Emergency Bridge Scour Countermeasure in Marin County, California, United States

Catherine M.C. Avila, *President, Avila and Associates Consulting Engineers, Inc., San Francisco, California; email: cavila@avilaassociates.com*

ABSTRACT: *The Lucas Valley Road Bridge over Miller Creek in Marin County, California was identified as scour critical in August 2017. Within four months (just before the rainy season in California), structural, hydraulic, and monitoring countermeasures were installed at the bridge. Structural countermeasures included lowering the foundation at Pier 2. Hydraulic countermeasures included rock riprap around Piers 2 and 3 to inhibit local pier scour and a series of criss cross weirs downstream to inhibit downstream head cutting. Monitoring countermeasures included a stage gage installation to monitor water surface elevation, a sonar device installation at the upstream and downstream ends of Pier 2 to monitor local pier scour and rock riprap movement, and sensitive tilt-meters to monitor movement of the bridge to give the local agency sufficient time to close the bridge prior to potential bridge collapse. This paper will focus on the case study of why the bridge is scour critical, and describe the countermeasures proposed to protect the safety of the travelling public.*

KEYWORDS: Scour Countermeasure, Scour Critical Bridges

SITE LOCATION: Geo-Database

INTRODUCTION

This paper presents the results of the scour analysis and scour countermeasure installation for the Lucas Valley Road Bridge over Miller Creek (Br #27C0016). The site is located on the western edge of San Rafael, California, 30 kilometers north of San Francisco in Marin County, California, United States.

SCOUR ANALYSIS

Bridges in the United States are inspected every two years. Bridges coded by the California Department of Transportation (Caltrans) with unknown foundations are required by the Federal Highway Administration (FHWA) to have a scour Plan of Action. The author first visited the bridge site under contract to the County of Marin in January 2017 with an interdisciplinary team of engineers including structural, geotechnical, and hydraulic engineers. Water was flowing rapidly upstream of the bridge due to a head cut through the bridge that had undermined the bridge foundations as well as exposed a sewer and gas line upstream of the bridge. The undermining of the bridge foundations subjected the bridge to potential collapse and the undermining of the utility pipes subjected them to impact loading from rocks and hydraulic forces from rapid water as shown in Figure 1.

The rapid water made it difficult to determine the actual pile exposure, as shown in Figure 2 during the January event. Figure 3 shows that the piles were exposed 0.6 to 1 meter after the water subsided.

The active head cut downstream caused 0.6 to 1 meter of pile exposure under Pier 3, as shown in Figure 4.

Submitted: 17 June 2022; Published: 28 December 2022
Reference: Avila, C.M.C.. (2022). Emergency Bridge Scour Countermeasure in Marin County, California, United States. International Journal of Geoengineering Case Histories, Volume 7, Issue 4, pp. 29-38,
doi: 10.4417/IJGCH-07-04-03

Figure 1. Looking upstream from the existing bridge at the undermined pipes (January 2017).

Figure 2. Looking at Pier 4 (Span 3). A 0.6 meter to 1.2-meter-high head cut in Span 3 moving upstream toward Piers 3 and 4.

Figure 3. Upstream of head cut looking at Pier 3. Approximately 0.6 to 1 meter of pile are exposed below the bottom of the footing.

Figure 4. Looking upstream at Pier 3 pile exposure with author (November 2017).

In January 2000, an Element Level Inspection (ELI) condition state for scour defects was coded a "2," meaning "scour exists at the bridge site and if left unchecked could adversely impact the structural integrity of the bridge," which prompted Caltrans to evaluate the bridge for scour. This condition state was caused by 0.3 meters of undermining of Pier 3 and exposure of 0.6 meters of the Pier 4 footing. A structural analysis of the bridge by the Caltrans Bridge Maintenance Ratings Section concluded that up to 2.1 meters of pile exposure could occur before the bridge became scour critical (to elevation 29 meters) (Marin County, 2017). Prior to ELI inspections, the National Bridge Inventory System (NBIS) used the "Item 113," or scour code, to document the condition of the bridge with respect to scour. In December 2000, the Item 113 was changed from a "6,"—meaning that the bridge has not been evaluated for scour—to a "5," meaning that the bridge foundations were determined to be stable for assessed or calculated scour conditions and the scour is within the limits of the footings or piles by assessment, by calculations, or by installation of properly designed countermeasures (FHWA, 2001).

In 2001, the bridge inspection report changed the ELI code to a "3," meaning "scour is significant enough to warrant a structural analysis of the bridge.". The ELI code remained the same until 2015, when the ELI manual was updated, and the scour code was removed. With this change in methodology, a direct comparison of the scour codes before 2015 and after 2015 cannot be made. The 2001 report also noted the Abutment 5 slope paving was breaking away from the main slab. This condition remained the same throughout the 2015 report. The field review in 2017, however, showed that the slope paving had failed on the downstream side of the bridge and had fallen downstream into the channel, as shown in Figure 5.

To determine historical patterns of channel aggradation or degradation, the available channel cross-sections between the oldest available section (1961) and the most recent section (2017) were reviewed. As shown in Figure 6, the channel thalweg had lowered from elevation 31.7 meters in 1961 to elevation 30.2 meters in 2017, a rate of 0.03 meters per year. Assuming a 75-year bridge life, an additional 0.6 meters of degradation could occur at the bridge.

The author and her colleagues documented the pile exposure which had increased dramatically since the previous bridge inspection before the January 2017 storm event. A Technical Memorandum (TM) was submitted to Caltrans less than a week after the field review in order to document the scour history, showing that the scour challenges at the bridge began in 1984 and continued until the last report available (in 2017) from 2015. The existing bridge scour was computed using the methodology outlined in HEC-18 (Arneson et al., 2012) and is shown graphically in Figure 6.

Figure 5. Slope paving at Abutment 5, which is undermined and has fallen into the creek.

Assuming no footing exposure and no hydraulic skew, the potential local pier scour is approximately 0.6 meters. With the existing footing exposure, however, the pier scour is increased to 1.5 to 2.1 meters.

The thalweg was surveyed in November 2017 from approximately 150 meters upstream of the bridge to 900 meters downstream of the bridge, as shown in Figure 7. Upstream of the bridge, the channel slope was approximately 2% while downstream it was 0.6%. Approximately 60 meters downstream, the thalweg drops 1.2 meters, as shown in *Figure 7*. It was anticipated that this discontinuity could headcut upstream to the bridge and it was likely that the headcut could travel upstream during the next storm, even causing an additional 0.6 to 1.2 meters of piles exposure at Pier 3 and undermining Pier 4.

At Pier 3, the piles were exposed to elevation 30.5 meters, while the thalweg was at elevation 30.2 meters. The headcut coming through the bridge was likely to lower the thalweg to elevation 29-29.6 meters. That means that if there was (a) additional degradation, (b) a nominal local pier scour of 0.6 meters, or (c) additional head cuts through the bridge, the channel elevation at Pier 3 or 4 would likely have been below elevation 29 meters, causing the bridge to be potentially scour critical.

The author and the project team recommend the Item 113 be changed from a "5" (not scour critical) to either a "2" or a "3," meaning that the bridge is potentially scour critical depending upon the structural analysis and potential failure mode. In addition, the team recommended that scour countermeasures should be placed at Pier 3 and 4 in the short term, and long-term scour countermeasures should be investigated.

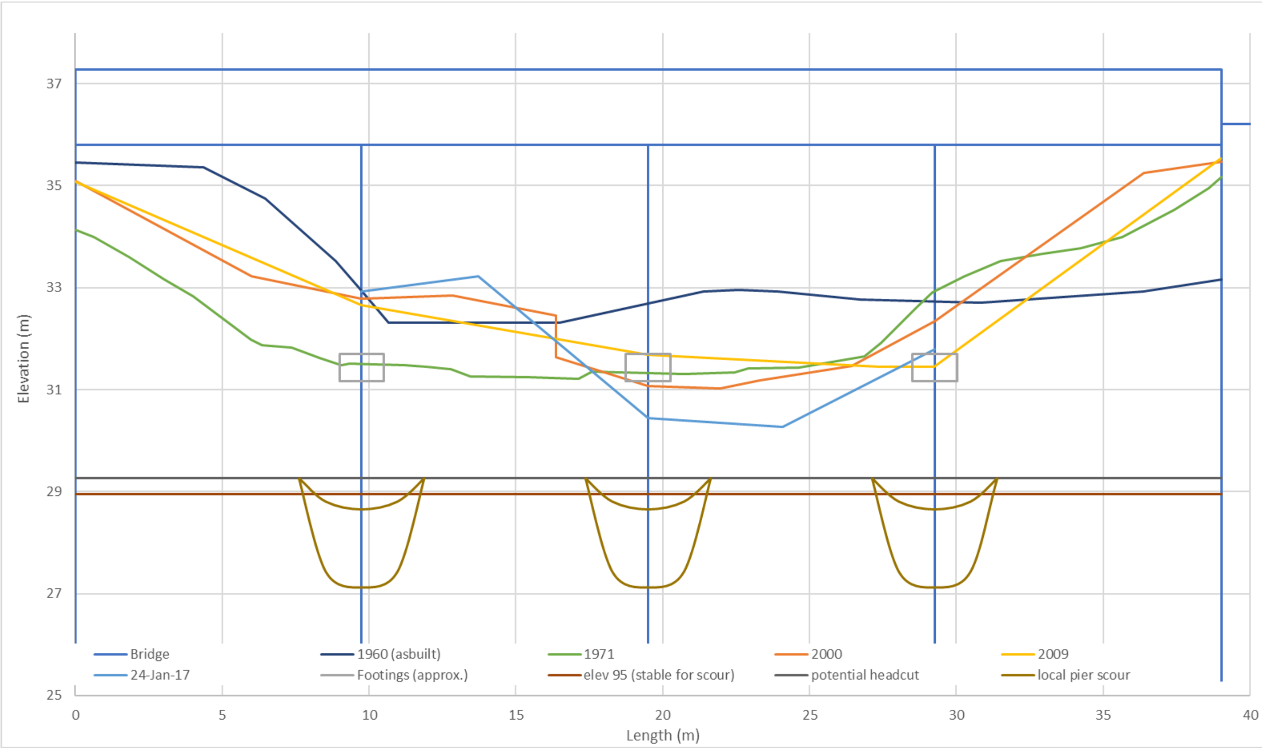

Figure 6. Channel cross sections over time at the upstream face of the existing bridge.

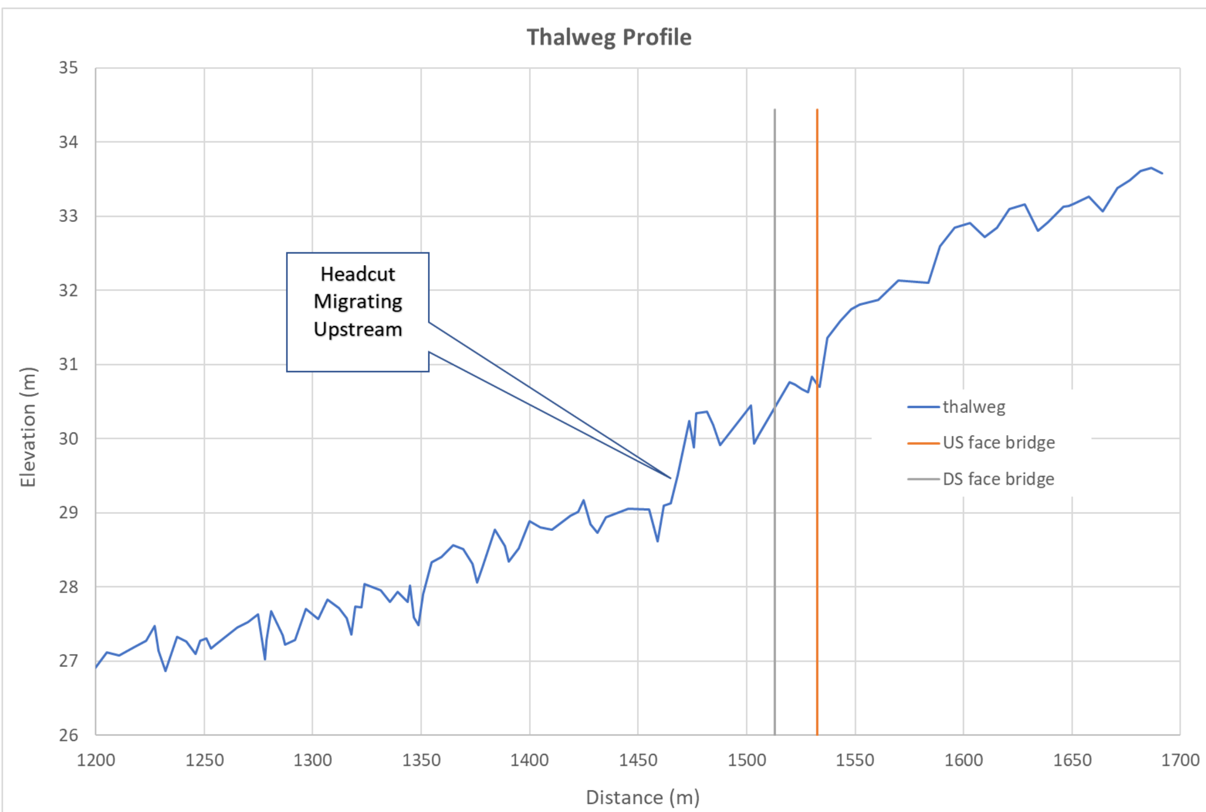

Figure 7. Thalweg profile from 11/2017 survey data.

SCOUR COUNTERMEASURES

The pile exposure at Piers 3 and 4 required scour countermeasures to stabilize the bridge and prevent bridge collapse during a significant storm or seismic event. The chosen structural countermeasure solution was to install structural countermeasures by lowering the pier foundations, as shown in Figure 8 and Figure 9. The structural solution included excavating a portion of the bridge foundation, placing steel plates, and backfilling with concrete to mitigate the undermined pile cap and exposed piles. Work progressed from downstream to upstream so that only a portion of the undermined channel was fully exposed at any one time in order to maintain the structural integrity of the bridge and to maintain traffic on the bridge.

Figure 8. (left) Looking upstream at Pier 3 pier footing construction (beginning construction, December 9, 2017).

Figure 9. (Right) Looking upstream at Pier 3 and Pier 4 (during construction, December 20, 2017).

As an additional hydraulic scour countermeasures, rock riprap (highlighted in green on Figure 10) was installed along the piers to inhibit the local pier scour, and criss cross weirs were installed downstream of the rock riprap (highlighted in blue on Figure 10). The criss cross weirs were installed to help meet the grade requirements from the environmental regulatory agencies at the downstream project limits, which would allow fish to migrate through the project and inhibit the anticipated channel headcutting from reaching the bridge.

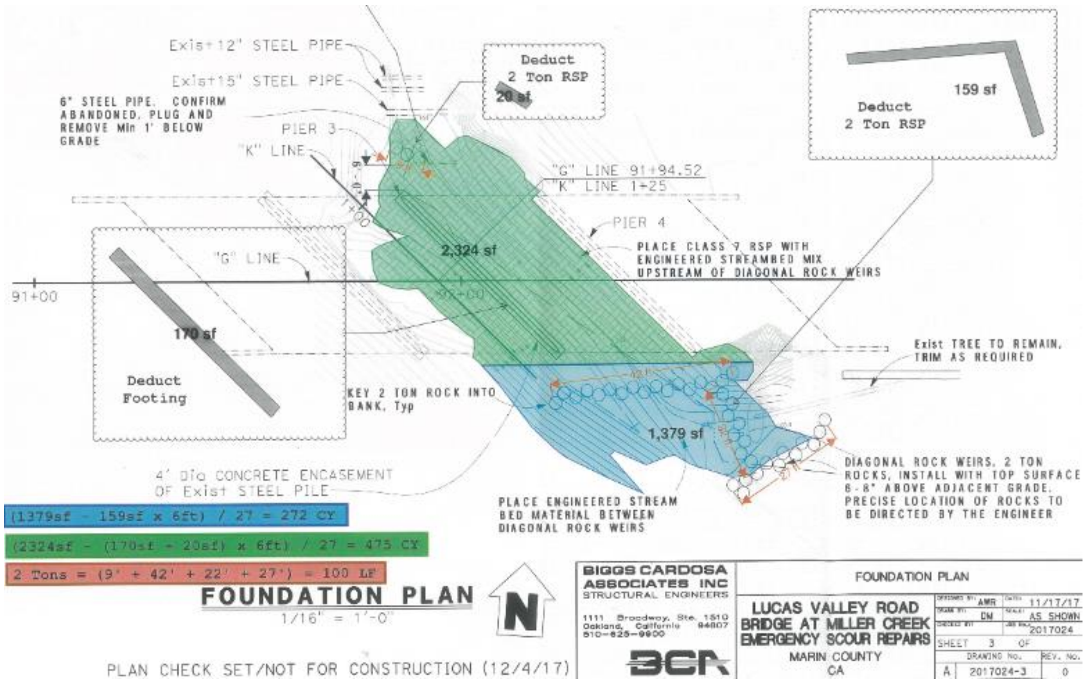

Figure 10. Layout showing 2-ton rock and criss cross weirs.

Finally, scour monitoring devices were installed to (a) monitor water stage, (b) monitor scour at the upstream and downstream limits of Pier 3, and (c) monitor movement of the bridge with a very sensitive tilt meter, as shown in Figure 11 and Figure 12. Available results from the initial monitoring are shown in Figure 13 following the installation in January 2018. These results show the bridge moves a small bit due to thermal changes as the sun rises and sets each day. If dramatic rotation caused by the undermining of the piers were to occur, the tilt meters would send a signal to the County, allowing them to close the bridge to traffic prior to bridge failure.

Figure 11. Looking downstream at Piers 3 and 4 (after monitoring device installation, February 2018).

Figure 12. Closeup looking downstream at Pier 3 sonar device.

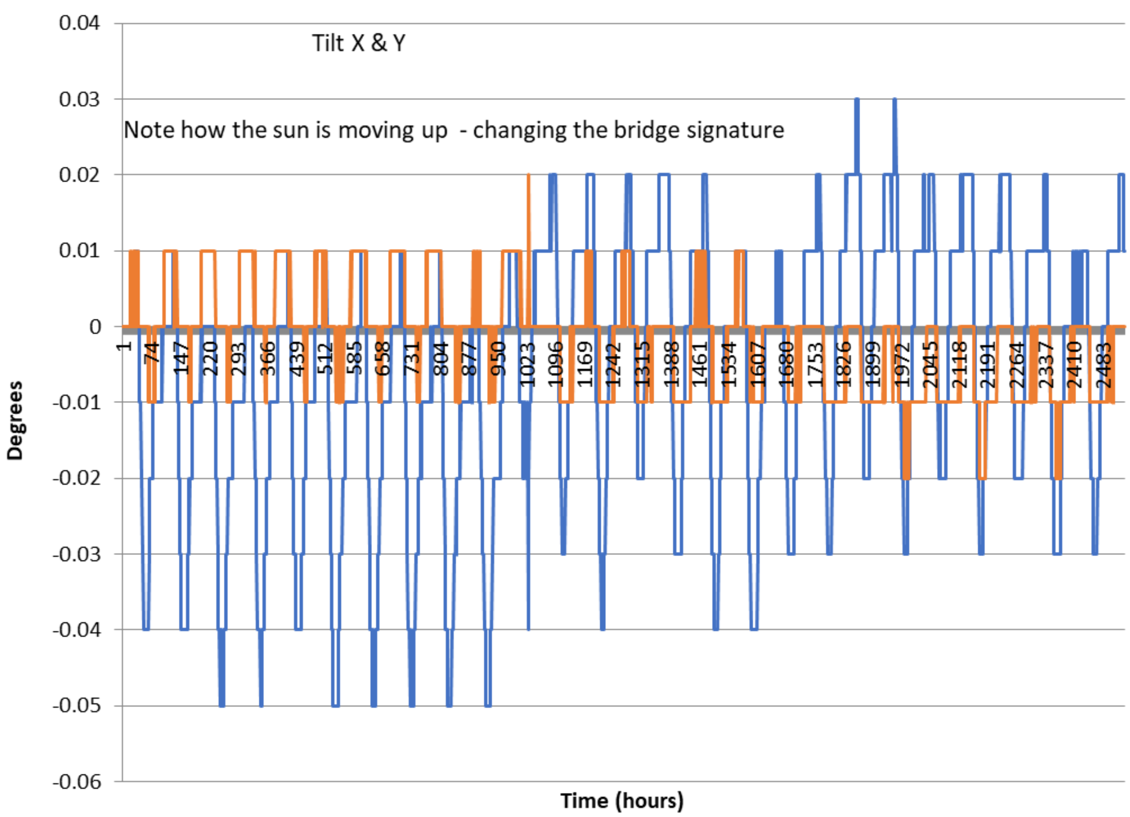

Figure 13. Tilt meter readings in degree

COUNTERMEASURE SIZING

The bridge pier riprap was sized using the Isbash equation as outlined in Design Guidance 11 in HEC-23 (Lagasse, 2009). The hydraulic variables were taken from the HEC-RAS model* and the equation is highly dependent upon velocity, as shown in Equation 1.

Isbash Equation from HEC-23 (Lagasse, 2012)

$$d_{50} = \frac{0.692(V_{des})^2}{(S_g - 1)2g} \quad (1)$$

where: d_{50} = Particle size for which 50% is finer by weight, ft (m)
V_{des} = Design velocity for local conditions at the pier, ft/s (m/s)
S_g = Specific gravity of riprap (usually taken as 2.65)
g = Acceleration due to gravity, 32.2 ft/s^2 (9.81 m/sec^2)

Based upon the Isbash equation, assuming subcritical flow, the minimum d_{50} stone size is 0.6 meters, which is 1/2 Ton or Class VII rock riprap. A minimum thickness of 3 d_{50} as shown in Figure 14 or 2-meter thickness was used for the channel design.

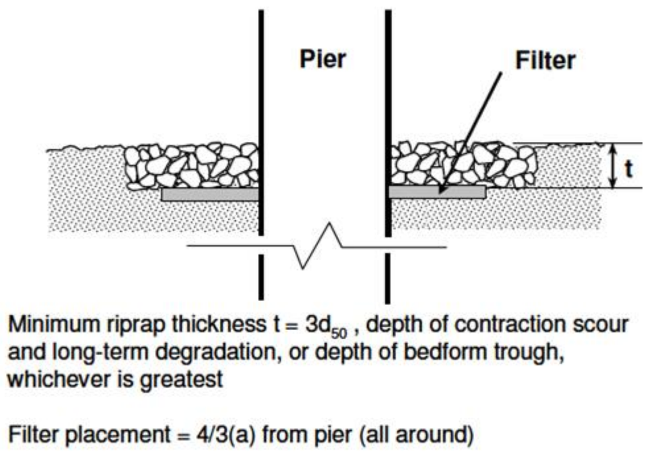

Figure 14. Rock riprap placement cross section per HEC-23 (from Lagasse et al., 2012).

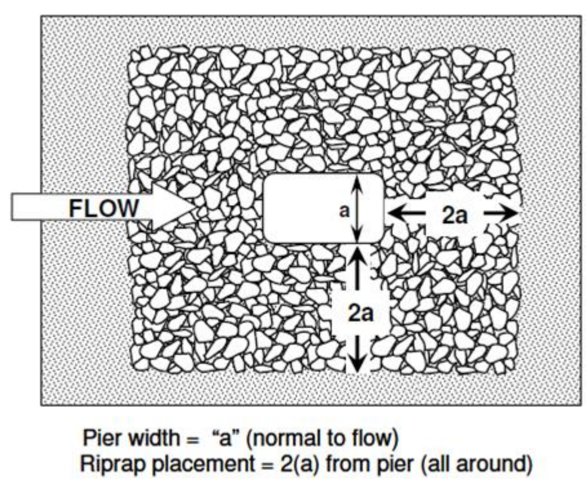

Figure 15. Rock riprap placement plan view per HEC-23 (from Lagasse et al., 2012).

*HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers.

The extent of the riprap is a function of the pier width. For the proposed pier width of 1 meter, the riprap needed to extend 2 meters from each side of the pier and upstream and downstream, as shown in Figure 15.

CONCLUSION

In January 2017, the Lucas Valley Road Bridge over Miller Creek in San Rafael, California, United States, exhibited significant scour with a 0.6 to 1 meter headcut in the main channel downstream of the bridge, and 0.6 to 1 meter of pile exposure at the bridge piers. Furthermore, the slope paving protecting Abutment 5 from scour had failed, leaving the bridge vulnerable to failure with additional scour. In the following months, a hydraulic analysis and scour analysis were completed, which determined an additional 2.1 meters of pier scour, 0.6 to 1 meters of channel bed lowering if the headcut were to move through the channel, and up to 0.6 meters of channel bed degradation were possible at the bridge, resulting in the bridge being classified as scour critical in August 2017.

Three types of countermeasures were proposed and constructed in December 2017 for the bridge. These countermeasures included structural countermeasures, where the pier footings were extended; hydraulic countermeasures, where rock riprap and criss cross weirs were used to prevent pier scour and headcutting through the bridge; and monitoring countermeasures, where stage gages, sonar, and tilt meters were used to continuously monitor conditions at the bridge, allowing for the bridge to be closed if needed. With these measures in place, the bridge has remained stable and open to the travelling public for four and a half years, as of the publication date of this paper (2022).

REFERENCES

Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., and Clopper, P.E. (2012). *Evaluating Scour at Bridges. Fifth Edition,* Hydraulic Engineering Circular No. 18. Federal Highway Administration Publication No. FHWA HIF-12-003, Washington, D.C.

California Department of Transportation (Caltrans) (2008). *Element Level Inspection Manual*, October.

Federal Highway Administration (1995). *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, Report No. FHWA-RD-96-0001, December.

Federal Highway Administration (2001). *Revision of Coding Guide, Item 113 - Scour Critical Bridges*, Memorandum, <https://www.fhwa.dot.gov/engineering/hydraulics/policymemo/revguide.cfm>, (June 2, 2022).

Lagasse, P.F., Clopper, P.E., Pagan-Ortiz, J.E., Zeverbergen, L.W., Arneson, L.A., Schall, J.D., and Girard, L.G. (2009). *Bridge Scour and Stream Instability Countermeasures, Volumes 1 and 2, Third Edition*, Hydraulic Engineering Circular No. 23, Federal Highway Administration Publication No. FHWA-NHI-09-112, Washington, D.C.

Marin County (2017). *Select Maintenance Records and As-Built Plans for the Miller Creek (Br #27C0016).*

The open access Mission of the International Journal of Geoengineering Case Histories is made possible by the support of the following organizations:

Access the content of the ISSMGE International Journal of Geoengineering Case Histories at:
https://www.geocasehistoriesjournal.org