Wind Monitoring of the Saylorville and Red Rock Reservoir Bridges with Remote, Cellular-Based Notifications

BRIDGE ENGINEERING CENTER

Final Report
May 2012

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

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 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.

This report describes the two monitoring systems, their components, upgrades, functionality, and limitations, and results from one year of wind data collection at both bridges.

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WIND MONITORING OF THE SAYLORVILLE AND RED ROCK RESERVOIR BRIDGES WITH REMOTE, CELLULAR-BASED NOTIFICATIONS

Final Report
May 2012

Principal Investigator
Brent Phares
Director
Bridge Engineering Center
Institute for Transportation, Iowa State University

Author
Brent Phares and Travis Hosteng

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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

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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 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 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 closures and duration of closures 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, 3 minute average wind speed, and 3 minute maximum wind speed. Overall, distribution of the average and maximum wind speeds was relatively similar for both bridges, but the Red Rock 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 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

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 southeast of Des Moines to provide the same wind-monitoring capabilities and notifications to Iowa DOT personnel.

The objectives of the system development and implementation are as follows:

- Notify Iowa DOT 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
- Gather historical wind data at these structures for future assessments

This report describes the two monitoring systems, their components, upgrades, functionality, and limitations, and the results from 1 year of wind data collection at both bridges.

BACKGROUND

Although measures were put into place following the 2006 event at the Saylorville Reservoir Bridge, knowledge of the performance of this bridge during high wind events was incomplete. Therefore, the Saylorville Reservoir Bridge was outfitted with an information management system to investigate the structural performance of the structure and the potential for safety risks. Because of the similarities between the Saylorville and Red Rock Reservoir bridges, a similar system was then added to the Red Rock Reservoir Bridge.

Immediately following the installation of the monitoring system at Saylorville, service live load tests were conducted to assess the structural response of the bridge under both ambient traffic loads and a controlled load (the Iowa DOT snooper truck). Results from the testing are documented in the final report for that project (Hosteng et al. 2008).

In summary, the accelerations measured in the structure during that testing were relatively small in magnitude and resulted in an experimental fundamental frequency for the bridge of approximately 2.8 Hz. 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. Measured strains at the girder bottom flanges were approximately 70-80 microstrain, which corresponds to a stress of approximately 2.0-2.3 ksi.

In addition, transverse load distribution is as would be expected and symmetrical with the load truck placed concentrically on the structure.

The monitoring system developed and installed on these two bridges was designed to monitor the wind speed and direction at the bridge and, via a cellular modem, send a text message to Iowa DOT staff when wind speeds meet a predetermined threshold.

The original intent was that, once the text message is received, the bridge entrances would be closed until wind speeds diminish to safe levels. Once the system was functioning and providing the Iowa DOT with accurate, reliable alerts that allowed for the safe and timely closing of the structure during high wind events, there was a desire to provide the wind data information to Iowa DOT personnel as well as to the public.

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.

MONITORING SYSTEM COMPONENTS AND UPDATES

Components

The desired functionality of the system was to capture wind-related information (wind speed and direction) and store, process, and disseminate that information quickly and accurately via the internet. To accomplish this, the following pieces of hardware were selected for the data acquisition system:

- Anemometer
- Campbell Scientific CR1000 datalogger
- Cellular modem
- Deep-cycle battery
- Solar panel
- A-frame mount
- Steel pole
- Antenna
- Offsite webserver

To facilitate the collection of accurate wind data and minimize effects from passing vehicles, the anemometer was mounted on a 20 ft, 2 in. diameter steel pole mounted to the bridge guardrail via a prefabricated A-frame bracket (Figure 1).

Figure 1. Anemometer mount at the Saylorville Reservoir Bridge

The A-frame mount, in addition to providing support for the pole, set the pole a safe distance away from the guardrail to provide room for oversized loads and snowplows in the winter months. Figure 1 shows the pole and A-frame mount at the Saylorville Reservoir Bridge and a similar configuration was used on the Red Rock Bridge.

The A-frame was also utilized for mounting the cellular antenna, solar panel, and hardware enclosure. Initially, these pieces of equipment were installed on top of the pier underneath the bridge; however, to allow for ease of maintenance, they were moved to the A-frame next to the guardrail. Figure 2 shows the cellular antenna and solar panel mounting configuration and Figure 3 shows the datalogger enclosure mounting configuration.

Figure 2. Cellular antenna and solar panel mounted on A-frame

Figure 3. Datalogger enclosure mounted on A-frame

The A-frames at Saylorville and Red Rock vary slightly in geometry, but the general concept and layout of equipment is similar. The enclosure provides security and weather protection for the datalogger, cellular modem, and deep-cycle battery. Figure 4 shows the equipment housed inside the enclosure.

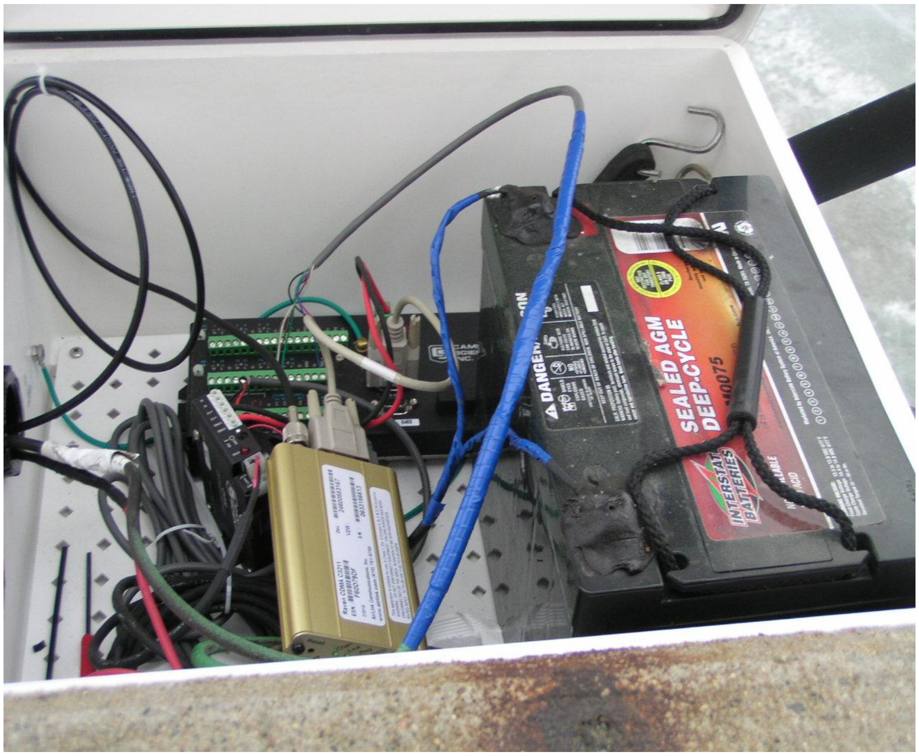

Figure 4. Monitoring equipment inside enclosure at Saylorville Reservoir Bridge

System Upgrades

Hardware and software upgrades to the system to facilitate data processing and publishing to the web included the addition of a webserver at the BEC office, upgrading webserver software, and significant modification to the program for reading, storing, and processing the data.

The two data tables created from readings were programmed to be sent wirelessly via Verizon cellular modem to a desktop computer at the BEC where they are archived. This data transfer is programmed to occur autonomously every 3 min, and corresponds to the time that pertinent data from those tables is published to the website (http://129.186.224.167).

The webserver application from Campbell Scientific allowed for the information stored in the data tables created in the logger to be published directly to a webpage created specifically for these applications. Data published on the website includes 24hr wind speed history plots of the 3 minute average and maximum wind speed, wind direction at time of the last 3 minute reading, and tabular data detailing the last 2 hrs of wind readings.

The tabular data includes the temperature on site, battery voltage, wind direction, average wind speed, average wind direction, wind direction standard deviation, and maximum wind speed.

Graphical and tabular data are presented and organized for both the Saylorville and Red Rock Reservoir bridges on the project web page. Figure 5 shows a typical 24 hr wind speed history plot from the webpage and Figure 6 shows a snapshot of the tabular data available on the webpage.

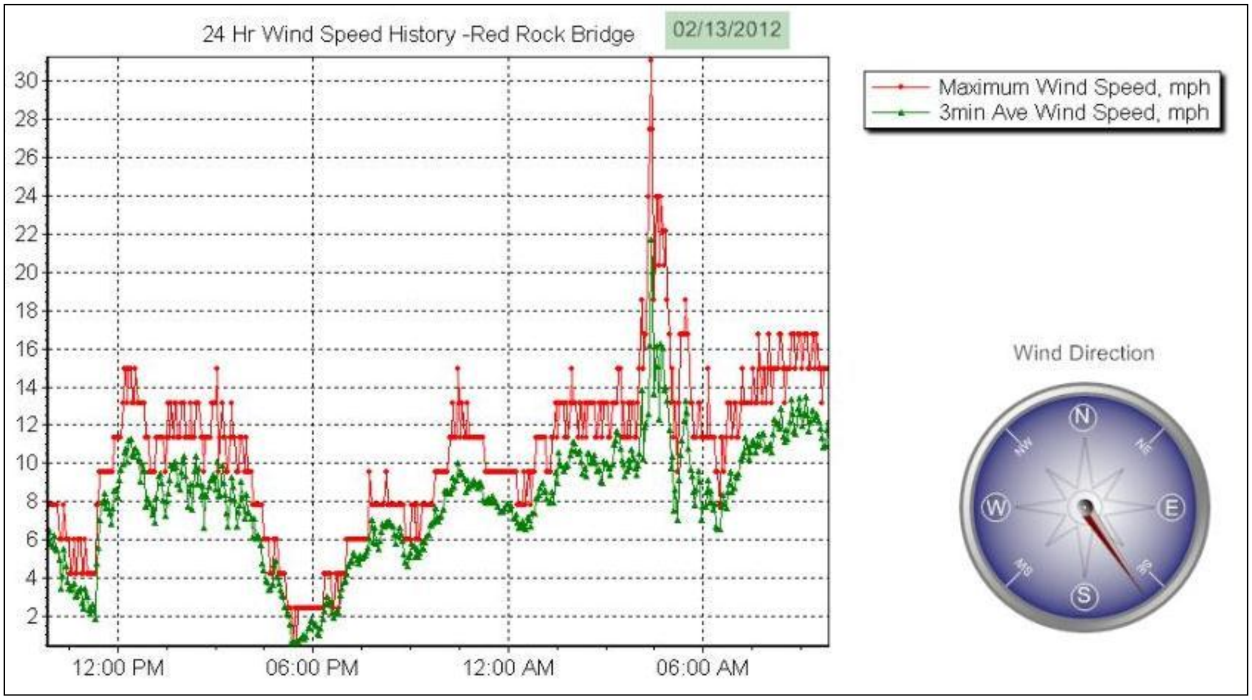

Figure 5. Typical 24 hr wind speed history plot from Saylorville/Red Rock website

Saylorville Bridge Tabular Wind Data - Past 2 Hrs								
Logger Time	BattVolt	Temp, C	Table Output Time	Wind Dir.	Ave. Wind Speed	Ave. Wind Dir.	Wind Dir. Std. Dev.	Max Wind Speed
02/13 07:57 AM	12.14	-2.89	02/13/2012 07:54:00	149.40	13.21	151.80	3.18	14.94
02/13 08:00 AM	12.14	-2.89	02/13/2012 07:57:00	154.30	14.46	150.70	3.56	18.52
02/13 08:03 AM	12.14	-2.87	02/13/2012 08:00:00	149.70	14.61	149.90	2.87	18.52
02/13 08:06 AM	12.14	-2.87	02/13/2012 08:03:00	150.40	14.78	150.90	2.95	16.73
02/13 08:09 AM	12.14	-2.85	02/13/2012 08:06:00	152.50	14.97	150.80	2.60	16.73
02/13 08:12 AM	12.15	-2.85	02/13/2012 08:09:00	147.90	15.01	152.40	5.23	16.73
02/13 08:15 AM	12.15	-2.81	02/13/2012 08:12:00	149.40	15.10	153.90	4.43	18.52
02/13 08:18 AM	12.15	-2.83	02/13/2012 08:15:00	153.50	14.63	153.60	3.18	16.73
02/13 08:21 AM	12.15	-2.81	02/13/2012 08:18:00	157.00	14.65	153.80	2.97	16.73
02/13 08:24 AM	12.16	-2.78	02/13/2012 08:21:00	159.80	13.89	153.40	3.50	16.73
02/13 08:27 AM	12.17	-2.78	02/13/2012 08:24:00	169.60	13.69	157.60	6.93	16.73
02/13 08:30 AM	12.17	-2.74	02/13/2012 08:27:00	160.10	13.38	159.60	3.89	14.94
02/13 08:33 AM	12.17	-2.72	02/13/2012 08:30:00	163.40	13.30	156.30	4.16	14.94
02/13 08:36 AM	12.17	-2.74	02/13/2012 08:33:00	157.00	14.10	155.10	5.47	18.52
02/13 08:39 AM	12.17	-2.72	02/13/2012 08:36:00	152.70	14.74	157.30	4.71	18.52
02/13 08:42 AM	12.18	-2.68	02/13/2012 08:39:00	152.90	13.84	158.20	4.76	16.73
02/13 08:45 AM	12.18	-2.65	02/13/2012 08:42:00	154.60	13.45	155.70	4.95	16.73
02/13 08:48 AM	12.19	-2.63	02/13/2012 08:45:00	151.30	12.85	157.80	4.76	16.73
02/13 08:51 AM	12.20	-2.63	02/13/2012 08:48:00	162.70	15.69	166.00	6.24	22.10
02/13 08:54 AM	12.20	-2.61	02/13/2012 08:51:00	154.80	14.24	165.00	5.81	18.52
02/13 08:57 AM	12.21	-2.59	02/13/2012 08:54:00	158.30	15.19	160.50	5.20	20.31
02/13 09:00 AM	12.21	-2.57	02/13/2012 08:57:00	160.90	14.85	158.20	5.67	18.52
02/13 09:03 AM	12.21	-2.55	02/13/2012 09:00:00	157.40	14.25	157.10	5.53	16.73
02/13 09:06 AM	12.21	-2.53	02/13/2012 09:03:00	160.70	14.17	159.00	4.43	16.73
02/13 09:09 AM	12.22	-2.51	02/13/2012 09:06:00	156.20	13.41	165.90	5.98	18.52
02/13 09:12 AM	12.22	-2.48	02/13/2012 09:09:00	153.70	13.18	156.60	6.47	16.73
02/13 09:15 AM	12.23	-2.46	02/13/2012 09:12:00	157.80	14.82	156.60	6.31	20.31
02/13 09:18 AM	12.25	-2.46	02/13/2012 09:15:00	158.60	15.63	155.40	4.98	18.52
02/13 09:21 AM	12.26	-2.44	02/13/2012 09:18:00	162.20	15.08	159.30	5.20	18.52
02/13 09:24 AM	12.28	-2.42	02/13/2012 09:21:00	171.40	14.26	161.40	4.02	16.73
02/13 09:27 AM	12.29	-2.40	02/13/2012 09:24:00	155.40	12.65	159.80	4.12	16.73
02/13 09:30 AM	12.30	-2.36	02/13/2012 09:27:00	159.00	13.48	161.60	5.54	16.73
02/13 09:33 AM	12.30	-2.33	02/13/2012 09:30:00	156.90	15.36	160.10	6.88	18.52
02/13 09:36 AM	12.24	-2.31	02/13/2012 09:33:00	172.40	14.63	152.00	7.61	18.52
02/13 09:39 AM	12.30	-2.29	02/13/2012 09:36:00	165.20	13.16	156.60	10.47	16.73

Figure 6. Typical tabular data display from Saylorville/Red Rock website

WIND DATA ANALYSIS

Illustrated in the following figures and plots are the wind data collected at the Saylorville and Red Rock Reservoir bridges over the course of one year. Figures 7 and 8 are Google Earth maps overlaid with wind rose plots for the respective bridges.

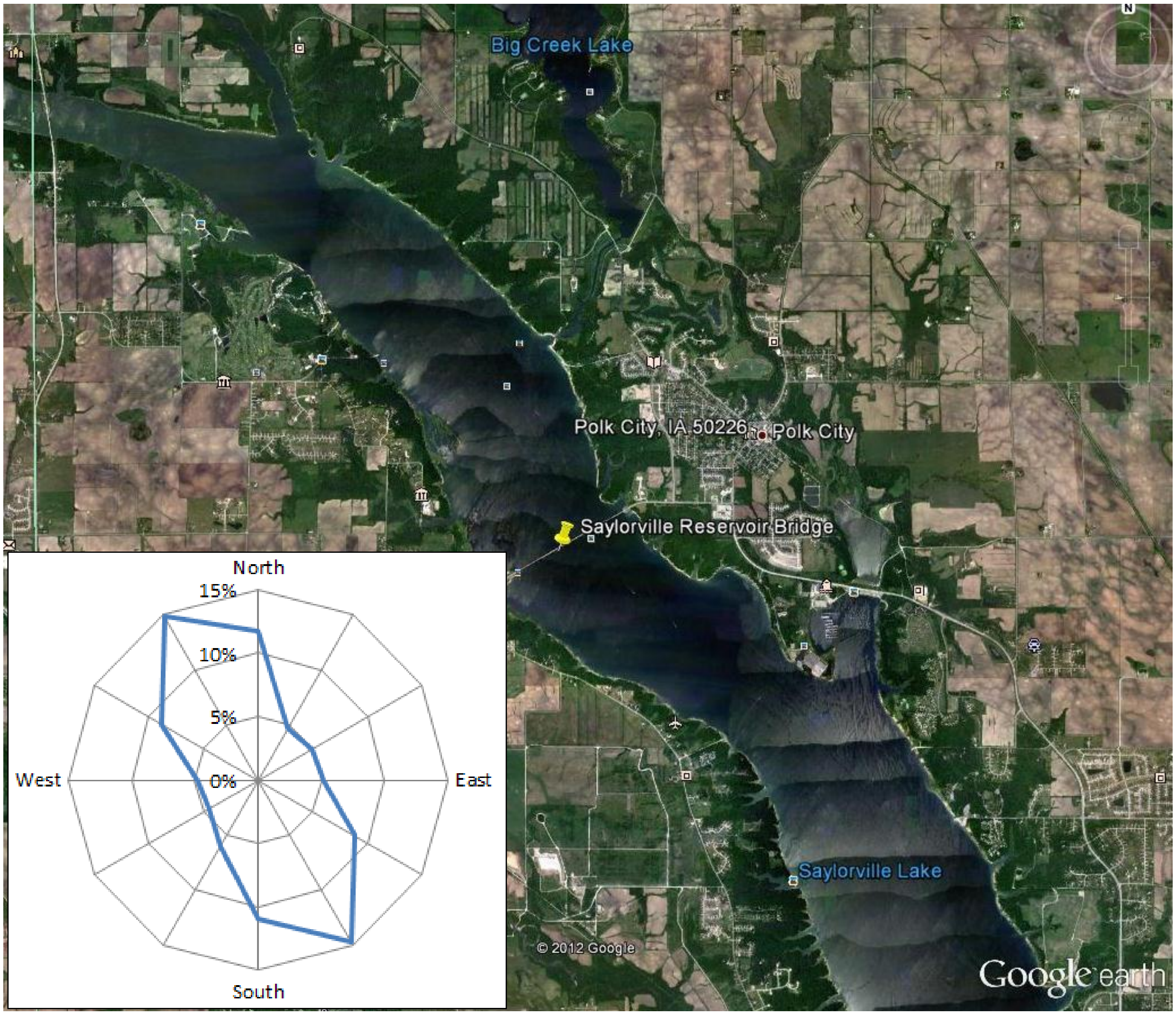

Figure 7. Saylorville Bridge wind rose for one year at Polk City, Iowa (Google Earth 2012)

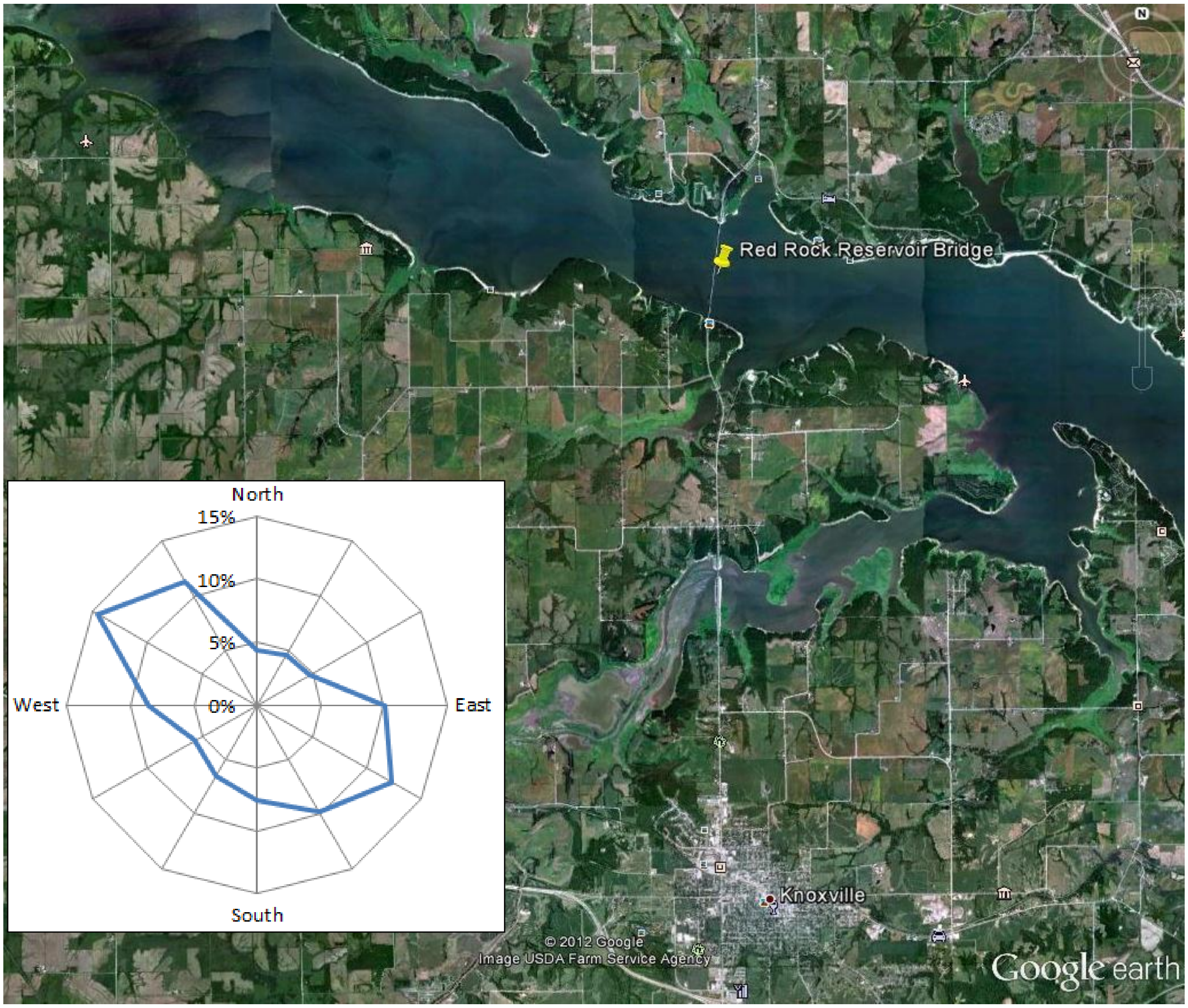

Figure 8. Red Rock Bridge wind rose for one year at Knoxville, Iowa (Google Earth2012)

In general, the most typical wind direction at both locations is the northwest (NW) or southeast (SE) directions, with the Saylorville location being slightly more toward the north and south directions than the Red Rock location. In both cases, these typical winds correspond to a direction nearly perpendicular to the bridge length and parallel to the river/reservoir channel.

Figure 9 shows the percent occurrences of the 3 min average wind speed for the Saylorville Reservoir Bridge and Figure 10 shows a similar graph for the Red Rock Reservoir Bridge.

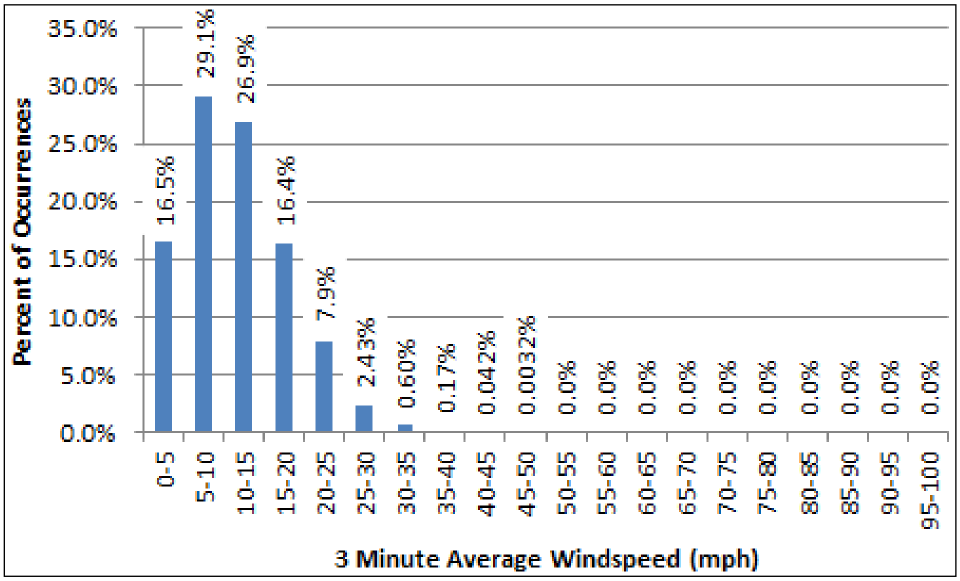

Figure 9. Saylorville Bridge 3 minute average wind speed

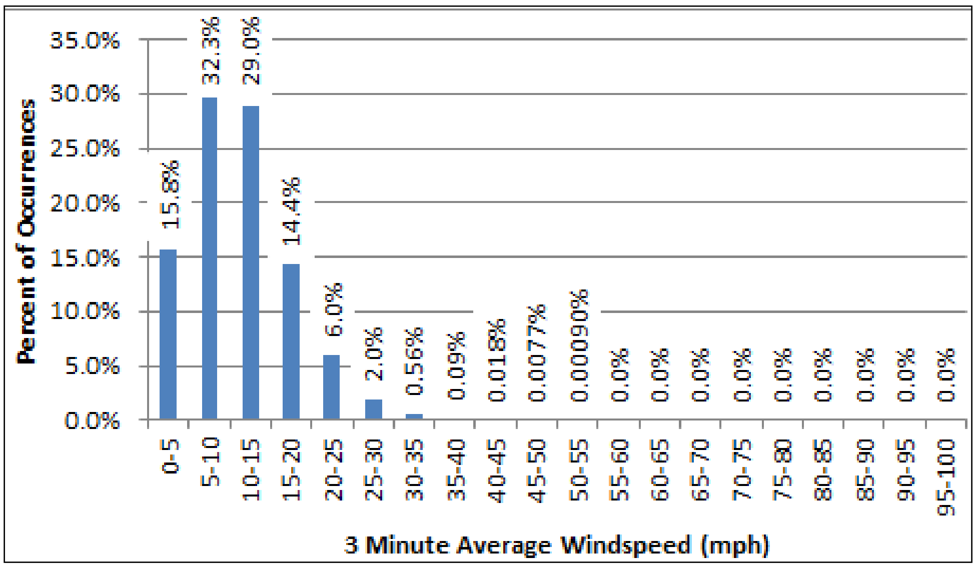

Figure 10. Red Rock Bridge 3 minute average wind speed

Comparison of the plots from Saylorville and Red Rock show striking similarities in distribution of average wind speed, with the Red Rock Bridge experiencing about a 30 to 34 percent increase in the frequency of wind speeds averaging between 5 and 10 mph and 10 and 15 mph, while all other categories are relatively similar in frequency. In addition, the highest percentages of average wind speed are between the 5 and 20 mph ranges for both locations.

Similar results were found when plotting the 3 minute maximum wind speed percentages for both locations, as shown in Figures 11 and 12.

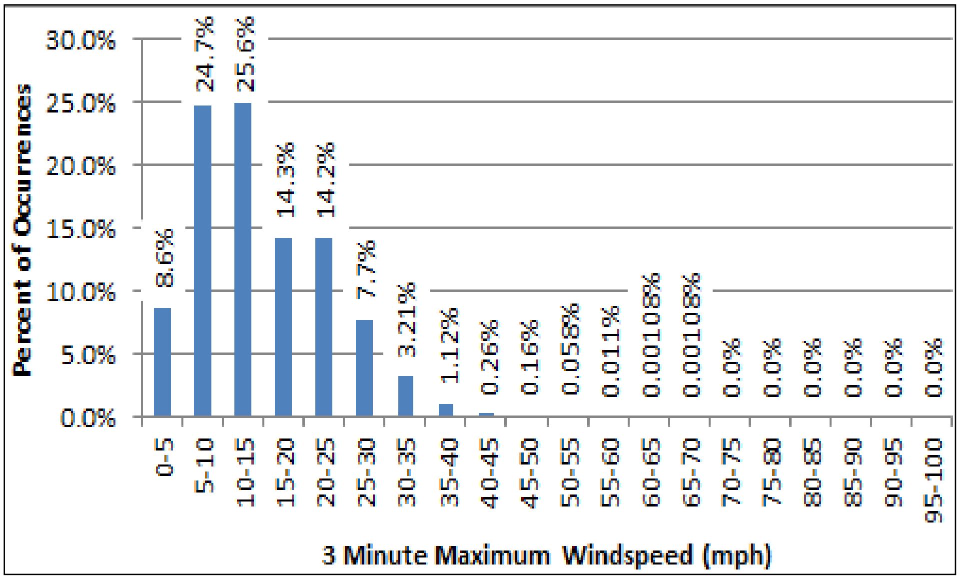

Figure 11. Saylorville Bridge 3 minute maximum wind speed

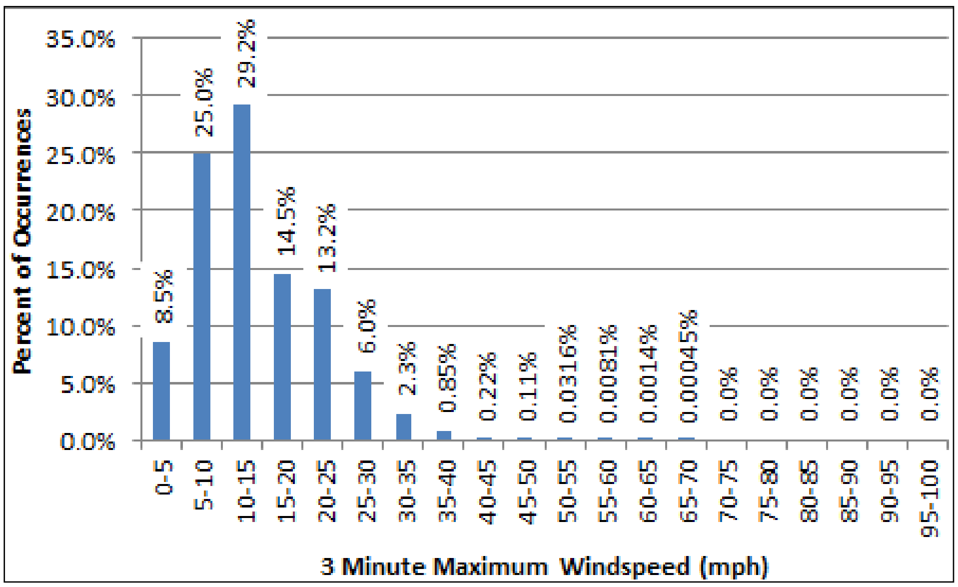

Figure 12. Red Rock Bridge 3 minute maximum wind speed

Again, the distribution was very similar in general. The highest 3 minute maximum wind speed category for both locations was the 65 to 70 mph category, with the Saylorville Bridge having two occurrences and the Red Rock Bridge having one occurrence during the one-year duration of this project.

Based on the research team’s experience with these two systems in the years prior to the upgrade (which allowed for more advanced data analysis), one to two occurrences of those peak wind speeds (65 to 70 mph) at these bridges appears to be typical.

SUMMARY

In summary, the Iowa DOT wind monitoring systems at the Saylorville Reservoir Bridge and Red Rock Reservoir Bridge are capable of recording, storing, and posting live wind data from the locations to the internet. Prior to modifications, the system only provided real time alerts to 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, 3 minute average wind speed, and 3 minute maximum wind speed. Overall, distribution of the average and maximum wind speeds was relatively similar for both bridges, but the Red Rock 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 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.

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