FULL-SCALE MEASUREMENTS ON THE FRED HARTMAN BRIDGE

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1. INTRODUCTION

Following the well-known collapse of Tacoma Narrows Bridge in 1940, many researchers have attempted to identify the mechanisms associated with wind-induced vibrations of long-span bridges. While very sophisticated response prediction techniques have been devised over the years in the field of bridge aerodynamics, relatively few long-term studies have been carried out in prototype structures to evaluate the performance of these techniques. The type of comprehensive instrumentation system needed as well as long-term commitments to data analysis and reporting pose great challenges associated with such long-term projects. However, it is evident that the data obtained from these measurements under various meteorological conditions can provide important insights about the principal mechanisms of bridge aerodynamics as well as helping to improve the current analytical prediction techniques.

Motivated in part by this idea, long-term full-scale field measurements are being performed on the Fred Hartman Bridge near Houston, Texas. Among the various objectives of this project are efforts to identify the modal characteristics, such as natural frequencies and mode shapes of the structure, develop estimates of modal damping values and examine the performance of the structure under a range of meteorological conditions. This paper summarizes findings from the efforts described above, as well as describing examples of interesting features of individual vibration events.

2. DESCRIPTION OF THE BRIDGE AND INSTRUMENTATION

Opened to traffic in 1995, the Fred Hartman Bridge (Fig. 1) connects the industrial towns of La Porte and Baytown, Texas. It is a twin deck cable-stayed bridge with a center span of 380 m and two side spans of 147 m The decks are composed of precast concrete slabs on steel girders and are 24 m wide each, carrying four lanes of traffic. The decks are carried by a total of 192 cables, arranged in four inclined planes and connected to the deck at 15 m intervals.

One of the biggest challenges related with such long-term monitoring projects is the need for robust, comprehensive instrumentation systems. The instruments are prone to extreme climate conditions, such as strong winds, rain, thunderstorms and temperature changes throughout the course of the multi-year test program. Therefore, it is vital to have an instrumentation system that maintains a high level of durability and accuracy.

The basic instrumentation system used in this project consists of the following components, although elements have changed and continue to change on a regular basis:

- 2 three-axis anemometers at the deck level
- Propeller-vane anemometer at the south tower top
- 19 two-axis accelerometers installed on stay cables (±4g range)
- 8 displacement transducers installed on stays
- 8 strain gauges and 2 load cells
- 5 accelerometers, 4 one-axis and a two axis, installed on the bridge deck (±4g range)

- 2 rain gauges (0.25 mm. resolution)
- Temperature probe and barometer
- 4-pole Bessel filters set to 10 Hz (sampling frequency 40 Hz)
- Windows-based Pentium PC with data acquisition and remote communication software.

Fig. 1 shows the locations of some of the instrumentation. All of the instruments are continuously monitored using a remotely interrogated self-triggering system which records trigger files on the basis of exceedance of threshold motion and wind levels. The recorded data files contain 5-minute trigger runs that are sampled at 40 Hz and are stored on high-capacity removable disks for further processing.

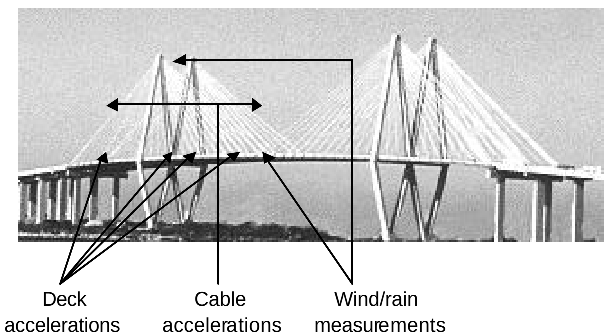

Figure 1. Instrument locations.

3. DECK VIBRATION MEASUREMENTS AND DATA ANALYSIS

Another significant challenge related with long-term monitoring projects is the process of analyzing large quantities of data. More than 8000 trigger files have been recorded during the three years of the test program and more are continuously being collected. Analyzing such a large number of data files demands extensive use of automated procedures. However, the use of such procedures must be carefully controlled to ensure that flawed or questionable data are not included in the study. The data analysis techniques used in this project have been automated to the greatest extent considered prudent, with careful consideration to maintaining the integrity and accuracy of the data and not missing important features of individual records.

The recorded files are initially processed to determine the general features of the raw data. These features include the mean, standard deviation and other higher moments of the data as well as one-minute average wind speeds/directions, accelerations and displacements, all of which are automatically added to a database. The database provides for easy analysis and correlation of these statistical quantities. It is also possible to readily interrogate the data using queries created and stored in the database.

Modal frequencies and mode shapes have been found and these values have been compared with values obtained from finite element (FE) analysis. Preliminary results of this comparison have been presented previously (Ozkan et al. 2001). Table 1 shows the comparison of measured modal frequencies with those obtained from a FE analysis for the first 20 modes. In general, good agreement between the two data sets is observed. Similarly, the mode shapes have been found for the first 20 modes, showing reasonable agreement with those calculated from the FE analysis (Ozkan et al. 2001).

To investigate the wind-vibration characteristics of the bridge deck, plots of root mean square (RMS) acceleration of the deck versus wind speed have been made (Fig. 2-a). A general trend of increasing RMS acceleration with wind speed can be observed from this figure. However, it is interesting to note two distinct patterns of acceleration amplitude. Measurements were taken over periods when the stay cables were damped and undamped during the three-year test program. Using this information, Fig. 2(a) can be divided into Fig. 2(b) and 2(c) corresponding to periods when the cables were damped and undamped, respectively. Two very distinct acceleration patterns can be seen from these figures, clearly suggesting the possibility of different interactions between the deck and the cable motions.

The characteristic appearance of Fig. 2(c) is believed to be primarily due to excitation of the deck caused by oscillation of the adjacent stay during wind-rain and other high-amplitude-inducing events (e.g., Main and Jones 1999). Fig. 2(b) is more representative of global motion of the deck, although to investigate this behavior further, specific records of interest must be analyzed in detail. An example of one such record from Fig. 2(b) is given in Fig. 3. This record forms the initial five-minutes of a series of triggers during the passage of a storm. For this specific record, Fig. 3(a) and (b) show the time-histories and power spectral densities (PSD's) of vertical deck acceleration at midspan and of the adjacent stay cable AS24 (length 198 m.; natural frequency approximately 0.59Hz) respectively. Fig. 3(c) shows the wind speed at deck level. These figures, and others similar that have been made for different deck instruments, show a dominant frequency of vibration at approximately 0.58 Hz. It is important to note that this frequency corresponds to the third symmetric vertical mode of the deck (given as approximately 0.56 Hz in Table-1), and is also

Table 1: Comparison of measured deck modes with FE analysis

Mode	Long-Term Measured Frequency (Hz)	FEM Frequency (Hz)	Percentage Difference	Phasing (I :in-phase O: Out-of-phase)	Description of the Mode (FE)
1	0.290	0.286	1.4	I	Vertical
2	0.299	0.291	2.8	O	Vertical
3	0.375	0.366	2.5	I	Vertical
4	-	0.377	-	O	Vertical
5	0.432	0.410	5.4	O	Lateral
6	-	0.426	-	I	Lateral
7	0.564	0.556	1.4	I	Vertical
8	-	0.562	-	O	Vertical
9	-	0.612	-	O	Torsional
10	0.586	0.625	6.2	I	Vertical
11	-	0.634	-	O	Vertical
12	0.665	0.658	1.1	I	Vertical
13	-	0.659	-	-	Torsional-Lateral
14	0.683	0.662	3.2	-	Torsional-Bending
15	0.714	0.735	2.9	I	Vertical
16	-	0.736	-	O	Vertical
17	-	0.756	-	I	Torsional
18	0.784	0.757	3.6	O	Vertical
19	-	0.817	-	I	Torsional
20	0.924	0.856	7.9	I	Vertical

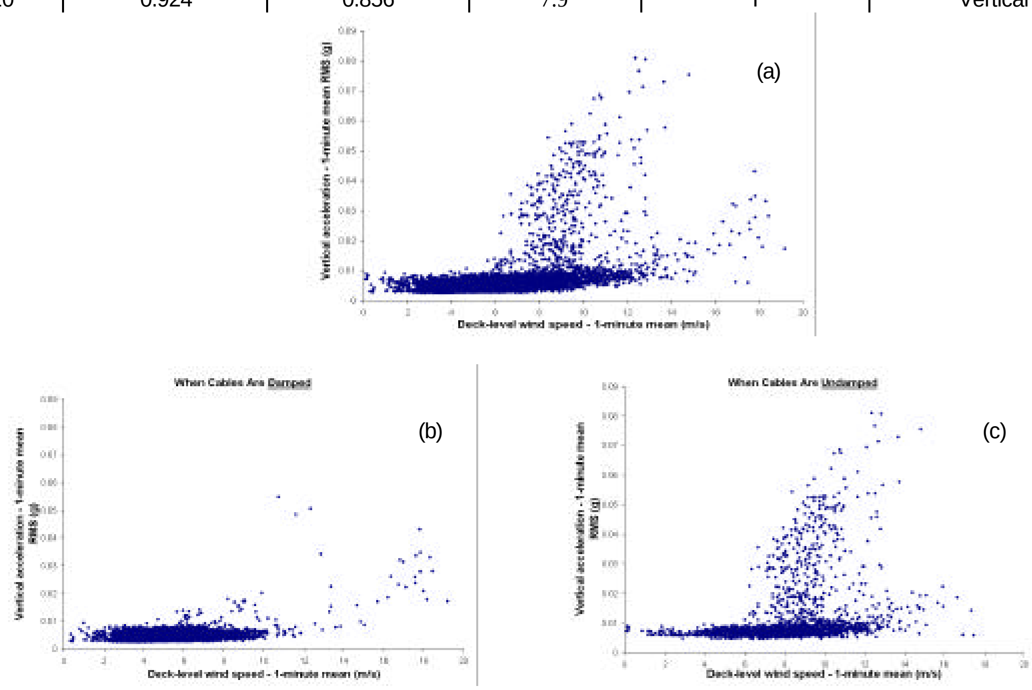

Figure 2. RMS deck acceleration vs. wind speed **a)** all, **b)** cables damped and **c)** cables undamped.

close to the first mode of the stay cable AS24. This is an interesting and important observation since the first-mode vibrations of a cable at this level of acceleration are generally associated with large displacements. In fact, by integrating the acceleration time-history, a displacement amplitude of approximately one meter (peak to peak) was estimated.

Furthermore, by observing the time-histories it can be seen that the significant vibrations are initially observed at the deck instead of the cable. This observation, as well as the similarity of modal frequencies suggests that the deck is driving the cable to vibrate with large amplitude in its fundamental mode. Vortex-induced vibration of the deck is thought to be the driving mechanism for this motion. Further studies are continuing to better understand the underlying mechanisms involved in this behavior and its consequences, and will be reported in the full paper.

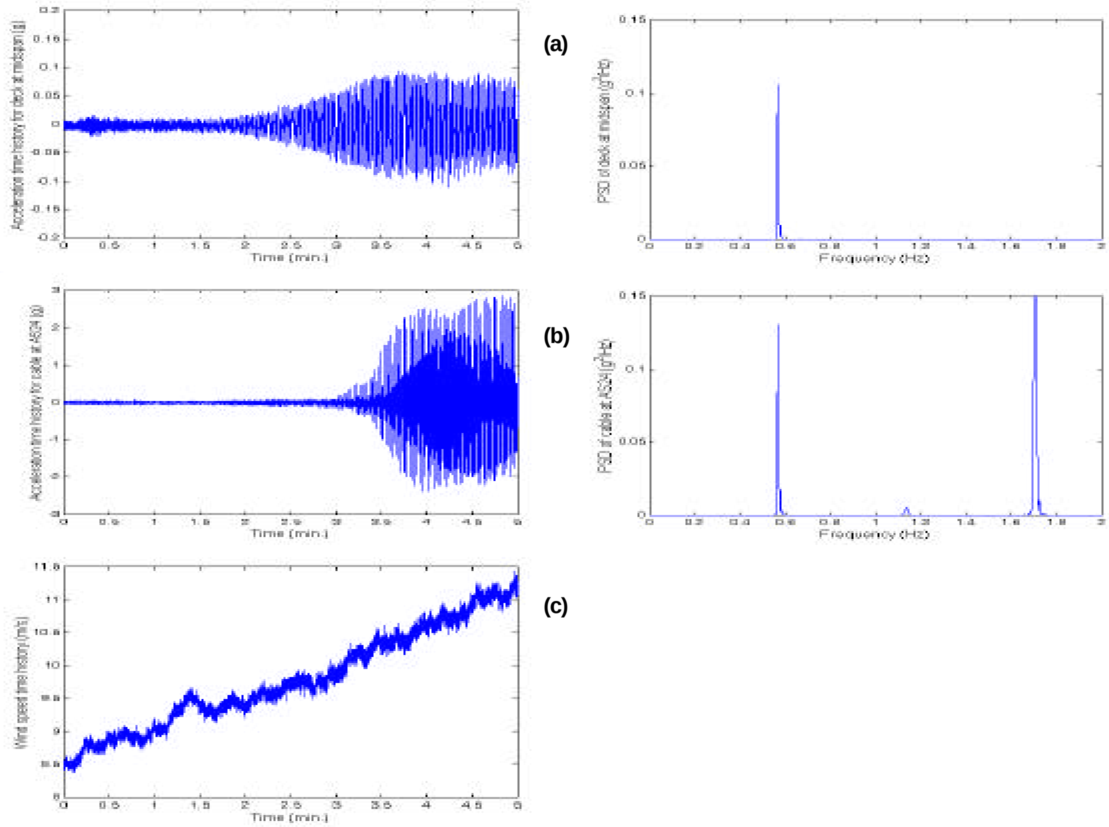

Figure 3. Plots of time history and power spectral density (PSD) of the first 2-Hz for **a)** deck at midspan (vertical dir.), **b)** cable at AS24 (in-plane dir.) and **c)** deck level wind speed.

4. CONCLUDING REMARKS

The preceding paper presents an overview of long-term efforts to monitor a cable-stayed bridge for a variety of purposes, including understanding the modal characteristics and wind-induced responses under ambient wind conditions. Using data files collected during various meteorological conditions, natural frequencies and mode shapes of the deck were found using an automated data analysis procedure. The measured modal frequencies and mode shapes observed to agree with the predicted values found from a finite element analysis.

While automated data analysis procedures are clearly necessary for such large volumes of data, care must be taken not to miss or obscure important phenomena or characteristics through this approach. The interaction observed between the deck and a stay is a good example of a situation where careful interpretation of the data is required to fully understand the relevant underlying mechanics.

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