Chapter 1
Ambient Vibration Testing and Modal Response Analysis of a Curved Concrete Bridge

Mehrtash Motamedi, Carlos E. Ventura, and Brook Robazza

Abstract This paper describes a series of ambient vibration tests conducted on a curved concrete bridge in British Columbia, Canada. Modal response analysis was performed to identify the dynamic properties of the structure, including predominant natural frequencies and the corresponding mode shapes to support seismic assessment and upgrading of the bridge.
The bridge was built in 1956, and spans over Nelson Creek near Horseshoe Bay, British Columbia to carry traffic. After the construction of a highway nearby, it serves as a pedestrian and utility bridge. The Nelson Canyon bridge is a six-span bridge with a total length of 80m. The superstructure consists of a concrete deck, steel longitudinal girders and transverse floor beams. The substructure includes two concrete abutments at both ends, concrete pier at the end of the jump span and two steel truss towers.

The ambient vibration testing method was implemented using sophisticated methods of modal analysis. Vibration Tests were conducted at the bridge in order to determine the dynamic modal properties (modal frequencies and mode shapes) of the bridge. The testing program consisted of multiple measurement setups. Tromino® velocity/acceleration wireless sensors were used for these measurements which were placed on predetermined locations. The computer program ARTeMIS was used to perform the system identification of the structure. The software allows to develop a 3D model of the structure and test points; the resulting mode shapes are displayed using this geometry. Two different techniques were used for modal identification: the Enhanced Frequency Domain Decomposition (EFDD) and the Stochastic Subspace Identification (SSI). These two modal identification techniques were used to cross-validate the results. The joint analysis of the signals measured in various strategic points of the structure made it possible to identify the modal configurations and the corresponding natural frequencies.

As result, a total of 8 modes were identified in the 2 to 11 Hz frequency range. Modal frequencies, modal damping and mode shape were identified for each of the 8 modes. The modes associated with vertical response of the deck showed that the bridge deck is flexible.

Keywords Ambient Vibration Test · Modal Response · Concrete Curved Bridge · Frequency, Mode Shape

Introduction

Nelson Canyon Bridge (located at 49.36299, 123.26039) was built in 1956 and spans over Nelson Creek near Horseshoe Bay in West Vancouver, BC, Canada. This bridge was built to carry the traffic but after the construction of Highway 99, it serves as a pedestrian and utility bridge that was categorized as a lifeline structure. The bridge is a curved six span deck with a total length of 80 m including a 12 m concrete jump span on the west approach with the radius of 87 m for the inner edge, with width of 10.1 m and cross-fall of 8%. The superstructure consists of a concrete deck with steel transverse floor beams supported by two lines of steel longitudinal girders. The substructure includes two concrete abutments at both ends with spread footings on bedrock, concrete pier at the end of the jump span and two steel truss towers. These towers were

Mehrtash Motamedi · Carlos E. Ventura
Department of Civil Engineering, The University of British Columbia, Vancouver, BC V6T 1Z4
e-mail: mmotamedi@civil.ubc.ca; ventura@civil.ubc.ca

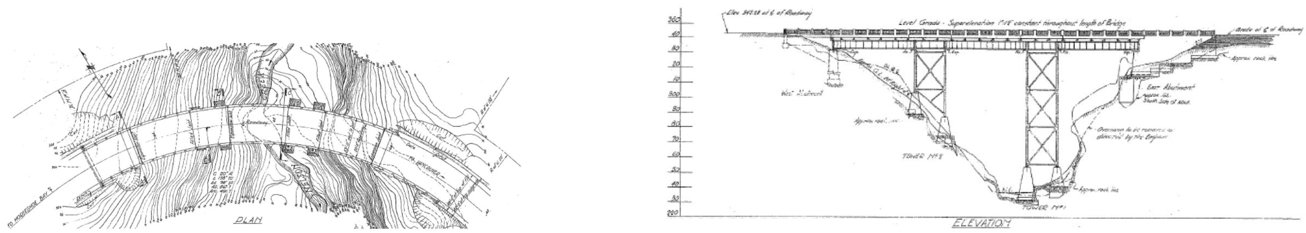
Brook Robazza
ISL Engineering and Land Services Ltd.
e-mail: brook.robazza@isl.com

Matthew Whelan et al. (eds.), *Dynamics of Civil Structures, Vol. 2*, Conference Proceedings
of the Society for Experimental Mechanics Series, https://doi.org/10.13052/97887-438-0147-4_1

constructed from W sections and built up lattice sections, which were built on the concrete pedestals cast directly onto the bedrock, ensuring a robust foundation. Fig. 1 shows the plan and elevation view of the bridge.

A targeted seismic evaluation of the bridge was planned in the District of West Vancouver. The purpose of this assessment was to determine whether the bridge has sufficient capacity to support the pedestrian and utility weight in earthquakes and, if required, quantify the extent of strengthening works required to increase the seismic capacity of the bridge [1].

A series of Ambient Vibration Test (AVT) were suggested for this bridge in order to determine the modal frequencies and the mode shapes of the bridge. Prior to the AVTs, a site visit to the bridge was conducted to determine the location of the measurements and develop a test plan. The test plan included ambient vibration measurements on the bridge deck, abutments and approaches. The vibration tests were then carried out using velocity sensors on the bridge. The main purpose of the AVTs was to determine the fundamental frequency and corresponding mode shape of the bridge. This information would help calibrate the computer model being used for the seismic evaluation of the bridge [2].



(a) (b)

Fig. 1 Plan and elevation view of the bridge: a) Plan view; b) Elevation view

Ambient Vibration Tests

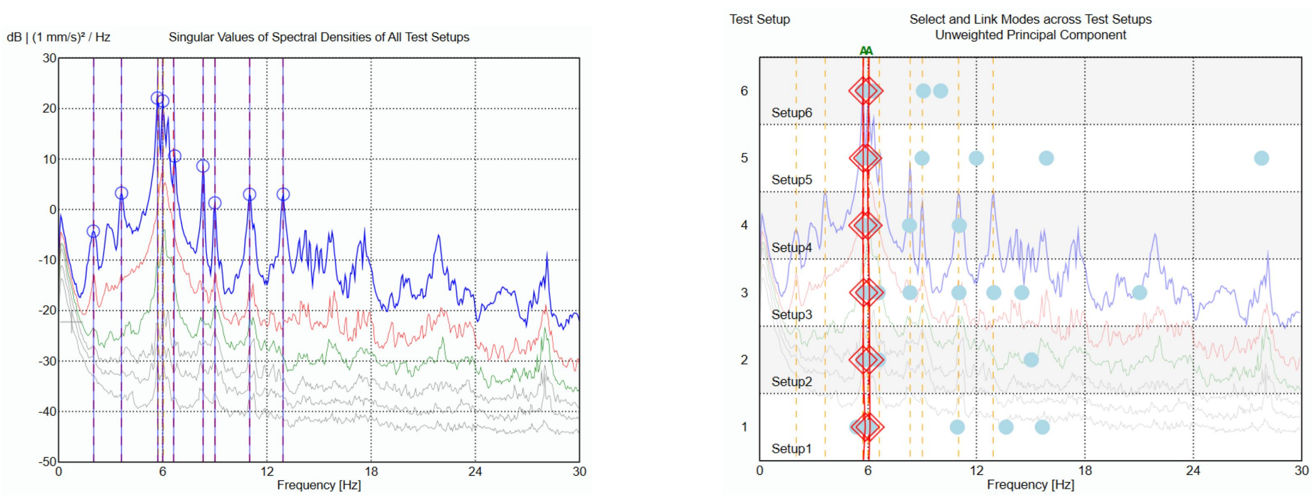
Vibration Tests (VTs) were conducted at the bridge in order to determine the dynamic modal properties (modal frequencies and mode shapes) of the bridge. The testing program consisted of six measurement setups. Tromino® velocity/acceleration sensors were used to carry out these VTs [3]. The collected records were time synchronized with a radio antenna and amplifier in each sensor. This allowed the synchronization of the recordings both within each measurement setup and between setups. The Tromino sensors are suitable for high-resolution ambient vibration tests as they are fully portable, wireless, compact, and light instruments. Each sensor is equipped with two sets of three orthogonal high-resolution electrodynamics sensors (high gain and low gain velocity meter) and one set of three orthogonal digital accelerometers with a frequency range of 0.1 to 300 Hz. For these tests the high-gain velocity data was used for the modal identification process. Fig. 2 illustrates the location of the sensors on the bridge during the tests.

(a) (b)

Fig. 2 Location of the sensors on the bridge during the tests: a) General view, b) Close up of a sensor

Modal Analysis

The computer program ARTeMIS Version 6, was used to perform the modal analysis of the specimen [4]. The software allows developing a 3D model of the structure and test points; the resulting mode shapes are displayed using this geometry. Two different techniques were used for modal identification: the Enhanced Frequency Domain Decomposition (EFDD) and the Stochastic Subspace Identification (SSI). These two modal identification techniques were used to cross-validate the results. The joint analysis of the signals measured in various strategic points of the structure made it possible to identify the modal configurations and the corresponding natural frequencies [5]. The Power Spectra Densities obtained from ambient vibration measurements are illustrated in Fig. 3 for both methods. The peak values show the natural frequency of the bridge in each mode.



(a) (b)

Fig. 3 Power Spectral Densities obtained from ambient measurements: a) Singular values of spectral densities of all test setups in EFDD method, b) Linked Modes for SSI UPC method

Based on this analysis, A total of 8 modal frequencies in the 2 to 11 Hz range were identified with confidence. The predominant frequency (the first natural frequency) of the structure is estimated to be 2.03 Hz, and it corresponds to the fundamental mode of the bridge in the vertical direction. The identified modal frequencies and associated damping values are presented in Table 1. The presented modal frequencies from the vibration data are those for which the confidence on the results is high from both the EFDD and SSI-UPC methods. Some of the associated mode shapes are presented in Fig. 4.

Table 1 Natural frequency, period and damping of combined analysis

Mode	Frequency (Hz)	Period (sec)	Damping (%)	Mode description
1	2.03	0.49	5.43	Vertical
2	3.63	0.28	0.00	Transverse
3	5.71	0.18	0.91	Torsional
4	6.00	0.17	0.86	Transverse and vertical
5	6.62	0.15	0.88	Transverse and vertical
6	8.33	0.12	0.51	Torsional and vertical
7	9.01	0.11	0.61	Torsional and vertical
8	11.01	0.09	0.73	Vertical

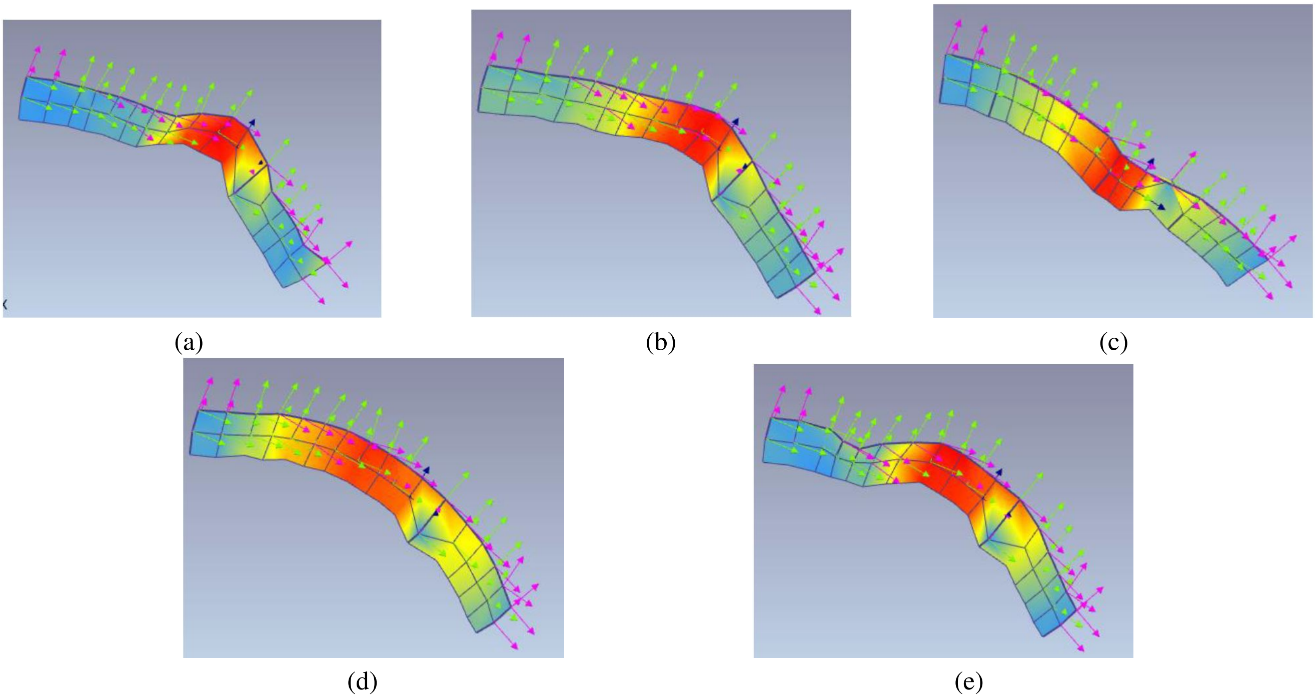


Fig. 4 Identified mode shapes of the bridge: a) 1^{st} mode, b) 2^{nd} mode, c) 3^{rd} mode, d) 4^{th} mode, e) 5^{th} mode

Conclusion

Ambient vibration tests of a concrete curved bridge in British Columbia, Canada were conducted. The main objectives of these vibration tests were: 1) to determine the vibration characteristics of the bridge; and 2) to perform a modal analysis using the vibration data in order to determine the predominant natural frequencies and the corresponding mode shapes of the bridge. The testing program consisted of six measurement setups. The results from the modal analyses indicated that the fundamental frequency of the bridge in the vertical direction 2.03 Hz. The first torsional mode of the deck is at 5.71 Hz. A total of 8 modes were identified in the 2 to 11 Hz frequency range. Modal frequency, modal damping and mode shape were identified for each of the 8 modes. The modes associated with vertical response of the deck showed that the bridge deck is flexible.

Acknowledgments This paper has been extracted from a term project report prepared by the following students of the CIVL508 course in the Department of Civil Engineering at the University of British Columbia, class of winter 2024: Ehsan Ferdosi, Sony Fu, Dyllon Hunt, Amber Shen, Jonathan Steele, Weite Su, Alex Sun, Bowen Wu. Their input is really appreciated. This project was carried out for the purpose of determining the modal properties and seismic assessment of the Nelson Canyon Bridge in West Vancouver, BC as part of the Bridge and Pier Inspection Program. This collaboration with the City of West Vancouver is acknowledged.

References

1. TYLin, "RFP22 112 - Bridge and Pier Inspection Program," TYLin Nelson Canyon Bridge Seismic Condition Memo, *District of West Vancouver, BC*, 2022
2. Wang, H., Li, A., Li, J. "Progressive finite element model calibration of a long-span suspension bridge based on ambient vibration and static measurements" *Engineering Structures*, 32 (9), September 2010
3. Micromed, "Tromino: Portable ultra-light acquisition system for seismic noise and vibration- User's manual", *Macromed*, Italy, 2012
4. Structural Vibration Solutions, A/S, "ARTeMIS Modal Software", Version 4, Copyright 1998-2014
5. Brincker, R., and Ventura, C.E., "Introduction to Operational Modal Analysis," *John Wiley & Sons, Ltd*, United Kingdom, 1^{st} Edition 2015