MODEL UPDATING OF A THREE-SPAN CABLE-STAYED BRIDGE

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ABSTRACT: The dynamic response of a three-span cable-stayed bridge is investigated using experimental and analytical analyses. The bridge was opened on December 1, 2012, and there are three sections: a cable-stayed main span and two approach sections. The focus of this study is on the main span. The deck consists of steel girders which support precast concrete deck panels and an asphalt surface. Two concrete towers and 288 cables support the deck. From ambient vibration testing, the dynamic properties of the main span were determined. These properties were used for calibrating a finite element model to better represent the behaviour of the real structure.

1. Introduction

The project involves using an operational modal analysis of the Port Mann Bridge to calibrate the finite element model. The process of updating the bridge model allows the model's behaviour to mimic more closely that of the observed experimental behaviour, and in this way, the finite element model can be deemed appropriate to represent the real structure. The modal analysis was carried out using ARTeMIS Extractor (Structural Vibration Solutions, Inc.), and the model updating was done using FEMTools (Dynamic Design Solutions NV.) and SAP2000 (Computers and Structures, Inc.).

The original finite element model was kindly provided by the Ministry of Transportation and Infrastructure, and it was further edited to be imported into SAP2000 and remove components that were beyond the scope of the study such as nonlinear elements and foundation modelling. In the study of the Port Mann Bridge, only the main span was analyzed.

2. Background

The Port Mann Bridge is a 10-lane, 65 m-wide cable-stayed bridge that spans a total of 2020 metres. It is one of the widest and longest cable-stayed bridges in the world. The bridge was designed as a replacement to the older bridge which was built in 1964.

The bridge is located between Port Coquitlam and Surrey, British Columbia, and it connects these two communities by spanning across the Fraser River. Fig. 1 shows a satellite image of the region where the bridge is located, and Fig. 2 displays the as-constructed elevation view of the Port Mann Bridge.
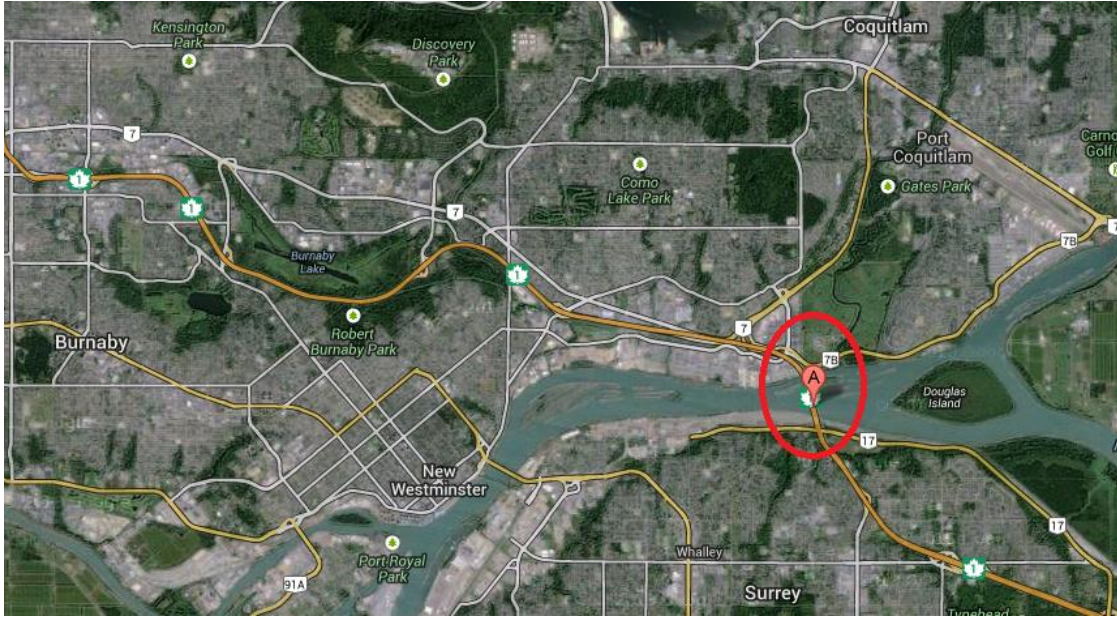
Fig. 1 – Satellite Image Showing Location of Port Mann Bridge

Fig. 2 – As-Constructed Elevation View of the Port Mann Bridge

Being so unique and just recently constructed, there is much interest in studying the dynamic behaviour of the bridge.

The Port Mann Bridge consists of three sections: cable-stayed main bridge, south approach, and north approach (Fig. 3). The cable-stayed portion of the bridge is 850 m long and consists of steel girders which

support precast concrete deck panels. There are a total of 288 cables that connect the deck to the towers. The entire main span is supported by two centre towers which are 160 m tall. The north and south approaches are also constructed using precast concrete sections with an asphalt road surface.
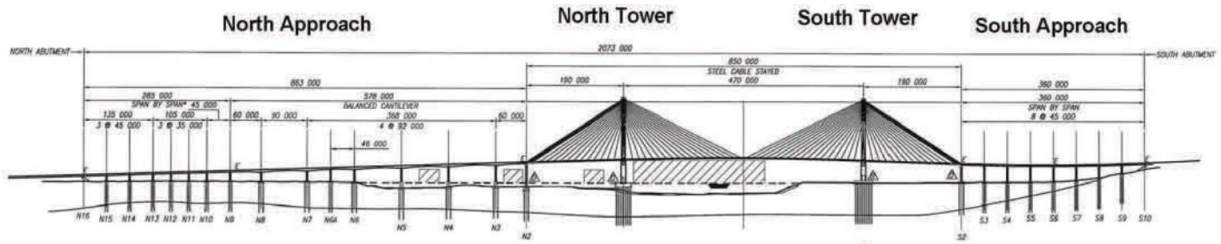

Fig. 3 – Design Drawing showing Elevation View of Port Mann Bridge

The main span is divided into two decks that are connected together by steel sections as shown in Fig. 4. This allows the two decks to share displacements.
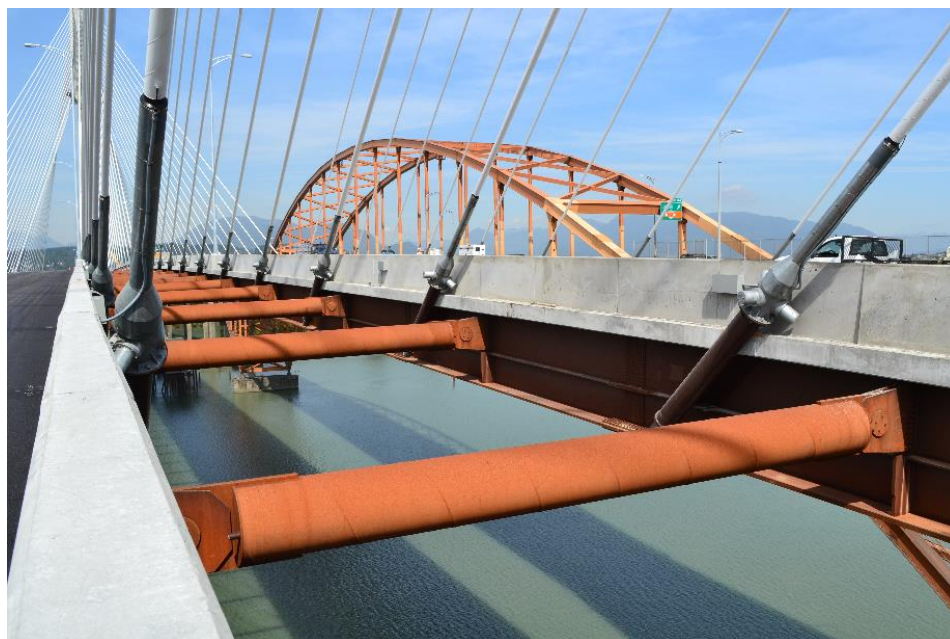

Fig. 4 – Pin Connections Between Two Decks

3. Ambient Vibration Results

The Port Mann Bridge is equipped with various sensors throughout the structure as part of its seismic monitoring system. Acceleration data was downloaded from these sensors and a modal analysis was carried out. The locations for the sensors used are shown in Fig. 5.
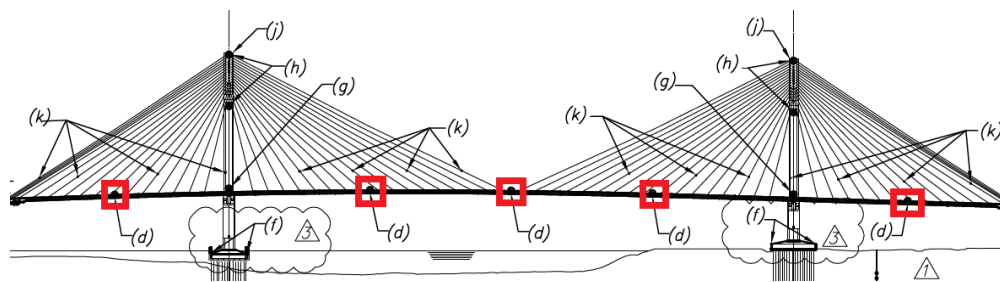

Fig. 5 – Location of Deck Sensors used in Analysis

The data setup is as shown in Fig. 6. The analysis identified six initial mode shapes, as shown in Table 1. Further vertical mode shapes could be identified but the scope of the model updating would include up to six modes.
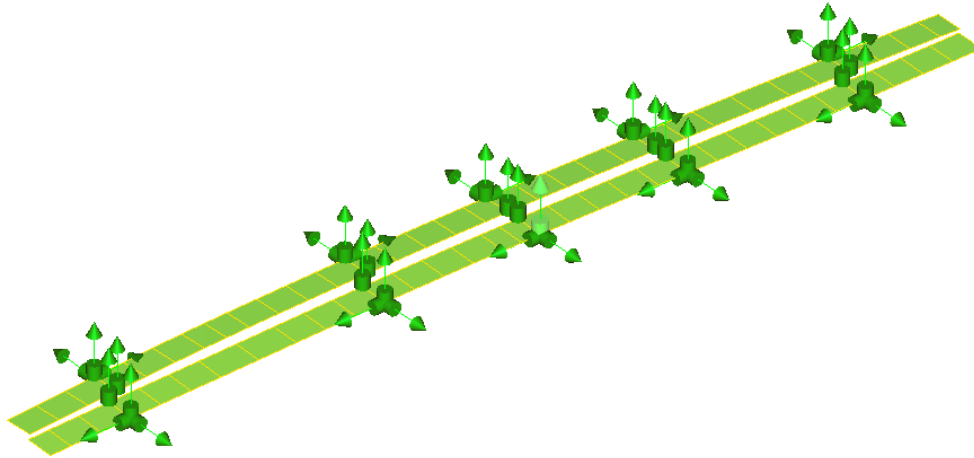

Fig. 6 – Setup with Sensor Locations

Table 1 – ARTeMIS Modal Analysis Results

Mode Number	Frequency	West Description
1	0.23	1st Vertical
2	0.25	Torsion
3	0.30	2nd Vertical
4	0.34	Transverse/Torsion
5	0.43	Torsion
6	0.48	3rd Vertical

4. Finite Element Model

The finite element model was created by the bridge designers in ADINA format (ADINA R & D, Inc.); however, in order to do the model updating and analyses, it was imported into SAP2000 and edited. Some features were not compatible between the two programs, so certain elements were re-modelled based on design drawings. The model is shown in Fig. 7.
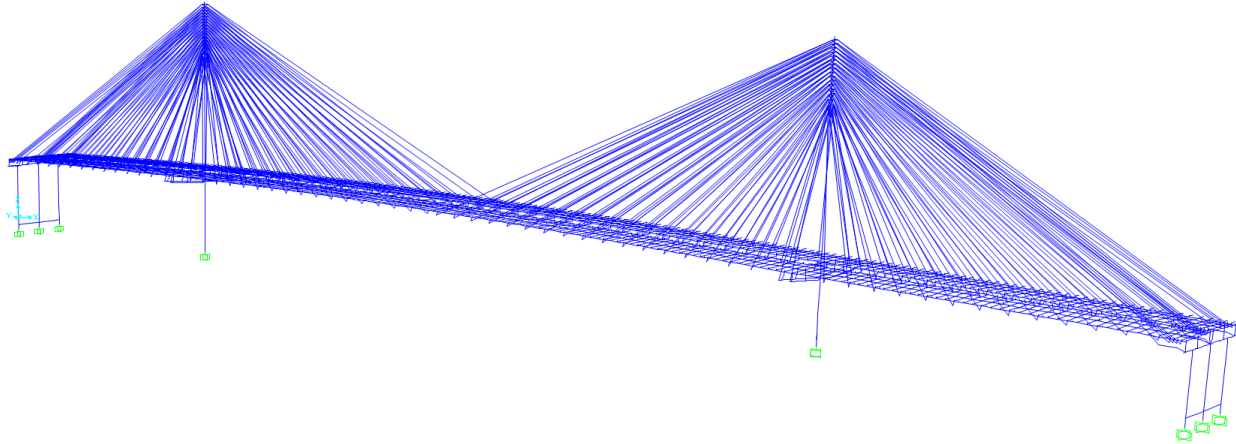
Fig. 7 – Port Mann Bridge Edited and Imported to SAP2000

The cables are modelled as generic frame elements with specified cross-sectional area and material properties. The deck components are also modelled as generic frame elements with their respective material and cross sectional properties. Each support is considered fixed, and the end piers are considered free from the approaches for the purposes of this study, but future research can use spring properties and consider the effect of the north and south approaches.

5. Finite Element Model Updating

Finite element model updating involves defining responses and parameters. The responses are your target for calibrating the model, and the parameters are the variables which are modified in order to reach the target responses.

5.1. Responses

Using FEMTools, experimental and analytical models were paired together, as shown in Fig. 8.
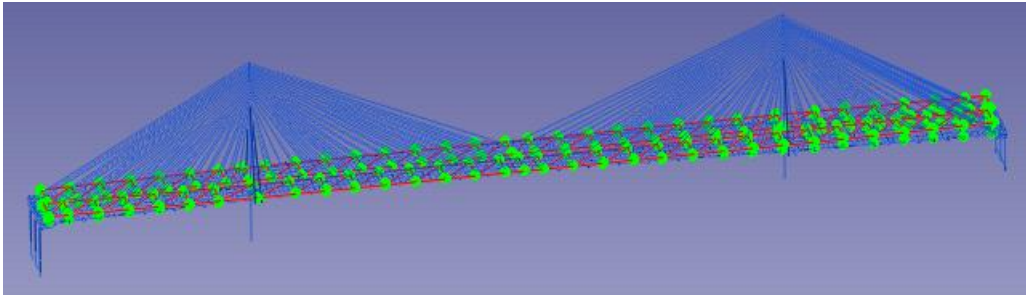

Fig. 8 – Analytical and Experimental Models Paired Together

With the nodes paired, the mode shapes could also be paired based on maximum deviation of frequencies and MAC values. For example, the first vertical mode pair is shown in Fig. 9.
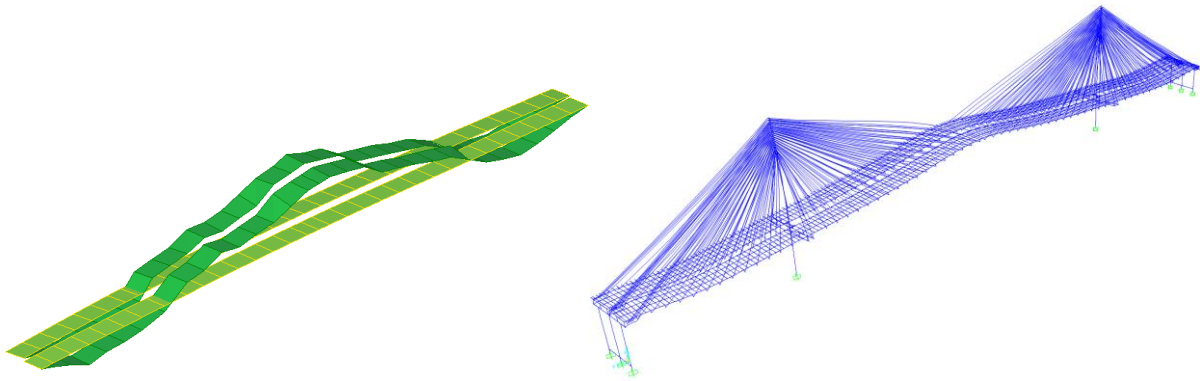
Fig. 9 – Example of 1st Vertical Mode in Experimental and Analytical Models

The responses chosen were based on the experimental results. All six mode shapes were picked and their corresponding frequencies and MAC correlation values were set as the target. Initially only the first three mode shapes were set as responses, and after various iterations, more responses were chosen.

5.2. Parameters

The model consists of some major structural components that were separated into groups:

1. Steel girder deck elements

2. Two main cable towers

3. Concrete pier sections

4. Cables

Since almost all 288 cables each have their own unique structural properties, it was decided to focus the model updating in the other three areas for efficiency and ease of computation. The two main cable towers also have a varying structural properties throughout the height of the towers, so the grouping was further separated into the pylon section above the deck, and the pylon section below the deck.

With these groups determined, a sensitivity analysis was conducted to determine which parameters to focus on for the model updating (Fig. 10). It was found that two basic material properties between the three sets were sensitive enough for modifying: elastic modulus and mass density.
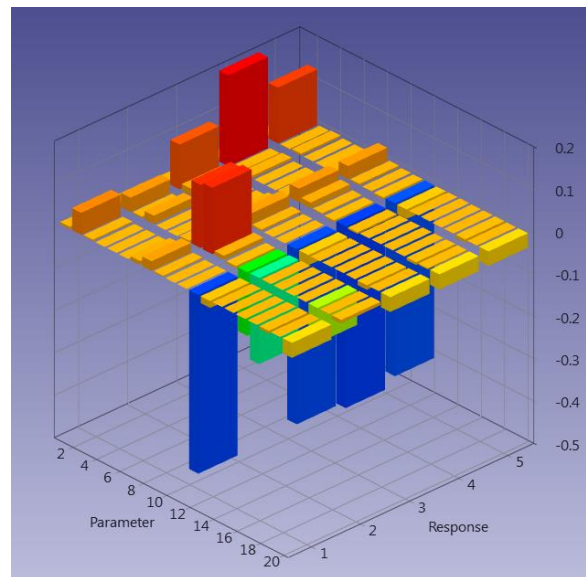

Fig. 10 – Sensitivity Analysis Between Parameters and Responses

5.3. Model Updating

Using FEMTools, the parameters were automatically updated through various iterations until a suitable goal in responses were achieved. The final results are shown in Table 2.

Table 2 – Modal Frequencies Before and After Updating

Mode #	FEA (Hz)	EMA (Hz)	Diff. (%)	FEA Updated (Hz)	Diff. (%)
1	0.26	0.25	3.78	0.24	2.35
2	0.30	0.23	27.12	0.26	1.74
3	0.38	0.30	24.05	0.30	0.37
4	0.43	0.34	25.36	0.39	14.67
5	0.50	0.43	16.35	0.42	-2.05
6	0.56	0.48	17.07	0.48	1.13
		AVG =	18.96	AVG =	3.04

As can be seen in the table, the average difference in frequencies went from 19% to about 3%. The average MAC values did not change much, going from 48% to about 50%. The parameter changes are shown in Table 3.

Table 3 – Changes in Parameters for Updated Model

	Density Change (%)	Elastic Modulus Change (%)
Steel Girder Deck	36.92	56.19
Pylons Above Deck	3.98	26.46
Piers	10.00	-97.18

There were significant property changes in the deck and the elastic modulus of the piers at each end. This large change may not be physically realistic, but it is important to note that model updating is a way of compensating for various errors and shortcomings such as:

- Limitations of finite element modelling in capturing structural behaviour
- As-built construction variances
- Operating conditions such as traffic flow

Finally, the exclusion of the bridge approaches may have also had a significant effect on the dynamic behaviour of the bridge, which could have contributed to the excessive parameter change.

6. Summary and Conclusions

The Port Mann Bridge was modelled in SAP2000 with some simplified assumptions. Experimental data was used from structural health monitoring sensors along the bridge to identify the mode shapes. The mode shapes were then correlated with the finite element model analysis, and the model was updated by varying the elastic modulus and density of the steel girders, pylons, and piers. In the end, an average frequency difference of 3% and an average MAC of 50% was achieved between the six correlated mode shapes.

7. Future Research

It would be beneficial in the future to consider the effects of the foundations and their sensitivity to the dynamic properties. Also consideration can be given to the effect of the approaches on the overall behaviour of the main span. The significant reduction in elastic modulus of the piers will also need to be

investigated by possibly including more parameters or considering the approach spans and/or foundations in the analysis.

8. References

[1]   Artemis Modal Software. (1999-2014). *Structural Vibration Solutions, Inc.,*. Retrieved from http://www.svibs.com/

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