PROJECT SUMMARY REPORT

TEXAS TECH UNIVERSITY
CENTER FOR MULTIDISCIPLINARY RESEARCH IN TRANSPORTATION

Project Summary Report 0-1400-S

Project 0-1400

Authors: R. S. Phelan, K.C. Mehta, P.P. Sarkar and L. Chen

Investigation of Wind-Rain-Induced Cable-Stay Vibrations on Cable-Stayed Bridges: Findings and Recommendations

In recent years, large-amplitude cable-stay vibrations have been observed on a number of bridges in the U.S. and abroad during relatively low wind speeds. The proposed cause of the wind-rain-induced vibration problem is the change in cross-sectional shape of the cable-stay that occurs when rain forms one or more beads, or rivulets, along the cable surface. Excessive vibrations accelerate fatigue of the cable-stays and cause distractions to passing motorists. Typically the wind-rain-induced vibration problem has not received adequate attention from bridge designers—resulting in the current need for mitigation devices.

Two highway bridges under the jurisdiction of the Texas Department of Transportation (TxDOT) have experienced a wind-rain-induced cable-stay vibration problem. These two bridges are the Fred Hartman and Veterans Memorial, located in Baytown and Port Arthur, Texas, respectively.

What We Did…

The principal areas of contribution by Texas Tech University (TTU) researchers have been the aerodynamic characterization of the wind-air-induced cable-stay vibration phenomenon, the development of meteorological instrumentation for field studies, and the exploration of aerodynamic damping devices. Prominent milestones achieved from the TTU work are as follows:

- Wind tunnel testing to characterize wind-rain-induced cable-stay vibrations.
- Wind tunnel evaluation development of aerodynamic damping strategies for cable-stay vibration mitigation.

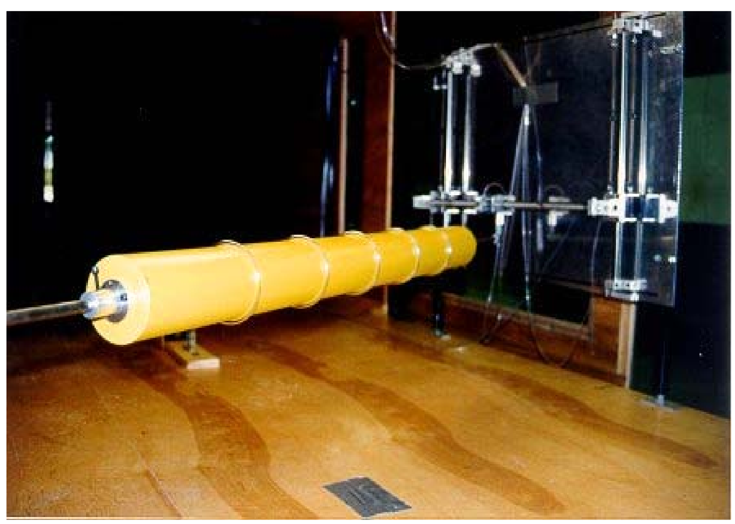

Figure 1. Circular Rings Placed on Cable-Stay

- Development of a field instrumentation system for the Veterans Memorial Bridge and system monitoring.
- Development of "aerodynamic rings" for prototype evaluation.
- Evaluation of aerodynamic prototype damper.
- Monitoring and analysis of the behavior of cable-stays both before and after ring installation.

TTU researchers designed and assembled a two-degree-of-freedom (2DOF) elastic suspension system (vertical and horizontal motions) so that the section model is able to behave more similarly to actual cable-stays. The suspension system used is designed to test yawed and inclined section models and is shown in Figure 1. Also shown in Figure 1 are the circular rings placed on the cable-stay.

Based on positive results from the wind tunnel tests, a decision was made to instrument and monitor several cable-stays at the Veterans Memorial Bridge. The intent of this field instrumentation and monitoring phase of the research project was to (1) verify the existence of the wind-rain-induced cable-stay vibration and 2) determine if a field installation of the circular aerodynamic ring dampers would mitigate these vibrations.

Aerodynamic rings were installed on three Veterans Memorial cable-stays in mid-January, 2001. Data was collected and analyzed for 18 months prior to the ring installations, and for 6 months after ring installation.

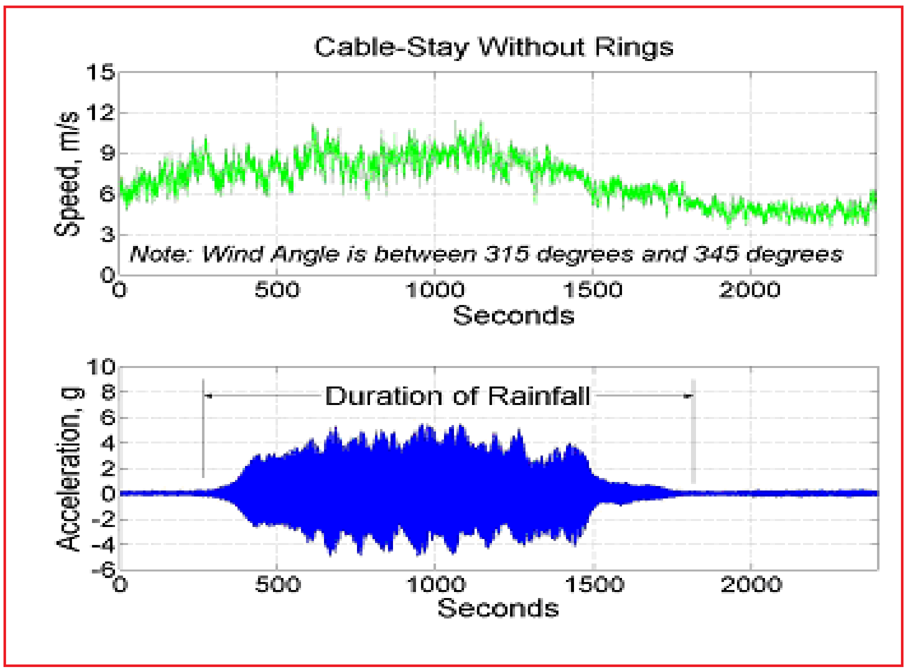

Figure 2. Instantaneous Acceleration Event

What We Found…

Wind Tunnel

A number of different aerodynamic damping devices were tested in the wind tunnel by TTU researchers. The installation of a helical strake, elliptical rings, or circular rings in the wind tunnel resulted in: a) interruption of the axial wind flow and b) modification of the cable-stay cross section, as well as c) disruption of the formation of a continuous water stream along the cable-stay. Both single-degree of freedom (SDOF) and two-degree of freedom (2DOF) wind tunnel experiments proved the effectiveness of circular aerodynamic rings.

The velocity-restricted nature of wind-rain-induced cable-stay vibrations was demonstrated as both low-wind speed and high-wind speed mitigation behavior of the circular rings were tested. Circular rings attached to the cylinder reduced the system response by up to 90% compared to the bare cylinder case at high reduced velocities. Circular rings with an outside cross-section diameter of $D/14$, where D is the diameter of the cylinder, were attached at regular intervals along the cylinder. The vibration of the cylinder decreases more as the spacing between the circular rings decreases. Currently, a circular ring thickness, t, between $D/20$ and $D/10$ has been found most effective. The damping effect increases with a larger value of t.

Field Site - Before Rings

Several significant events were recorded over an 18-month period. In particular, an instantaneous acceleration event of 5 g was recorded on October 8, 1999. The plot of this event, shown in Figure 2, demonstrates that under favorable conditions, the cable-stay will vibrate and will continue to vibrate until one or more of the parameters causing the favorable conditions ceases. In this case, the vibration began and continued due to a) rain with wind, b) wind speed in the velocity-restricted region, and c) wind from a critical angle for the cable-stay. For this particular cable-stay, one range of critical angles is between 315° and 345°, where a 0° wind direction is perpendicular to the plane of the cable-stay. The angle of this cable-stay from tower to anchor is 90°. In this case, the vibration ended once the rainfall ceased. Figure 2 represents a major accomplishment of this research effort.

Field Site – After Rings

Based on data collected from the Veterans Memorial Bridge, severe wind-rain-induced vibration did not occur on cable-stays after ring installation. Wind-rain-induced vibration often occurred on these two cables prior to the ring installation. In contrast, a number of severe wind-rain-induced vibrations occurred on cable-stays where no rings were ever installed. Thus, it appears that aerodynamic rings may be suppressing the wind-rain-induced vibrations. However, with the limited number of data points collected in the field to date, firm conclusions concerning the effectiveness of the aerodynamic rings cannot be made at this time. Also, as expected, the circular aerodynamic rings do not mitigate cable-stay vibrations due to low-speed flutter, where the wind direction is perpendicular to the plane of stays (i.e. 0°). Comparisons of the cable-stays before and after the rings were installed are presented in Table 1.

The Researchers Recommend...

Future work should be directed at determining an optimal cross-sectional size and shape of the circular ring, with aesthetics of the cable-stayed bridge in mind. Several potential changes in the ring and/or cable-stay surface area parameters should be investigated. Smaller rings can be used to decrease drag.

Full-scale testing of the circular rings in natural wind, along with other vibration mitigation devices, should be performed when possible. To accomplish this task, a controlled full-scale test site should be developed. Such a field site must have a large tower with the ability to record actual wind, rain and other meteorological data. One such site is the Wind Engineering Research Field Laboratory in Lubbock, Texas. Full-scale testing, using the TTU 200 m (650-foot) tower, would allow confirmation or rejection of numerous, conflicting claims from a variety of mitigation device manufacturers. Knowledge gained from such full-scale tests would allow TxDOT and other government agencies to make better decisions when developing cable-stay vibration mitigation strategies.

Mitigation of cable-stay vibrations appears to be an excellent candidate for active control technology. Unlike typical building structures designed to resist seismic forces, active control of cable-stays should have many fewer constraints, as massive forces and associated power requirements are not needed.

	Cable-Stays with Rings		**Cable-Stays without Rings**	
	Before Rings Before 1/10/01	**After Rings After 1/10/01**	**No Rings Before 1/10/01**	**No Rings After 1/10/01**
WIND VS. RMS ACCELERATION	Wind-rain	No wind-rain	Small number of wind-rain	Large number of wind-rain
	Low-speed flutter events occurred	Low-speed flutter events occurred	Low-speed flutter did not occur *	Low-speed flutter events occurred
DOMINANT MODES	13th	10th	13th	13th
	Pattern altered after rings installed		Similar before and after 01/10/2001	

Table 1. Cable Stay Comparisons Before and After Ring Installation

For More Details

The research is documented in the following reports:

Report No. - 0-1400-1, Investigation of Wind-Rain Induced Cable-Stay Vibrations on Cable-Stayed Bridges: Final Report

Research Supervisor: Kishor Mehta, Ph.D., Texas Tech University, (806) 742-3476
Project Director: Keith Ramsey, TxDOT Bridge Division, (512) 416-2250

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