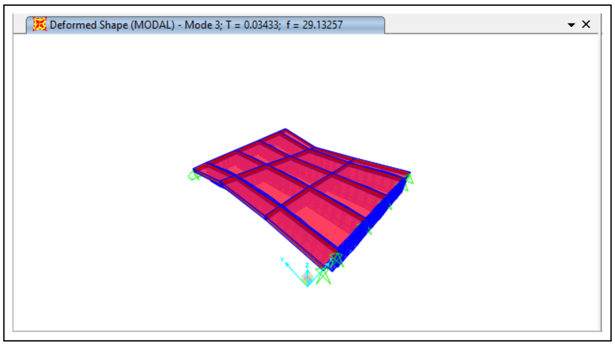

Figure 14: Mode 3 (Mahadev Khola Bridge)

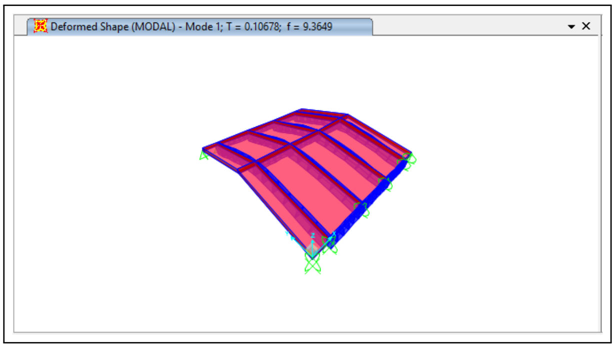

Figure 15: Mode 1 (Jagati Bridge)

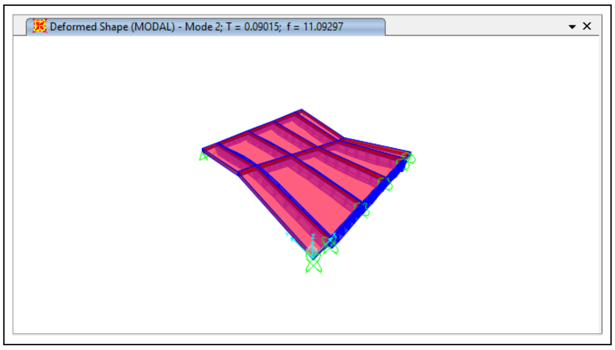

Figure 16: Mode 2 (Jagati Bridge)

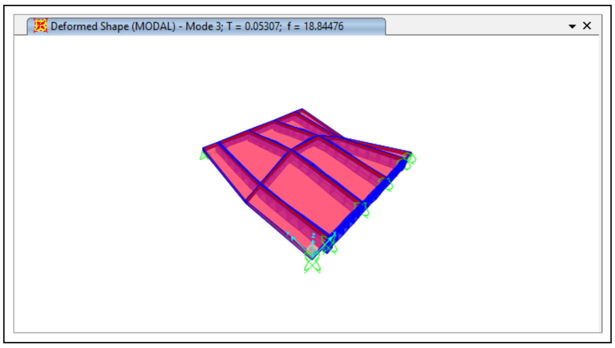

Figure 17: Mode 3 (Jagati Bridge)

Table 1: Summary of Frequencies (Experimental Setup)

	Frequencies (Hz)	
	Mahadev Khola Bridge	Jagati Bridge
1st setup	16.43	13.17
	26.6	16.53
2nd setup	16.43	13.29
	27.3	20.58
3rd setup	16.06	13.31
	26.83	19.96
4th setup	16.09	13.29
	26.06	19.44
5th setup	16.45	13.3
	26.04	19.2
6th setup	16.05	12.94
	26.43	18.03

Table 2: Summary of Modal Frequencies,Hz (Finite Element Analysis)

Mode	Mahadev Khola Bridge	Jagati Bridge
1	19.199	9.36
2	20.20	11.09
3	29.13	18.844

6. Comparison with Numerical Model

The collected acceleration data is processed to obtain power spectral density of measured signal and peak picking technique is used to identify natural frequency. The modal parameter values obtained from the experimental and computational stages were compared. It is seen that ambient vibration measurements are enough to identify the most significant modes of all bridge. There is a good agreement between natural frequencies obtained from experimental and numerical results. The maximum differences are obtained as nearly as 20 percent. Frequency of second mode for Mahadev Khola bridge and first mode for Jagati bridge cannot be distinguished using peak picking technique from FFT plot as they are closely spaced as seen in table 2, which is one of limitation of peak picking technique [4]. It can be seen that the first three natural frequency of the bridge can be quite accurately extracted using data collected from smartphone.

Table 3: Percentage Difference of Experimental and Numerical Frequency

Bridge	Mode	Percentage Difference Between Experimental and Modeling Frequency					
		1st setup	2nd setup	3rd setup	4th setup	5th setup	6th setup
Mahadev Khola	1	14.4	14.4	16.4	16.19	14.3	16.4
	2	-	-	-	-	-	-
	3	8.6	5.9	7.9	10.54	10.6	9.2
Jagati	1	-	-	-	-	-	-
	2	18.75	19.7	20	19.83	19.9	16.68
	3	12.27	9	5.9	3	1.8	4.3

7. Conclusion

The vibration response of two in-service RC bridges were collected using smartphone sensors. Modal analysis algorithm was used to extract modal properties from acceleration response collected from the structure using sensor. In this study most popular output only algorithm (FFT) was studied and applied to two bridge cases. Frequencies corresponding to highest amplitude were picked using peak picking technique. The finite element modeling of the bridge was performed using finite element analysis tool and modal analysis was performed to obtain the modal frequencies. The variation of the frequencies shown by experimental results and model analysis has been studied for Mahadev Khola and Jagati bridge.The conclusion derived from the study is as follows:

- Ambient vibration source alone is sufficient to excite the most significant mode of the bridge.
- The ambient vibration test allowed the identification of predominant modes in the frequency range of (0-37) Hz.
- A good agreement was found between the frequencies obtained from experimental and numerical results.
- The MATLAB FFT implementation along with peak picking technique was able to obtain first three modal frequencies of considered bridges with quite accuracy.

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