4. LONG-TERM TEMPERATURE MONITORING

Temperature monitoring instrumentation was installed on span 2 of the bridge on November 8, 2011, at pier 2. Web-based monitoring of real-time data from the instrumentation was employed until January 8, 2012. This allowed close observation of bridge steel temperatures as a precaution against brittle fracture during the cold winter months when retrofits were underway, as well as understanding the response of the bridge to thermal cycling.

4.1 Temperature Monitoring Instrumentation and Data Acquisition

In order to remotely monitor the temperature of the bridge steel over an extended period of time, various instrumentation and data acquisition equipment were required. A total of 4-thermocouples, a thermistor, an inclinometer, and a string potentiometer were used. The following section briefly describes these key components of the long-term temperature monitoring system used on the bridge.

4.1.1 Thermocouples, Thermistor, Inclinometer, and String Potentiometer

Omega’s model EXPP-T-20-TWSH-UL twisted, shielded thermocouple wires were installed on the east portal of span 2, at T23 (T0), as can be seen in Figure 4-1. Two thermocouples were mounted to each of the upstream and downstream sides of the span. A

![Figure 4-1: Thermocouple installation east portal of Span 2](image-url)
thermistor and inclinometer were installed below the lower deck at the center pier, Pier 2. The thermistor was Campbell Scientific’s 109 temperature probe housed in the MET 20 Unaspirated Radiation Shield, and was used to measure ambient air temperatures. The inclinometer was Seika’s model NG2u and was used to measure any tilt of the pier as the bridge expanded and contracted during thermal cycling. It was mounted on the southern side of pier 2 (Kentucky side). Additionally, any longitudinal movement of the bridge resulting from thermal cycles was measured by UniMeasure’s model P510-10-NJC-DS string potentiometer. The string pot was also installed on pier 2 below the lower deck. Its installation can be seen in Figure 4-2.

![String pot installation, pier 2, looking upstream (north)](image)

4.1.2 Temperature Monitoring Data Acquisition

The data acquisition system used for the temperature monitoring was the same used for the ambient temperature and wind measurements for the stress monitoring described in section 3 of the present report. It included a Campbell Scientific CR3000 Micrologger and high-speed cellular modem connected to an antenna, seen in Figure 4-3. This equipment was stored onsite during monitoring in a weather-tight steel box that was kept locked to eliminate potential tampering.
4.1.3 Web-based monitoring

Campbell Scientific’s RTMC Pro Developer software was used to create an HTML site where real-time data displays shared via the internet could be viewed publically (see Figure 4-4). The site was set up to email an alert if communication with the instrumentation was lost or if temperatures became too extreme. A warning alarm was illuminated on the website and emailed when either the ambient or steel temperature dropped below 10 ºF and a critical alarm was illuminated and emailed when either dropped below 5 ºF. Thus, the most current data from the field was closely observed.

Figure 4-3: Temperature monitoring instrumentation setup

Figure 4-4: Web-based monitoring of real-time data
4.2 Results from Long-term Temperature Monitoring

During the winter months between November 2011 and January 2012, the temperature of the bridge’s steel was closely watched as a precaution against the potential for brittle fracture during retrofit operations, as well as to identify thermal cycling response of the bridge. In addition to the temperature of the steel, ambient temperature, pier inclination and axial translation of the bridge were also monitored.

Figure 4-5 plots a sample of data retained during the long-term temperature monitoring. The black dotted trace marks the temperature of the steel, averaging the recorded values of the 4 thermocouples previously mentioned. The blue (thick solid) line is the axial translation of the bridge along its longitudinal axis. In other words, this is the bridge’s displacement along the expansion bearing for span 1, on pier 2. The red (thin solid) trace is the lateral displacement of the top of pier 2. At first glance it would appear that the pier and the bridge were moving in opposite directions. Figure 4-6 below helps to clarify the significance of a gain versus a loss for both of these instruments.
Figure 4-6: Sketch clarifying the significance of a gain versus loss (+ or – measurement) in the string potentiometer and inclinometer data

As can be seen above, a loss (or negative slope on the plot) for the inclinometer represented a rotation of the pier toward Indiana and an expansion of the bridge. The string potentiometer’s measurements indicated movement toward Indiana and bridge expansion, however, when there was a gain (or positive slope on the plot). As a result, Figure 4-5 shows the valleys of the inclinometer measurements matching up chronologically, with the peaks of the string pot. This is evidence that the bridge and the pier moved together in the same direction. The raw data from the inclinometer were recorded in degrees, representing a rotation. For the purposes of this analysis, the inclinometer measurements were converted to lateral displacements in the following way. The original design drawings for Sherman Minton show that pier 2 stands 107'-7 1/8", from the rock line at its foundation to the ledge at which the inclinometer was mounted. Using basic trigonometry, and assuming no bending in the pier, the lateral displacement was calculated using Equation (4):
\[
\tan(\theta \times \pi/180^\circ) = x/(107 \text{ ft. } \times 12 \text{ in.}/\text{ft.})
\]  
(4)

In Equation (4), \( \theta \) is the angle of inclination measured by the inclinometer in degrees, and \( x \) is the lateral displacement in inches. Therefore, the displacement was found by converting \( \theta \) to radians, and the pier height (which was conservatively rounded down to 107') to inches, then solving for \( x \), the displacement. The maximum displacements of pier 2 recorded during this study was \( \frac{1}{2}'' \) inch toward Indiana, and 3 inches toward Kentucky. The maximum displacement toward Kentucky occurred on January 3, 2012, when the temperature of the steel was approximately 18 \(^\circ\)F. The maximum displacements measured by the string potentiometer were 1 inch toward Kentucky, with a steel temperature of about 35 \(^\circ\)F, and at another time, 1 inch toward Indiana, with a steel temperature of approximately 65 \(^\circ\)F.

![Figure 4-7: Plot showing lateral displacement of Pier 2, bridge displacement, and average temperature of the steel](image)

The data further showed that although the bridge was sliding on its bearing, there remained a level of binding, which was pushing or pulling the pier as it expanded or contracted.
with the temperature fluctuation. This is reiterated in Figure 4-7 where the relative displacements of the pier and the bridge with the day-night temperature oscillations are shown. The bridge slid on its bearing as much as ½”, while the pier was displaced up to 1 ¼”.

A quick check can be performed to establish if these displacements were what is expected. Equation (5) is the temperature-displacement relationship of materials and is analogous to force-displacement where an applied force stretches or compresses the material.

\[ \delta_T = \alpha (\Delta T) L \]  

Where \( \delta_T \) is the temperature-induced displacement, \( \alpha \) is the coefficient of thermal expansion (for steel \( \alpha \approx 7.3 \times 10^{-6} \text{ in/inºF} \), \( \Delta T \) is the temperature change, and \( L \) is the length of the material. Taking data from Figure 4-7, the temperature was at ~25 ºF at 0645 hrs on December 11th. It then heated up during the day to ~52 ºF (\( \Delta T = 27 \) ºF). The tie girder is 800 ft. long and there is one expansion bearing at pier 2. Plugging in these values produces a \( \delta_T = 1.9 \) inches. During that same period of time the pier was recorded displacing ~1.25 in. due to tilt and the bridge moving ~0.5 in. for a total of about 1.75 inches. The 0.15 inch disparity could be attributed to the assumption for the calculation that the bridge was uniformly heated, the effect of the stress introduced into the tie due to the restraint offered by the pier and/or the mechanical restraint of the statically indeterminate arch span. In addition, in order to move the pier, the adjacent span must also be shifted, which of course offers additional restraint thereby decreasing the amount of expansion.

4.3 Summary of Long-term Temperature Monitoring

The effects of temperature on the Sherman Minton Bridge were monitored for 2 months beginning in November 2011. The data were carefully observed via web-based monitoring with built-in email notification settings for steel temperature thresholds. The temperature data was monitored and used to stop work on the tie if the temperature fell below predetermined levels, as retrofit operations were taking place on the bridge in the cold winter months. Furthermore, analysis of the data from that period showed that the bridge underwent expected temperature-induced expansion and contraction with the thermal cycles. However, the bearing was not acting as a completely free bearing. The expansion wind anchor was shown to allow movement, but larger displacements were seen at the top of pier 2, indicating that the expansion bearing was also resisting bridge movement, thereby resulting in pier tilt.