Investigation of traffic induced vibrations and luminaire behavior

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Abstract— *Since the mid-1980s there has been numerous research on vibration and fatigue of traffic signal and sign structures. Recently, it has been recognized that both wind and traffic can cause vibration problems in roadway lighting and that the more severe problems usually exist on bridges where both wind and traffic provide exciting forces. Lighting manufacturers are primarily concerned with damaging fatigue that can cause structural failure of luminaires, but departments of transportation also are interested in excessive lamp failures. Usually excessive lamp failures are found in bridge lighting installations for poles located away from bridge supports. This paper summarizes research efforts made in the recent past to investigate the relationship between traffic induced vibrations and luminaire failures on a cable-stayed bridge.*

Keywords— vibration, monitoring, luminaires, fatigue, light-pole.

I. INTRODUCTION

Primary vibrations of luminaire-pole structures are considered low frequency and generally have been measured in the 0.6 to 25 Hz range. Peak accelerations of luminaires and lamps usually are less than 1 g. Although short lamp life often is attributed to traffic vibrations, the short life also could be due to lamp and luminaire design. The usual manufacturer's vibration testing of luminaires considers fatigue of the luminaire but not lamp life associated with the vibration.

Studies of retrofit measures for bridge lighting installations with short lamp life have focused on the addition of dampers rather than other measures such as replacement of luminaires or poles. The dampers that have worked well are the inertial type. Optimal damper placement has been determined at 50 or 70% of the height of the pole, depending on the specific installation. A study conducted by Burt et al. [1] indicated that the use of elastomeric isolation pads proved to be ineffective. However, some departments of transportation have used the isolation pads to retrofit lighting installations with vibration problems and routinely specify the pads for new bridge lighting installations.

In the recent past, attention was drawn to failing luminaires on the Burlington Cable Stayed Bridge across the Mississippi river in Iowa. Many light bulbs have failed prior to reaching their expected life. It was hypothesized that vibrations from vehicular traffic may have caused the premature failures. In order to study how traffic affects the light poles, several tests were conducted under different load conditions. The primary purpose of these tests was to understand the relationship between traffic induced vibrations and luminaire behavior and subsequent failures.

II. DESCRIPTION OF SUBJECT LIGHT POLE

The original Burlington Bridge lighting design placed the forty-two light poles for lighting efficiency but without regard to the locations of superstructure supports. Each of the forty-two light poles is anchor-bolted directly to the bridge or ramp barrier rail at 2.5 feet above the roadway and extends to the luminaire mounting height at an elevation of 40 feet. Each pole is a round steel tube, tapered and bent to form a mastarm, with a welded base plate and welded 2-3/8 inch diameter tube extension at the top for mounting the luminaire.

Because of the concern that typical high pressure sodium (HPS) lamps would attract mayflies and cause a slippery roadway surface during late spring and early summer, the bridge lighting designer selected low pressure sodium (LPS) lamps.

Each LPS luminaire is 65 inches long, weighs 52 pounds, and has an effective projected area of about 1.5 square feet. The luminaire has a slipfitter connection that fits over the tube extension at the top of the light pole. Inside the luminaire there is a socket for the LPS lamp and a wire loop and spring for supporting the loose end of the lamp. The lamp is secured by inserting its pins in the socket and twisting the lamp. A 180-watt LPS lamp is relatively long and heavy (larger and heavier than a baseball bat).

III. MONITORING PLAN

After a review of the literature [2,3,4&5] and consideration of manufacturers' and lighting consultant's advice, it was thought that the most promising options for retrofitting the Burlington bridge lighting were to replace the LPS luminaires with approximately equivalent but vibration resistant HPS luminaires and to attach dampers to the light poles as needed. Although replacing all of the luminaires would require changes to the two lighting circuits for the bridge, replacing a single luminaire on each circuit for vibration monitoring would not alter circuit performance sufficiently to cause problems.

To test the greatest variety of combinations within the limits of two HPS luminaires and two pole dampers, the following plans were developed.

- Replace a luminaire on the north lighting circuit and mount a damper on the same pole. The pole selected for the retrofit was on the curved exit ramp.
- Replace a luminaire on the south circuit and mount a damper on an adjacent pole. The selected poles were on the cable-stayed span of the main bridge tower.

The plan permitted the comparison of an existing pole and LPS luminaire with three retrofitted poles: a pole with a new HPS luminaire (POLE 2), a pole with both a new HPS luminaire and a damper (POLE 5), and a pole with an existing LPS luminaire and damper (POLE 3).

Based on manufacturer's and lighting consultant's advice, the replacement HPS luminaire had the following specifications:

- GE Lighting Systems, Inc. product M-400A with cutoff optics [6].
- 250 watts; HPS light source; 480 volts; HPF reactor or lag ballast.
- No PE function; non plug-in/none ignitor mounting.
- Flat glass lens type; medium, cutoff, Type III IES distribution type; fiber gasket filter.
- Suitable for severe vibration up to 3 Gs; ballast not mounted on Powr/Door module.
- 32 inches long (approx.); 33-39 pounds; 1.1 square foot maximum effective projected area.

From the three dampers available from the pole manufacturer, an external vibration damper was selected. The damper is a capped, 2-3/8-inch diameter tube 12 inches long containing a loose 1-1/2-inch diameter steel rod with plastic end caps. A slotted aluminum extrusion bracket provides for a strap or hose clamp attachment to the side of the light pole.

IV. TESTS AND TEST PROCEDURE

Accelerometers for measuring vibration were installed at specified locations on the test poles prior to testing. A total of five light poles were instrumented. Notations for each general class of tests conducted (e.g., Mainline Test 1, Mainline Test 2 and Ramp Test) are given in Fig. 1. Accelerometers were typically installed at three locations on each of the poles and connected to a central data acquisition system. The accelerometers were placed on the luminaire casing, on the middle section of the pole approximately 28 ft from the base, and on the base of the pole as shown in Fig. 2. A typical photograph of the bridge is shown in Fig. 3. Also, typical photographs of the installment can be found in Fig. 4.

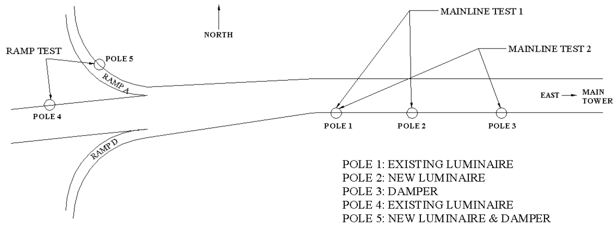


Fig. 1: Condition and location of poles

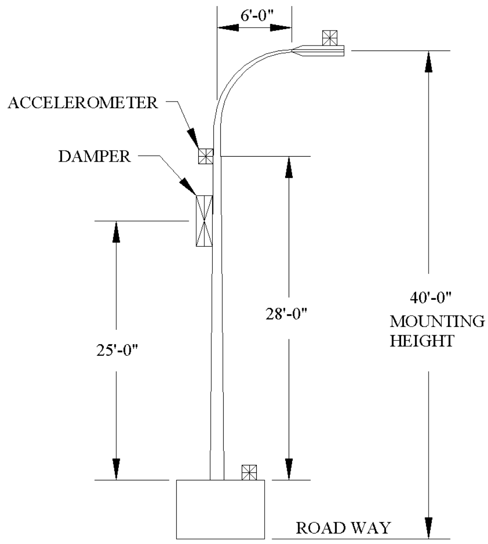


Fig. 2: Location of accelerometer and damper

Wind speeds in the morning, during testing on the ramp and approach span, were approximately 10 mph (±3 mph). Wind speeds in the afternoon, during testing on the cable-stayed span, were approximately 14 mph (±4 mph). Generally, winds were from the southwest but varied from west-southwest to south-southwest. The wind speed values are a combination of site-measured values and published values.

Tests could generally be divided into two categories: 'Free Vibration' and 'Forced Vibration'. For the Free Vibration tests, data from the accelerometers were recorded when there was no traffic in the vicinity of the poles. For the Forced Vibration tests, data were recorded with traffic in the vicinity of the poles. Measurements were made under various traffic conditions (i.e., different vehicle types and combinations, etc.).

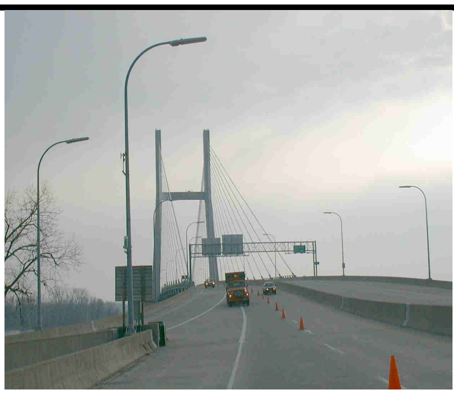


Fig. 3: Typical photograph of bridge (looking east)

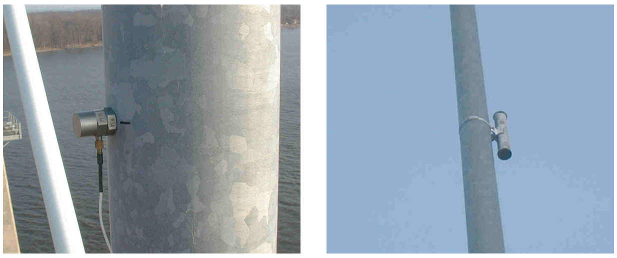
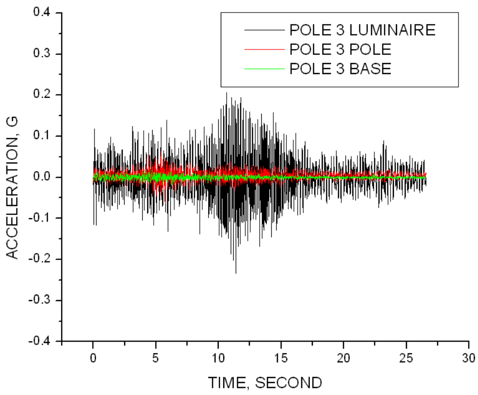


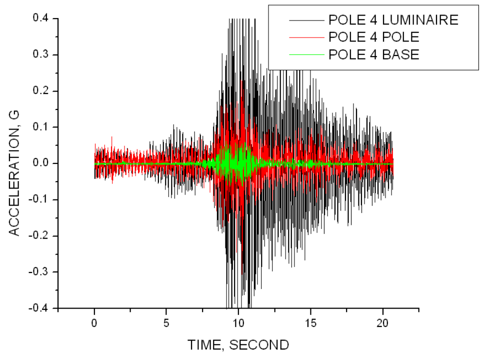
Fig. 4: Typical photograph of installment

V. DATA ANALYSIS

The first step in the data analysis process consisted of a basic statistical analysis and graphical presentation. Accelerations obtained from each accelerometer were plotted with respect to time. From this, peak positive and negative accelerations were obtained from the test statistics. Fast Fourier Transform (FFT) analyses were then performed, after which frequency amplitudes were plotted with respect to frequency for each accelerometer. The FFT analysis employs the principle of the Fourier integral in discrete form to transfer a function or data from the time domain to the frequency domain. From the FFT results, the dominant vibration frequency from each test was determined by selecting the frequency that had the highest amplitude. Examples of acceleration and frequency content data are given in Figs. 5 and 6.

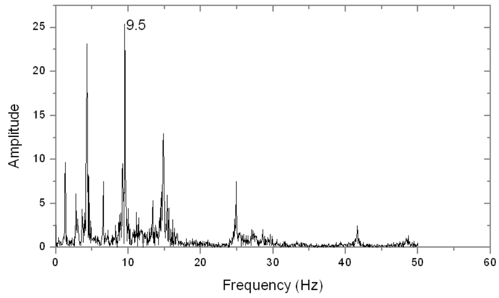


(a) Mainline Test 2, Pole 3

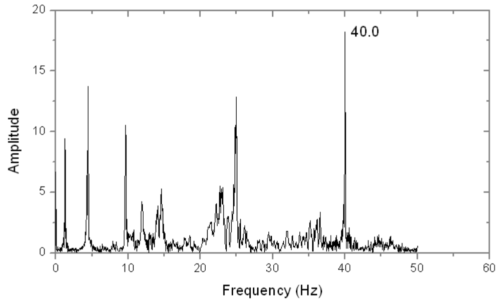


(b) Ramp Test, Pole 4

Fig. 5: Typical acceleration data



(a) Mainline Test 1, Pole 1 Luminaire



(b) Ramp Test, Pole 4

Fig. 6: Typical frequency content data

VI. TEST RESULTS

The data collected from these tests indicates that installing a damper on the exit ramp light pole tended to reduce the acceleration level. However, it was found that installing dampers on main span pole had no impact on acceleration levels. It should also be pointed out that it was also qualitatively noted during testing that vibration of the bridge, and also in the light poles, tended to continue for a relatively long duration after the test load had passed. Unfortunately, the testing procedure used, specifically the fact that the bridge was continuously open to traffic, did not allow for quantification of the length of these vibrations. Several general observations can be made from the data taken during the testing as follows:

- Peak accelerations at pole bases on the ramp and approach span were consistently higher than on the cable-stayed span (±1.06 g vs. ±0.02 g to 0.03 g). Observations made from standing on the bridge decks during testing also indicated higher vibrations on the ramp and approach span. This suggests that traffic has more of an effect on the ramp and approach span than on the cable-stayed span.

- Peak accelerations on poles on the ramp and approach span were consistently higher than on the cable-stayed span (±0.14 to 0.31 g vs. ±0.06 to 0.09 g). This suggests that the poles on the ramp and approach span are responding to the higher traffic vibrations.
- The luminaire, pole, and base measurements for peak acceleration for the LPS pole without a damper and the LPS pole with a damper were nearly the same. This suggests that the damper was ineffective in reducing accelerations for the existing LPS liminaire and pole installation.
- The LPS luminaries on the cable-stayed bridge had lower peak accelerations than the LPS liminaire on the approach span (±0.21 to 0.40 g vs. +0.68/-0.48 g). This suggests that the LPS luminaries on the approach span and ramps are responding to the higher traffic vibrations on the ramp and approach span than on the cable-stayed span.
- Peak accelerations and dominant frequencies on the LPS luminaries and bulbs were essentially identical. This suggests that the bulbs were not moving independently of the luminaries under the traffic vibrations on the cable-stayed span.

Table 1 shows typical data obtained from each accelerometer.

Table 1. Typical data analysis

(a) Mainline Test 1

Accelerometer	Peak Positive Acceleration, g	Peak Negative Acceleration, g	Dominant Frequency, Hz
POLE 1 TOP	0.33	-0.40	9.5
POLE 1 BULB	0.32	-0.39	9.5
POLE 1 POLE	0.08	-0.09	1.3
POLE 1 BASE	0.03	-0.03	10.9
POLE 2 TOP	0.32	-0.30	22.9
POLE 2 POLE	0.09	-0.07	2.9
POLE 2 BASE	0.02	-0.03	33.4

(b) Mainline Test 2

Accelerometer	Peak Positive Acceleration, g	Peak Negative Acceleration, g	Dominant Frequency, Hz
POLE 1 TOP	0.21	-0.24	4.3
POLE 1 BULB	0.22	-0.24	4.3
POLE 1 POLE	0.07	-0.07	4.3
POLE 1 BASE	0.02	-0.02	3.5
POLE 3 TOP	0.20	-0.23	9.6
POLE 3 POLE	0.06	-0.06	4.3
POLE 3 BASE	0.02	-0.02	7.0

(c) Ramp Test

Accelerometer	Peak Positive Acceleration, g	Peak Negative Acceleration, g	Dominant Frequency, Hz
POLE 5 TOP	0.37	-0.30	5.0
POLE 5 POLE	0.15	-0.14	5.0
POLE 5 BASE	0.06	-0.06	8.0
POLE 4 TOP	0.68	-0.48	9.7
POLE 4 POLE	0.23	-0.31	40.0
POLE 4 BASE	0.06	-0.06	12.0

VII. DISCUSSION

It was expected initially that the traffic-induced vibrations were the primary cause of the luminaire failures. However, due to the relatively low vibration levels obtained from the test, it appears that mechanical vibrations alone were not the cause of such failures. It is thought that wind-induced excitation, unlike the traffic-induced vibration monitored during this testing, might have a significant impact on the light system failure. Therefore, more study to understand the behavior of the light pole may be needed.

The most recent research by Johns and Dexter [7], which follows the direction of the new AASHTO sign support specifications [8], indicated that wind effects due to vortex shedding could be expected for wind velocities in the 10-35 mph. During testing, wind speeds were at the low end of that range, and therefore the effects of vortex shedding during the testing could have been minimal. Changes in wind velocity were gentle, and therefore the effect of wind gusts may have been minimal as well.

Johns and Dexter [7] indicated that wind should excite higher pole vibration modes. The dominant modes measured on the Burlington Bridge ranged from low to high, but most were at lower modes. Van Dusen [9,10&11] stated that wind generally excites a pole at a resonant frequency but that traffic excites poles at non-resonant frequencies. It appears that the frequency measurements indicate that traffic rather than wind was the driving force for the measured vibrations.

Although not completed, with the data collected, tools could be developed to more fully understand the dynamic behavior of the light pole under traffic loadings for further retrofit design. For example, an envelope of dominant frequencies could be plotted to establish the expected behavior of the light pole. This envelope could serve as a guide for defining acceptable vibration limits. This information could be used by engineers to design a light pole system to accommodate and withstand the vibration intensities within the envelope.

Based on the test results, it is difficult to give a definitive answer about whether the new luminaires will or will not improve the situation. Although some useful information was obtained from the single-day test, the test results give no definitive basis for determining if the previous bulb problems have been caused by what could be described as global (e.g., pole and/or luminaire) vibration problems or local (e.g., bulb wiring, bulb connection, etc.) vibration problems. It is known that the ‘g’ levels measured on the luminaries were relatively low given the bulb specifications. However, it is possible that the excitation that has caused the previous problems were more extreme than the excitation created during this data collection. It should also be pointed out that the bulb did not experience differential vibrations relative to the luminaire. This would suggest that the bulb is not “bouncing around” in the luminaire.

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