

# Development of a Bridge Safety Information System for the Saylorville Reservoir Bridge

**Final Report**  
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Institute for Transportation

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<b>16. Abstract</b> <p>In 2006, a bridge safety issue was brought to the attention of the Iowa Department of Transportation (DOT) regarding the response of the Saylorville Reservoir Bridge during a high wind event. Although stop-gap measures were put into place, the current knowledge of the performance of the bridge during high wind events was incomplete. Therefore, it was determined that the Saylorville Reservoir Bridge near Polk City, Iowa could further benefit from an information management system to investigate the structural performance of the structure and the potential for safety risks.</p> <p>The monitoring system that was in place at the Saylorville Reservoir Bridge monitors wind data and strain data separately and, through a wireless data connection, uploads this information to a webserver and a website created for the bridge. In addition, the system is programmed to send alert messages to safety personnel when wind speeds reach the predetermined threshold of 50 mph or greater.</p> <p>Once an alert is received, safety personnel determine if it necessary to close the bridge until wind speeds diminish. However, there was no input from the structural monitoring side of the system into the alert to provide safety personnel or engineers with information pertaining to the response of the bridge to the high winds.</p> <p>Therefore, development of an autonomous bridge safety monitoring and alert system for the Saylorville Reservoir Bridge would 1) provide quantitative information regarding any correlation between high wind events and excessive bridge movement, 2) result in considerable savings in manpower and cost by eliminating the need for local authorities to physically close the bridge, 3) eliminate the exposure of local authorities to potential unsafe conditions to close the bridge, and 4) allow for the safe and efficient closing of the bridge to facilitate safer driving conditions on the bridge for motorists.</p>			
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# **DEVELOPMENT OF A BRIDGE SAFETY INFORMATION SYSTEM FOR THE SAYLORVILLE RESERVOIR BRIDGE**

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**Principal Investigator**  
Travis Hosteng  
Bridge Engineering Center  
Institute for Transportation, Iowa State University

**Authors**  
Travis Hosteng, Terry J. Wipf, and Douglas L. Wood

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A report from  
**Bridge Engineering Center**  
**Institute for Transportation**  
**Iowa State University**  
2711 South Loop Drive, Suite 4700  
Ames, IA 50010-8664  
Phone: 515-294-8103  
Fax: 515-294-0467  
[www.intrans.iastate.edu](http://www.intrans.iastate.edu)



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## **EXECUTIVE SUMMARY**

Following a high wind event on January 24, 2006, at least five people claimed to have seen or felt the superstructure of the Saylorville Reservoir Bridge in central Iowa moving both vertically and laterally. Since that time, the Iowa Department of Transportation (DOT) contracted with the Bridge Engineering Center (BEC) at Iowa State University to design and install a monitoring system capable of providing notification of the occurrence of subsequent high wind events.

In subsequent years, a similar system was installed on the Red Rock Reservoir Bridge to provide the same wind monitoring capabilities and notifications to the Iowa DOT. The objectives of the system development and implementation are to notify personnel when the wind speed reaches a predetermined threshold such that the bridge can be closed for the safety of the public, correlate structural response with wind-induced response, and gather historical wind data at these structures for future assessments.

The system modifications described in this report provided a means for the monitoring system to not only provide wind-related safety alerts, but also store and process the recorded data and, then, publish that information, live, to a website for viewing.

Prior to modifications, the system only provided real-time alerts to the Iowa DOT, and pertinent law enforcement personnel, related to wind speed thresholds measured on the bridges (and these capabilities still exist). The alerts allow the Iowa DOT and law enforcement to divert traffic quickly when wind conditions make bridge passage unsafe.

With the recent modifications, the Iowa DOT and law enforcement personnel are able to make decisions based on real-time weather information, so that more accurate decisions about bridge closure and duration of closure may be made.

Based on data collected over the one-year duration of the project, the wind data suggest that both locations (Saylorville and Red Rock) experience similar trends in wind direction, three-minute average wind speed, and three-minute maximum wind speed.

Overall, distribution of the average and maximum wind speeds was relatively similar for both bridges, but the Red Rock Reservoir Bridge did tend to have slightly higher numbers of occurrences in two categories (with wind speed averages ranging from 5 to 15 mph) compared to the Saylorville Reservoir Bridge.

Finally, overall maximum wind speeds measured at both sites were in the 65 to 70 mph range, with two occurrences at the Saylorville Reservoir Bridge and one occurrence at the Red Rock Reservoir Bridge during the course of the year.

The system that was developed on this project can be implemented on other bridges with the data being presented in a similar form and format.



## INTRODUCTION

Wind and bridges have a long-standing history, often involving uncertainty, fatigue-inducing movements, and, at times, collapse. A classic example is the Tacoma Narrows Bridge collapse, which is often the keynote example for discussions about the effects of wind on bridges.

This suspension bridge spanned the strait of Puget Sound between Tacoma and the Kitsap Peninsula in Washington. The bridge, which opened to traffic on July 1, 1940, collapsed on November 7, 1940.

The bridge deck began to pitch and sway due to a unique and unforeseen bridge-wind coupling and soon thereafter collapsed into the Puget Sound below, forever etching its mark in history. This event brought forward the recognition that wind must be a factor of consideration in both design and construction of new bridges and maintenance, monitoring, and management of existing bridges.

In addition, the effects of weather events on everyday traffic have been a concern for decades. Disruption of traffic access and/or flow may come from physical damage to roadway infrastructure, slick roads, reduced travel speeds, decreased visibility, and many other factors.

A little more than half a decade after the Tacoma Narrows Bridge collapse, wind-induced effects on bridges are still a significant concern for bridge engineers for various reasons.

On January 24, 2006, a bridge safety issue was brought to the attention of the Iowa Department of Transportation (DOT) regarding the response of the Saylorville Reservoir Bridge near Polk City, Iowa during a high wind event. The following day, an article in the Des Moines Register indicated that the Saylorville Reservoir Bridge had been observed to be swaying in the wind the previous day, and subsequent investigative efforts identified at least five other people claiming to have seen or felt the superstructure moving on January 24.

In response to these observations, on February 5, 2006, bridge engineers from the Iowa DOT and the Iowa State University Bridge Engineering Center (BEC) conducted an inspection of the bridge; however, no signs of excessive bridge movement were found.

Immediately following inspection of the structure, measures were put in place to protect the traveling public, but there was incomplete knowledge of the performance of this bridge during high wind events. Therefore, the Iowa DOT and the BEC determined the Saylorville Reservoir Bridge could further benefit from an information management system to investigate the structural performance of the bridge and the potential for safety risks during high wind events.

This report summarizes the development and implementation of a monitoring system for the Saylorville Reservoir Bridge, as well as the collection and analysis of wind and structural data from that system during the course of the project to aid in the development of recommendations for a bridge safety information system.

## **BACKGROUND**

### **Saylorville Monitoring System**

Following the wind event in January 2006, short-term live load testing was conducted on the bridge to gain a better understanding of the bridge's behavior. Dynamic and static behavior data were collected under ambient traffic and the 54,800 lb Iowa DOT snoop truck during the fall of 2007 and spring of 2008, respectively.

The goal of this data collection was to obtain general behavior characteristics of the bridge. Unfortunately, no high wind events occurred during either of these short-term tests such that correlations between wind speed and structural bridge response could be made.

Dynamic load test results from 2007 indicated that accelerations measured in the structure due to the load truck were relatively small in magnitude and resulted in an experimental fundamental frequency for the bridge of approximately 2.8 Hz. Static load test results from 2008 measured mid-span bottom flange girder strains of approximately 70 to 80 microstrain, which corresponds to a stress of approximately 2.0 to 2.3 ksi.

Further analysis indicated that transverse load distribution was as would be expected and symmetrical with the load truck placed concentrically on the structure. Comparison of the strain data from the 2007 dynamic testing and the strain data from the 2008 static testing resulted in an experimental dynamic amplification factor (DAF) of approximately 1.1 to 1.15.

In addition to the load testing, a system that monitored the wind speed and direction at the bridge and, via a cellular modem, sends a text message to local authorities when wind speeds meet a predetermined threshold was developed and installed. For this particular system, 50 mph was the agreed upon threshold for the alert message.

Once the text message is received and a decision to close the bridge is made, local authorities must then physically drive out to the bridge and close off its entrances until wind speeds diminish to safe levels. This requires the coordination of several personnel and agencies (Iowa DOT, Iowa State Patrol, and Polk City Police). In addition, the inherent unsafe conditions associated with high wind events may pose a safety risk to the authorities and personnel in charge of closing the bridge to protect the public.

### **Other Wind Monitoring/Alert Systems**

Several other states across the country are currently implementing weather monitoring systems to assist in operating their transportation systems and assist the public in their daily travels during major weather events. Some of these systems are designed for snow or ice events, others for rain and/or flooding, others for fog, and others for high winds. However, most of these systems simply track the condition of the weather and assess the safety risk to the traveling public based on that input alone.

Typically, these systems are set up in areas where a) high profile vehicles are susceptible to overturning on bridges or overpasses, b) wind speeds change dramatically with elevation changes, such as mountain passes, c) the topography tends to produce a natural wind tunnel, such as in rural sections of freeways. The following case studies briefly outline three wind-monitoring systems utilized in other states.

### *Case Study #1*

The Oregon Department of Transportation (ODOT) has a high-wind warning system covering a 27 mile section of US 101 through a mountain pass between Port Orford and Gold Beach. This particular wind monitoring system uses an on-site anemometer to monitor wind speeds and, through a controller, activates static signs with flashing beacons at both ends of that stretch of highway.

Each static sign reads CAUTION/HIGH WINDS/NEXT 27 MILES/WHEN FLASHING. To activate the flashing beacons, the controller monitors the recorded wind speeds and, when the average sustained wind speed exceeds 35 mph for more than two minutes, the controller activates the beacons through a dial-up telephone connection.

### *Case Study #2*

The Montana Department of Transportation (MDT) has a network of environmental sensing stations throughout the state's transportation infrastructure providing real-time weather and pavement condition information. Similar sensors located in the Bozeman/Livingston area are being used as part of a high-wind warning system on a stretch of I-90.

The monitoring system includes four dynamic message signs (DMSs). The system monitors wind speeds and, when average wind speeds exceed 20 mph, the system automatically sends a message to traffic and maintenance managers.

The managers then post alert messages on the DMSs throughout the corridor reading CAUTION: WATCH FOR SEVERE CROSSWINDS. When average wind speeds exceed 39 mph, the following message is posted SEVERE CROSSWINDS: HIGH PROFILE UNITS EXIT, requiring high-profile vehicles to exit the freeway and take alternate routes.

### *Case Study #3*

The Nevada Department of Transportation (NDOT) uses a wind monitoring system on a section on US 395 in the Washoe Valley between Carson City and Reno, which frequently experiences crosswinds in excess of 70 mph. An environmental sensing station measures and transmits wind and other weather-related information every 10 minutes to a computer at the Reno Traffic Operations Center (TOC).

In the case of high winds, operators in the Reno TOC activate DMSs located at each end of the corridor to issue vehicle restrictions to the motorists. High-profile vehicles are recommended not to enter the area when average wind speeds or wind gusts exceed 15 mph and 20 mph, respectively, and the vehicles are prohibited from entering the corridor when average wind speeds or wind gusts exceed 30 mph or 40 mph, respectively.

### *Summary*

As the three case studies illustrate, most wind monitoring systems are typically used to protect the traveling public and particularly high-profile vehicles from potentially hazardous environmental conditions. Few incorporate monitoring systems on bridges or other structures in the transportation infrastructure because either there are no such structures in the monitored corridor or structures within the monitored corridor are not believed to be critical during high wind events.

In cases where there is a structure with the potential for being affected by high winds, the addition of the structural response component, along with the environmental (wind speed/direction), allows the engineer or traffic control personnel to gain a more accurate picture of the risk posed to the public and, subsequently, can make a more informed decision on how to protect the public as quickly, safely, and efficiently as possible.

### **BRIDGE DESCRIPTION**

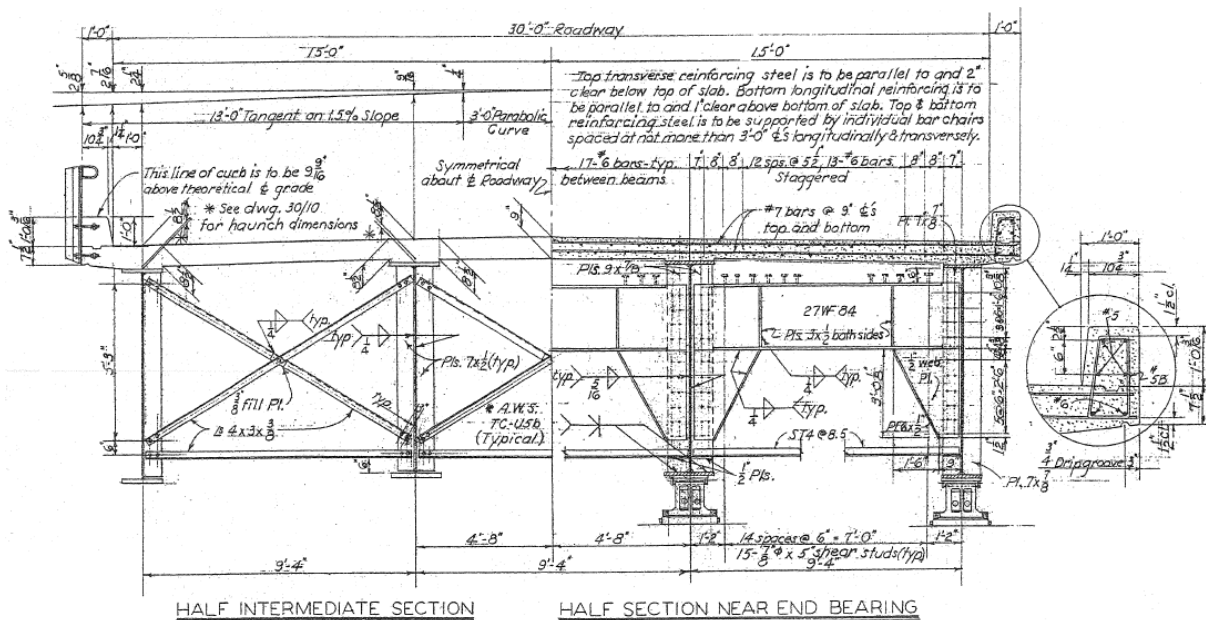
The Saylorville Reservoir Bridge, shown in Figure 1, is a multiple span structure made up of five sections, each section consisting of five spans.



**Figure 1. Saylorville Reservoir Bridge**



The end spans of each section are 168 ft long and the interior spans of each section are 216 ft long. The superstructure of the bridge consists of four 84 in. deep steel girders, concrete deck and curb, and steel guardrails (See Figure 2 for a typical cross-section).



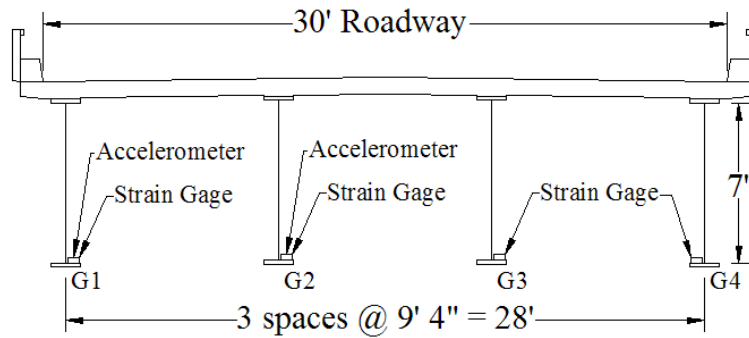
**Figure 2. Cross-section of the Saylorville Reservoir Bridge**

## INSTRUMENTATION

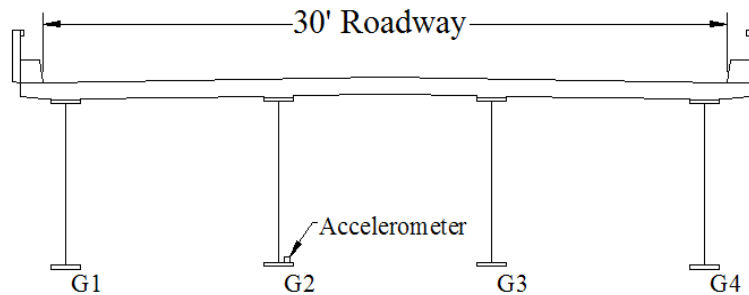
### Structural Monitoring

An interior span, Span 9, between Piers 8 and 9, was selected as the representative span for instrumentation, given it was located in an area likely to be subjected to the most significant winds during a given event. As shown in Figure 3, Span 9 was instrumented with four strain gages installed at midspan, one on the bottom flange of each of the four girders, and three accelerometers installed on the bottom flange of girder 2 at quarter span, as well as on girder 1 and girder 2 at midspan on the bottom flanges.

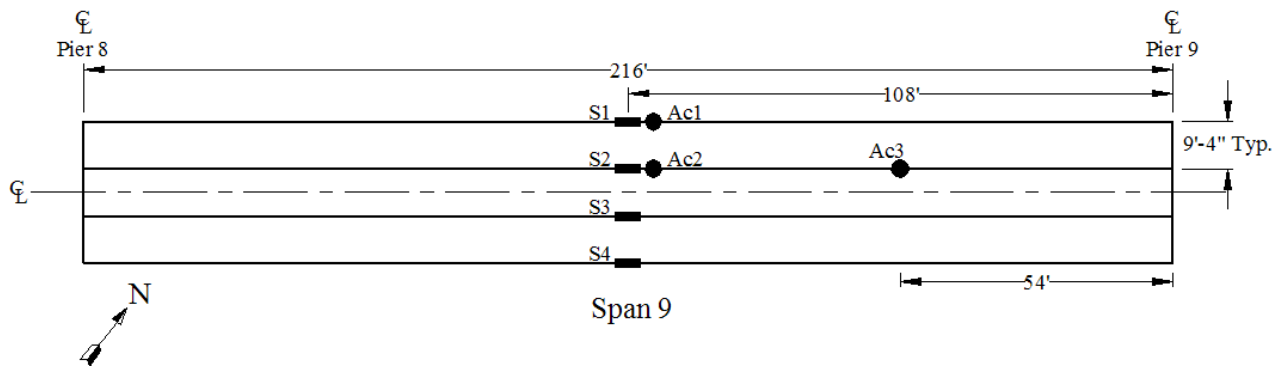
All the above instrumentation was connected to an on-site data acquisition system (DAS) set up near Pier 9 on the mounting frame for the anemometer (discussed in subsequent sections).



**a. Cross-section view near midspan looking northeast**



**b. Cross-section view at 1/4 span looking northeast**



**c. Plan view of Span 9**

**Figure 3. Instrumentation plan for the Saylorville Reservoir Bridge**

### *Wind Monitoring*

Monitoring of wind speeds at the Saylorville Reservoir Bridge is accomplished with an anemometer installed at Pier 9, which is located approximately midway between the banks of the reservoir, providing the best access to peak wind speeds. Typical recommendations for accurate wind measurement suggest an installation height of 33ft or greater above the ground and/or high enough not to be affected by wind gusts from passing vehicles.

The final mounting configuration of the anemometer consists of the anemometer being approximately 20 ft above the road surface and approximately 5 ft outside the edge of the deck. This configuration provides enough lateral clearance from passing snow plows in the winter and any potential extra-wide vehicle overhanging the guardrail.

Due to the need to be clear of the guardrail with all mounting attachments, the 20 ft post height of the anemometer was the best attainable without additional bracing and believed to be sufficient vertical clearance based on measured wind data. The mounting frame and post for the anemometer also served as the final mounting location for the solar panel, cellular antenna, and DAS enclosure as illustrated in Figures 4 and 5.



**Figure 4. Anemometer, solar panel, and antenna at the Saylorville Reservoir Bridge**



**Figure 5. Data acquisition system enclosure mounted at the Saylorville Reservoir Bridge**

## **MONITORING SYSTEM**

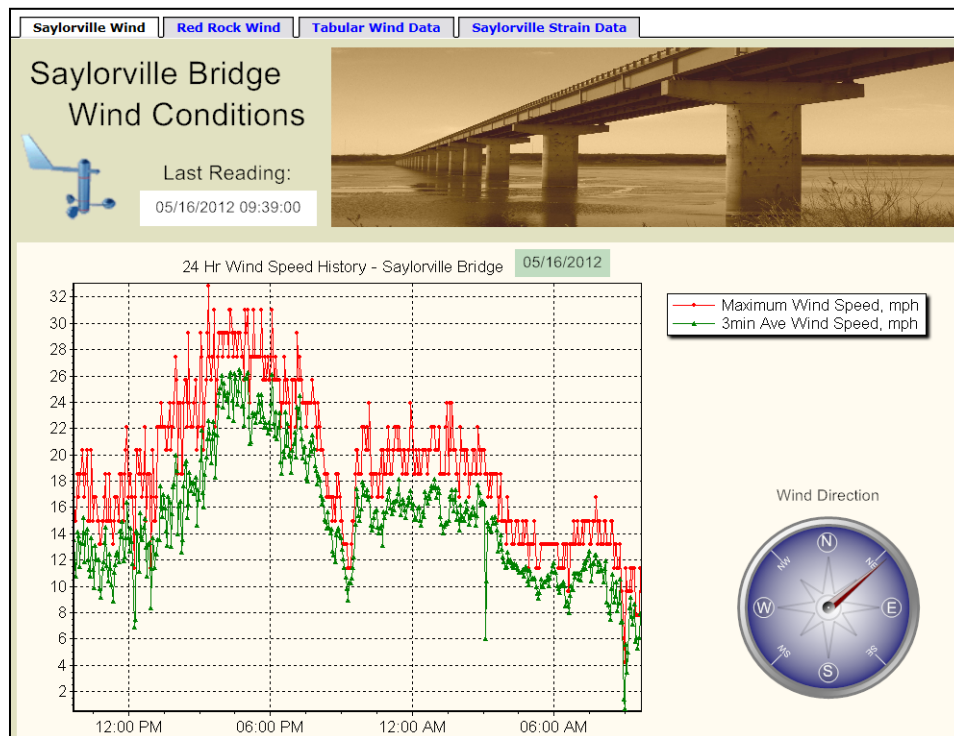
The monitoring system, including the strain sensors, accelerometers, and anemometer, are all controlled by one DAS consisting of a Campbell Scientific CR1000 data logger, deep cycle battery, 20 watt solar panel, a wireless cellular modem connected to the Verizon Wireless Network, and an omni-directional cellular antenna.

The key function of the data logger is monitoring the wind speed and direction and, based on preset thresholds, triggering the system to send alert messages to transportation officials. Standard protocol is that when wind speeds reach the predetermined threshold of 50 mph or greater, the system sends a text message alert that notifies officials of these high wind speeds and allows them to make the decision to close or restrict access to the bridge by physical means.

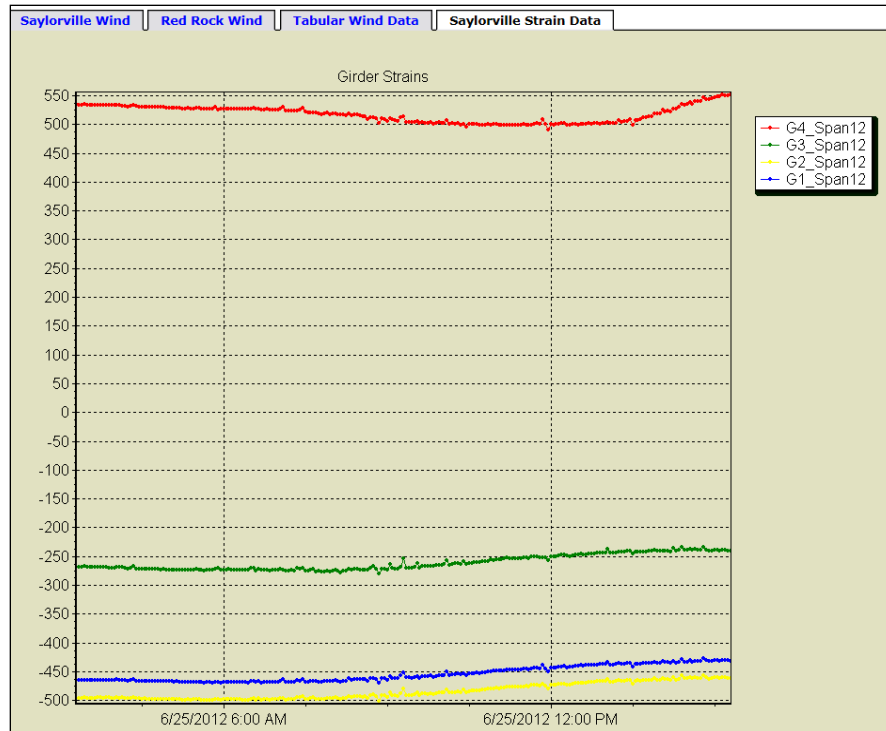
At the time of installation, none of the data provided by the alert system contained information related to the response of the structure itself, only to the condition of the natural elements at the bridge (i.e., wind speed).

With the goal of providing more useful information to engineers and safety personnel, the system was upgraded to measure and record girder strains and accelerations along with wind speed and direction; whereas, previously only the anemometer data were being recorded. The structural data and anemometer data are recorded in individual data tables and then downloaded autonomously every three minutes via the cellular connection to a dedicated desktop computer and webserver at the BEC.

As the data are downloaded, pertinent wind and strain data are posted simultaneously to a publically-accessible website. In addition, the stored data are post-processed periodically to look at historical characteristics and correlations between the wind and structural data. The correlation between the wind data and structural data is a fundamental change in the system, as is the posting of the structural strain data to the website. Figures 6 and 7 are snapshots of the website showing the wind and strain data, respectively, for the Saylorville Reservoir Bridge.



**Figure 6. Website snapshot illustrating wind data for Saylorville Reservoir Bridge**

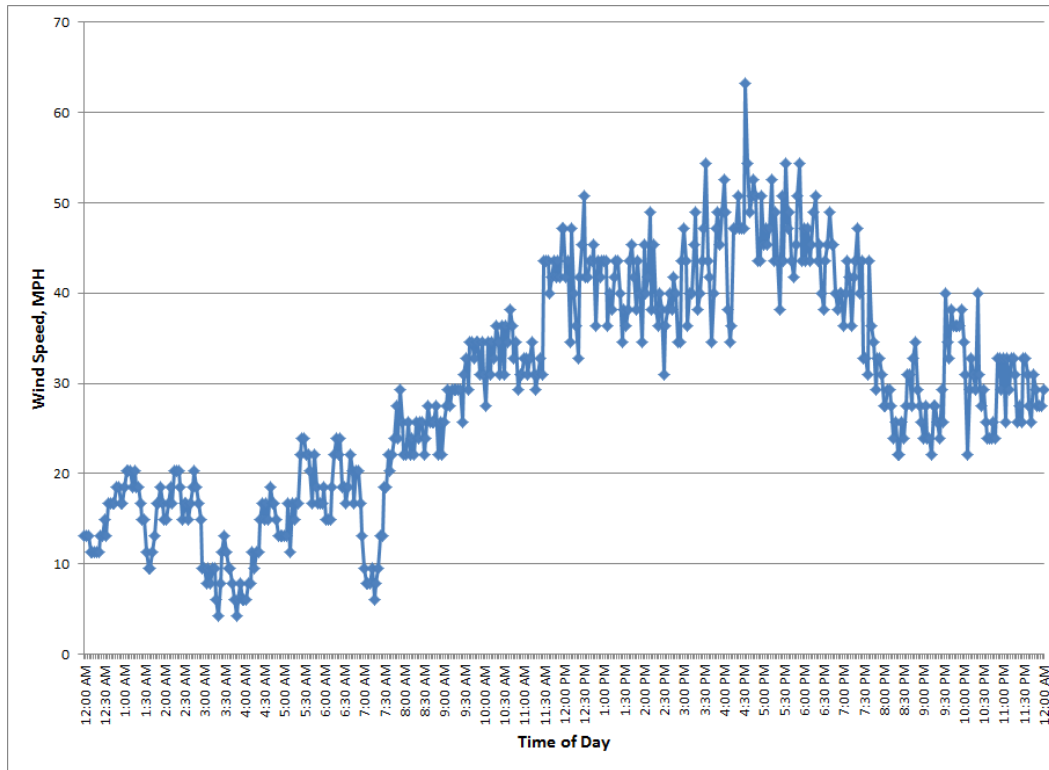


**Figure 7. Website snapshot illustrating strain data for Saylorville Reservoir Bridge**

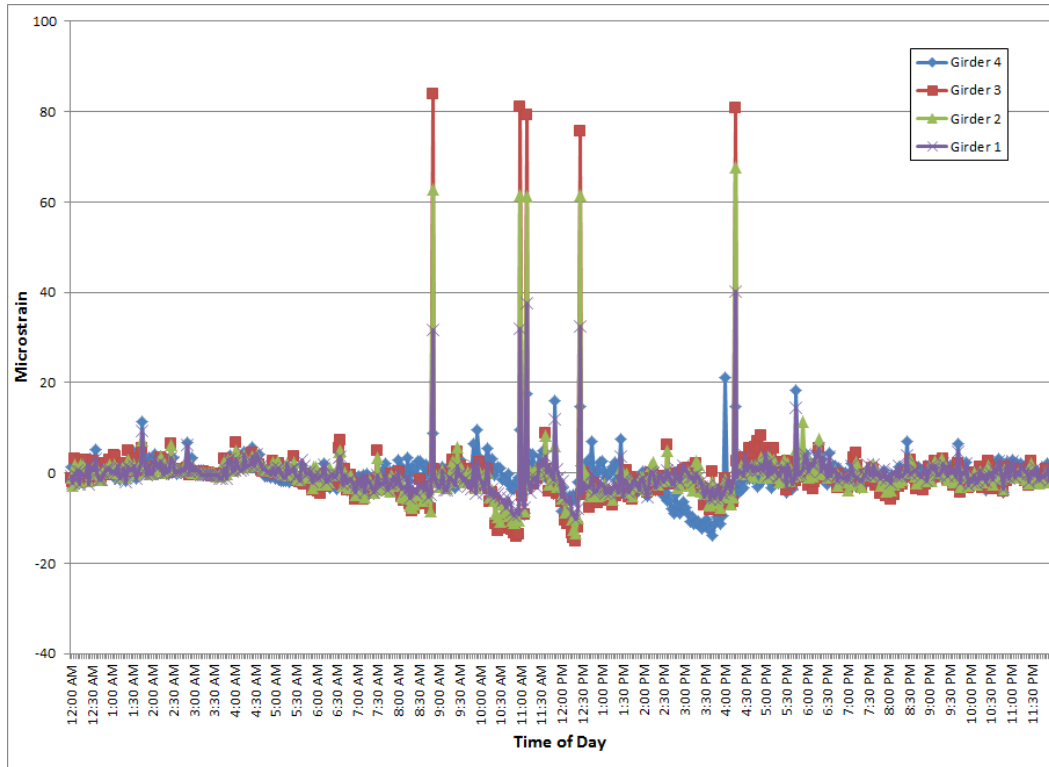
## **STRUCTURAL RESPONSE TO WIND**

Over the next year, structural strain data and wind data recorded from the DAS at the Saylorville Reservoir Bridge were analyzed and evaluated to look for any correlation between the two during high wind events. From December 2011 to June 2012 (six months), seven days had triggered events, with 23 triggered alerts recorded.

Comparison of strain and acceleration plots with wind speed plots for those 23 different triggered events revealed no direct discernible correlation between the structural response of the bridge and the measured wind speed. Figures 8 and 9 show one day worth of wind speed and girder strain data, respectively, plotted versus time for April 15, 2012.



**Figure 8. Wind speed readings for April 15, 2012 at Saylorville Reservoir Bridge**



**Figure 9. Girder strain measurements for April 15, 2012 at Saylorville Reservoir Bridge**

On this day, nine triggered alarms were sent due to high winds. Note there are 14 data points in Figure 8 above the 50 mph threshold. However, only nine of those 14 sent alarms. This is because there is a programmed 20 minute time lag between each trigger. The time lag helps reduce the number of alarms during an event with sustained winds above the threshold wind speed.

Inspection of Figures 8 and 9 indicates no correlation between the increase in measured wind speed at the bridge and the measured strain in the girders. The peak strains illustrated in Figure 9 are likely due to ambient truck traffic, which is low on this particular day because it was a Sunday. Furthermore, if the peak strains due to ambient truck traffic are omitted from the data in Figure 9, the pattern of average strain in the girders also indicates that there is no correlation with the pattern of maximum wind speed plotted in Figure 8.

In addition to maximum wind speed, the duration of the wind event and direction of the wind during the event were also considered in the analysis of the data. Most of the triggered events lasted less than an hour and were likely gust measurements. However, there were two days that had sustained winds of more than 50 mph for periods of a couple hours and on occasion lasting nearly half the day (April 15 and 27, 2012).

Based on the data, neither the duration of the event nor the direction of the wind during the event affected the response of the bridge. However, typical wind directions for these events were between either the 270 and 280 degree range or the 160 and 190 degree range, neither of which is directly perpendicular to the bridge, which would theoretically provide the worst case scenario for observing any bridge response to a wind event.

The fact that none of these 23 triggered events showed any correlation between structural response and a wind event does not suggest that all wind events will have no effect on bridge response. However, having a monitoring system in place that monitors both wind speeds and bridge response during a critical wind event, such as the one experienced on January 24, 2006, will provide invaluable safety information to bridge engineers and more importantly to the traveling public.

## **SUMMARY/RECOMMENDATIONS**

Currently, most transportation infrastructure monitoring systems tend to focus their attention on one monitoring aspect, structural health monitoring (strain, displacement, etc.) or environmental monitoring (weather, wind, rain, etc.). The next step is implementing a system that quickly, accurately, and concisely provides alert information to the traveling public based on real-time, on-site information from both structural and environmental aspects, such that motorists are able to avoid critical bridges during hazardous conditions with as little disruption as possible.

In areas where environmental monitoring systems have been or are currently implemented, flashing beacons, static warning signs, and dynamic message signs have been highly functional.



These systems provide alerts, warnings, access restriction/prohibition information, and detour information to the public in real time through traffic control centers.

At the Saylorville Reservoir Bridge, implementation and integration of these pieces of safety equipment into the current monitoring system with autonomous control from the wireless alert system would not only improve the capabilities of the system, but the efficiency and safety of the system by the following means:

- The presence of static and dynamic message signs, year round, keeps the public aware of the potential safety concerns at the bridge
- Clearly marked and posted detour signs reduce delays
- Autonomous integration of dynamic message signs into the monitoring systems provides immediate feedback from the monitoring system to the public on both wind conditions and any access restrictions or closures
- Providing traffic restriction and detour information through dynamic message signs reduces or potentially eliminates the need for the physical presence of safety personnel on the bridge; this removes these personnel from the inherent unsafe conditions at the bridge during the wind event (and the current monitoring system requires safety personnel to manually close the bridge during high wind events)
- Establishment of real-time analysis of correlations between wind and structural response data such that the response of the structure could be used more quickly (i.e., omitting necessary post-processing)



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