Wireless Strain Monitoring System on the Hernando de Soto Bridge During Critical Repairs

MEHDI KALANTARI KHANDANI
and MOHEB GHORBANISHEIKHNESHIN

ABSTRACT

The article discusses the use of a wireless structural health monitoring system supplied by Resensys, after a major fracture was discovered in the tie girder of one of the arch span bridge units on the Hernando de Soto Bridge. The bridge is significant to the US transportation system and the business community in Memphis, as it connects Memphis to Arkansas and most western states in the US. The fracture discovery resulted in an immediate shutdown of the bridge, causing significant economic impacts due to traffic rerouting and massive congestion. According to multiple reports and studies, the cost of closure of the bridge was estimated to be $2-3 million per day. Due to the high urgency of the repairs, monitoring and instrumentation had to be done quickly and before conducting repairs on the tie girder. The Resensys SenSpot™ [1] strain gauges were a perfect solution, providing reliable, precise, and real-time data (strain and temperature) on all high-risk members. The wireless strain gauges were attached to all high-risk members to monitor loads during the repair process, which involved applying tension to the fractured members. Furthermore, the strain gauges monitored strain/stress in critical members when heavier equipment such as cranes were moved on the bridge to carry special equipment and retrofit plates. The Resensys monitoring system provided data to help the bridge repair engineers gather information around real-time strain, and studying stresses and strains on critical elements caused by thermal effects and live loads has helped to ensure that the repair process was effective.

Due to the size and other complexities of this project, wiring systems and their associated installation on structures were cost prohibitive. Resensys wireless monitoring system provided numerous benefits in the project which made the implementation of the monitoring program cost-effective and practical. These advantages include longevity, fast and easy installation, cloud-based monitoring, superior sensing, advantageous in construction sites, reusability, etc. Wireless SenSpot™ sensors use non-rechargeable batteries with a battery life of ten years.

SeniMax™ [2] remote communication gateways are solar powered. As a result, the complete system is energy self-sufficient and does not require access to external electrical input or infrastructure for its operation.

Mehdi Kalantari Khandani, CTO and President, Resensys LLC, 6517 Mid Cities Ave, Beltsville, Maryland 20705-1434, U.S.A., Email: mehdi@resensys.com
Moheb Ghorbanisheikhneshin, Civil and Structural Data Analysis Engineer, Resensys LLC, 6517 Mid Cities Ave, Beltsville, Maryland 20705-1434, U.S.A., Email: moheb@resensys.com

BACKGROUND

The Hernando de Soto Bridge, located in west Memphis and Arkansas, serves as a crucial passage for Interstate 40, spanning the Mississippi River. With a two-span continuous tied-arch design featuring 900-foot spans positioned approximately one hundred feet above the water level, the bridge holds significant structural importance. This article aims to provide insights into the implementation of a wireless structural health monitoring system, supplied by Resensys, in response to the detection of a major fracture in the tie girder of one of the arch span bridge units. By examining the deployment and performance of this monitoring system, the study focuses on its role in enhancing the detection and assessment of structural issues, thereby ensuring the bridge's stability and resilience.

Figure 1. I-40 over Mississippi River Bridge (The Hernando de Soto Bridge)

PREVIEW AND SIGNIFICANCE OF THE BRIDGE

The Hernando de Soto Bridge holds immense importance within the transportation system of the United States due to its strategic location. Situated in Memphis, this bridge serves as a crucial link for the business community, with a daily average of approximately 60,000 vehicles traversing over it and over 200 barges passing beneath it. Additionally, the bridge plays a critical role as a primary evacuation route, frequently utilized by emergency vehicles. Memphis, renowned as the logistics capital of the United States and a significant global logistics hub, has made substantial investments in transportation, sorting, dispatch, and distribution services for national and international transit. The city accommodates numerous prominent courier and transportation companies, including the renowned FedEx headquarters, which handles a substantial daily influx of over 100 bulk-loaded trailers and nearly 80 containerized transport vehicles (CTVs). Consequently, the Hernando de Soto Bridge assumes an indispensable position as one of the most vital transportation resources, connecting Memphis to Arkansas and serving as a pivotal gateway to several Western states in the United States.

FRACTURE DISCOVERY

The construction of the Hernando de Soto Bridge commenced in 1977, and it was officially opened on August 17, 1973. In the United States, numerous steel bridges erected between the 1940s and 1970s suffer from a design deficiency in terms of redundancy. During that period, raw materials were scarce due to the aftermath of World War II and other factors, and the incorporation of redundancies, which are commonplace in contemporary bridge designs, was considered a luxury. Despite their aging nature, most of these steel bridges continue to serve and bear the increasing traffic demands as each decade unfolds.

During routine inspections conducted on May 11th, 2021, a partial fracture was discovered in a tie girder responsible for supporting one of the two tied-arch truss spans. The fracture was observed at a welded plate transition located in the upstream section of the box-shaped tension tie member (which functions as a tension strut to counteract the outward thrust forces exerted by the arches at the piers). In response to the crack, bridge inspectors promptly contacted emergency services through a 911 call, leading to an immediate closure of the six-lane bridge. The bridge remained non-operational to traffic until emergency repairs were completed in August 2021 [3] [4].

Figure 2. On May 11th, 2021, a crack was detected in main load bearings member of an I-40 bridge in Memphis, Tennessee and as a result, the bridge was closed immediately for the emergency repair.

ECONOMIC IMPACTS DUE TO BRIDGE CLOSURE

The immediate shutdown of the Hernando de Soto Bridge necessitated significant efforts to redirect traffic and alleviate the resulting congestion for both vehicles and barges. Bridge closures tend to create bottlenecks as traffic is funneled through limited alternative crossings, thereby affecting local traffic flow and potentially generating broader economic ramifications. In this case, the bridge remained closed for a period of approximately three months, leading to the implementation of detour routes that, unfortunately, resulted in increased congestion and heavy traffic in the vicinity. Multiple reports and studies have indicated that the daily cost incurred due to the bridge closure ranged between $2 million to $3 million, underscoring the substantial economic impact associated with the temporary unavailability of this vital transportation link [5].

INSTRUMENTATION AND MONITORING EFFORTS

During the emergency repairs of the bridge, the application of tension to the fractured members was necessary to ensure proper installation of retrofits. However, this operation carried two significant risks. Firstly, the equipment required for the operation, such as cranes and hydraulic machinery, posed a substantial risk due to their weight, especially when maneuvering them on the bridge with compromised load-bearing members. Secondly, there was a concern that the applied tension to the fractured members could result in excessive strain in other areas, potentially causing further damage to the bridge structure.

Given the urgent nature of the repairs, it was essential to quickly implement monitoring and instrumentation measures before proceeding with the tie girder repairs. Thus, a fast and deployable monitoring system was required to effectively monitor critical bridge members. Resensys SenSpot™ strain gauges emerged as an ideal solution to meet the project's monitoring requirements. The wireless nature of these instruments provided a significant advantage, enabling expedited installation on the large-scale structure. These sensors effectively monitored the bridge structure throughout the repair process. With adhesive mounting, each wireless strain gauge SenSpot™ could be installed within a matter of minutes. Once installed, the connected wireless strain gauge SenSpot™ provided real-time data, reporting strain and stress levels in the monitored members. Additionally, the absence of wiring systems allowed for the installation of numerous wireless strain gauges (approximately 44) with two SeniMax™ gateways on the bridge in just two days. These wireless strain gauge SenSpot™ sensors were affixed to all high-risk members to monitor loads, both tension and compression, during the repair process, which involved applying tension to the fractured members. Furthermore, the strain gauges served the additional purpose of monitoring strain and stress in critical members when heavier equipment, such as cranes carrying specialized equipment and retrofit plates, was moved onto the bridge. SeniMax™ remote communication gateways are solar powered. As a result, the complete system is energy self-sufficient and does not require access to external electrical input or infrastructure for its operation.

The data obtained from the Resensys wireless strain gauge SenSpot™s played a pivotal role in the prompt decision-making process, ensuring the safety of all critical members and operations. The Resensys monitoring system supplied valuable real-time strain data, enabling bridge repair engineers to gather crucial information [6]. Additionally, following the completion of bridge repairs and the subsequent reopening of the bridge in August 2021, the analysis of stresses and strains experienced by critical elements due to thermal effects and live loads has played a crucial role in verifying the performance of the repairs, confirming that they meet the expected standards.

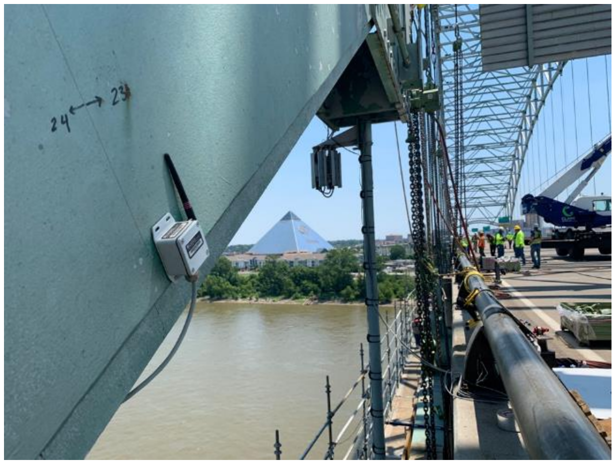

Figure 3. Examples of installed wireless strain gauge SenSpot™ sensors on I-40 bridge (the wireless unit with the antenna on the left side of the picture)

Figure 4. Installed wireless strain gauges SenSpot™ sensors on I-40 bridge

Figure 5. Installed solar powered SeniMax™ gateway on I-40 bridge for data acquisition

The collected data showed the downstream tie girder responses to temperature changes much more meaningfully than the upstream tie girder. Both tie girders experience an increase in stress with reducing temperatures typically happening in the early morning hours. These data were collected in May 2021 when the sun was in its northern-most position. Straight exposure to sun inclined to decrease the tie tensions and loads.

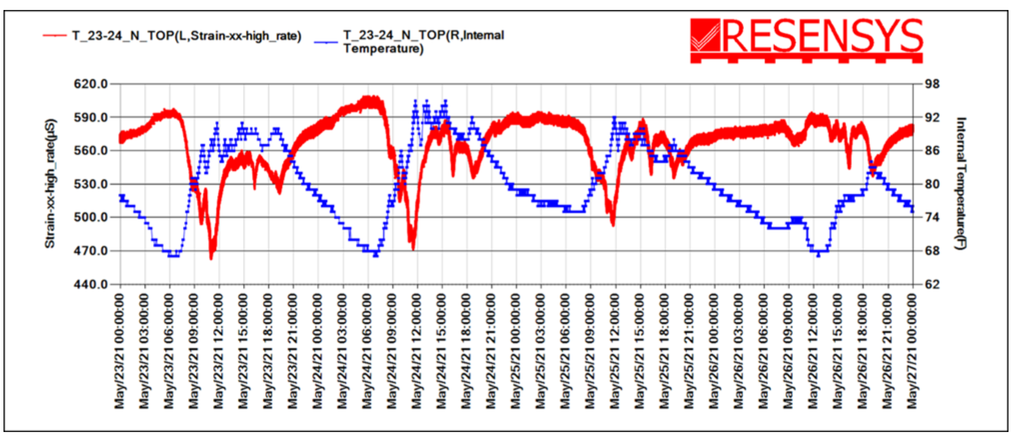

Figure 6. Sample of strain and temperature measurements of an installed wireless strain gauge SenSpot™ sensor on a tie girder of I-40 Bridge in May 2021. The graph shows most strain changes are due to temperature changes. This graph is obtained from SenScope™ software.

CONCLUSION

The utilization of wireless strain gauge SenSpot™ sensors proved to be a successful approach in this project. It is worth highlighting that the wireless strain gauge

SenSpot™, as a connected device, offers a remarkable battery life of ten years, making it an ideal choice for long-term and low-maintenance monitoring of the repaired members. With their compact design and wireless transmission of real-time data, the adhesive-mounted wireless gauges effectively minimized the downtime of the Hernando de Soto Bridge. Moreover, these instruments provided near-real-time data on strain and stress levels in all critical members, thereby ensuring the safety of the bridge's vital components during repair operations. Lastly, the devices were employed for long-term monitoring following the completion of initial repairs, allowing for the identification of any potential recurrence of issues by detecting changes in strain patterns caused by thermal effects or live loads.

REFERENCES

1. Resensys. 2023. "SenSpot™". https://www.resensys.com/r20/wireless-products-senspot/critical-component-condition-monitoring-instrumentation.html
2. Resensys. 2023. "SeniMax™". https://www.resensys.com/r20/wireless-products-senspot/senimax-low-power-performance-data-collector-communication-gateway.html
3. Wiss, Janney. October 2021. "Fracture Investigation I-40 MS River Bridge Report," Elstner Associates, Inc, pp. 1-9.
4. The Arkansas Department of Transportation. 2021. "I-40 HERNANDO DESOTO BRIDGE, EMERGENCY REPAIR AND INSPECTION, after action report," ARDOT, pp. 1-7.
5. Katherine Shaver. August 2021. "Cracked interstate bridge over Mississippi River reopens after nearly three months of repairs," The Washington Post. https://www.washingtonpost.com/transportation/2021/08/03/mississippi-river-bridge-reopens-memphis/
6. Mehdi Kalantari Khandani. August 2016. "Critical Mass; Wireless sensors are highly suitable for monitoring fracture-critical bridges and they also provide additional benefits," Bridge Design & Engineering magazine, Remote Surveying & Inspection, Issue 84. https://www.resensys.com/documents/BridgeMag-Aug-2016-Resensys.pdf