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Development and Implementation of a Scour Monitoring Program for Selected Bridges Crossing the Trukee River

Keith E. Dennett[1], Pat Fritchel[2], Raj Siddharthan[3], and Amir Soltani[4]

PROJECT OVERVIEW

Based on the results of a bridge scour assessment conducted in 1993, hydraulic engineers at the Nevada Department of Transportation (NDOT) concluded that the accepted mathematical methods typically used to predict bridge pier scour (e.g., HEC-18) are likely to substantially overestimate the potential for scouring around bridge piers in the Truckee River. This was evidenced by the fact that most of the bridges classified as "scour critical" by these methods withstood a significant flood (a 100+ year storm event) in 1997 with little or no detectable damage.

A preliminary analysis of the scour equations presented in HEC-18 has indicated limitations in predicting scour depths when the riverbed consists mainly of large diameter particles (+0.4 ft). The bed of the Truckee River consists mainly of coarse gravels, cobbles, and boulders which is consistent with glacial outwash geomorphology.

The long-term objective of the research project is to calibrate the accepted scour equations for conditions in the Truckee River. To accomplish this objective, a bridge scour monitoring program is being implemented. This program will incorporate both fixed and portable scour monitoring devices to quantify bridge scour during significant runoff events. The monitoring data that is collected will enable specific parameters in the HEC-18 equations, such as the factor K_4, which accounts for coarse grain particles, to be adjusted to reflect the local conditions.

BACKGROUND SUMMARY

A bridge scour evaluation program was developed and implemented by NDOT in November 1993 in order to comply with recommendations from the Federal Highway Administration (FHWA) (Soltani *et al.*, 1993). Under this evaluation program, all of the bridges owned by NDOT were evaluated and the vulnerability of these bridges to scour was estimated.

Bridges are classified as either "stable" or "scour critical" according to their vulnerability to scour using a rating system developed by the FHWA (FHWA, 1995). A "scour critical" bridge is

[1] Assistant Professor, Department of Civil Engineering, Mail Stop 258, University of Nevada, Reno, NV 89557, USA, E-mail: dennett@unr.nevada.edu
[2] Graduate Research Assistant, Department of Civil Engineering, Mail Stop 258, University of Nevada, Reno, NV 89557, USA
[3] Professor, Department of Civil Engineering, Mail Stop 258, University of Nevada, Reno, NV 89557, USA
[4] Chief Hydraulic Engineer, Nevada Department of Transportation, 1263 S. Stewart Street, Carson City, NV 89712, USA

one that has abutment or pier foundations that are considered unstable due to (1) observed scour at the bridge site or (2) the potential for scour as determined from a scour evaluation study (FHWA, 1995).

A scour evaluation study may consist of three parts identified as Level 1, Level 2, and Level 3 (Williams *et al.*, 1997). A Level 1 study is a qualitative evaluation of the stability of a streambed at a bridge crossing and an examination of the bridge structure for evidence of scour. A Level 1 study is often used to identify bridges that require more detailed study. A Level 2 study involves the collection of field data, hydraulic modeling, and prediction of the estimated maximum depth of scour for a selected design flood. A Level 3 study typically involves sediment transport modeling.

The development of realistic models for sediment transport is presently limited by the ability to identify, formalize, and parameterize the individual transport and reaction processes that occur (Van Cappellen and Wang, 1995). The rate of erosion or resuspension depends on the erosive forces exerted by the flowing water at the sediment-water interface and the resistance of the sediment to erosion or resuspension (Lagasse *et at.*, 1995).

Determining an expression for the rate of erosion or resuspension remains one of the most challenging aspects of modeling the bed exchange process (Bedford, 1992). The currently accepted expressions for predicting the amount of sediment transport and potential for scour around bridge piers (e.g., HEC-18) have been successfully applied in many locations (Richardson and Davis, 1995). However, when these expressions are applied to channel reaches along the Truckee River, they seldom provide results that are consistent with observed field measurements of sediment transport and potential for scour. This may be due to a combination of geomorphic, hydrologic, and hydraulic conditions in the Truckee River.

This research project will extend earlier studies completed by NDOT. The results of the earlier work indicated that a number of bridges should be classified as scour critical. However, subsequent field inspections conducted by NDOT personnel suggested that there was no evidence of excessive scouring at a number of these locations.

RESEARCH AND ANALYSES

This project focuses on bridge sites located along the Truckee River and involves the installation of devices to monitor bridge scour. Four bridge sites have been selected initially based on the availability of historical information at bridge sites, previous field measurements of scour, site accessibility, and pier construction and configuration. Specific tasks being conducted during this project are described below.

Preliminary Review of Bridge Sites

Four bridges (Keitzke Lane, Kuenzli Street, Keystone Avenue, and Mayberry Drive) were selected for initial evaluation out of several bridges along the Truckee River. A literature review was performed to gather historical information contained in bridge construction reports, periodic bridge inspection reports, and any available reports on field monitoring of pier scour. Bridge sites that have been classified as "scour critical" based on previous Level 1 and/or Level 2 scour analyses received primary consideration. Boring logs were examined in order to define the geologic strata at each bridge site. However, the geotechnical information was usually too general to obtain a detailed classification of the particle sizes. Therefore, it will be necessary to conduct more a detailed geotechnical investigation at each of the selected bridge sites in order to classify particle sizes and subsurface conditions.

The selected bridges vary in pier construction and orientation in the flow as indicated below and shown in Figures 1 through 4.

- Kietzke Lane: square pier with the corner skewed into the direction of flow
- Kuenzli Street: elongated square pier oriented in direction of flow
- Keystone Avenue: cylindrical pier groups oriented in direction of flow
- Mayberry Drive: elongated square pier with chamfers in direction of flow

Evaluation of Scour Monitoring Devices

Information on a variety of scour monitoring devices (e.g., fixed and portable) has been gathered and evaluated (Lagasse et al., 1997). The selection of appropriate scour monitoring devices for a monitoring program depends on site conditions and operational limitations of particular types of instrumentation. Site conditions that affect monitoring include streambed composition, bridge height, depth of flow, and flow velocity. Operational limitations are related to poor performance during periods of excessive sediment transport and bed load transport, debris flows, and ice flows, as well as specialized training required to operate certain pieces of equipment.

The channel bed in the Truckee River consists mainly of very coarse, large materials that may require pre-drilling or track-hoe excavation for the installation of embedded rod devices (e.g., sliding collar and piezoelectric). The costs associated with installation as well as right-of-way constraints made the use of these devices cost prohibitive for this project. As a result, they were eliminated from further consideration.

The sounding rod device is ideal for the coarse bed materials in the Truckee River. However, because of high velocities associated with seasonal flow variations in the Truckee River, the use of this type of device has been excluded due to problems with the unsupported length.

From the research completed to date, fixed sonar devices and geophysical devices appear to be the most appropriate choices for the proposed long-term monitoring in the Truckee River. Sonar devices should be relatively easy to install and are considered to be one of the more accurate types of scour monitoring devices. They are also capable of providing time-history and aggradation measurements. Installation by equipment on the bridge deck may be possible on some of the lower bridges. A major shortcoming of this device is that debris may inhibit its ability to make accurate streambed measurements during high flow conditions.

The geophysical devices which employ ground-penetrating radar also appear to be a viable option. This device could possibly offer an alternative to sonar devices in case a sizable storm event does not occur in the near future. Instead of monitoring future scour, it may be possible to use geophysical monitoring to correlate previous scour depths to historical runoff events. In addition to recording historical scour depths, this technique could potentially be useful in determining unknown pier depths. Further research and evaluation is ongoing in these areas.

Scour monitoring programs will typically involve a combination of fixed, portable, and geophysical instrumentation to collect data in the most efficient manner. Portable instrumentation should be used to “ground truth” fixed instruments to ensure accurate results and to evaluate the potential shift of the location of maximum scour. The sonar device appears to be the best alternative for portable instrumentation. Although its functionality during high flows is suspect, it can be used as a secondary device for confirmation of the results from the fixed device during lower flows.

The portable scour monitoring device owned by NDOT has been evaluated in several trials along the Truckee River. The device, which consists of a sonar instrument mounted on a surfboard frame, needed to be modified slightly to deliver consistent results. As shown in Figure 5, these modifications include a PVC frame and balancing weight. After several trials of different measuring techniques and board configurations, it was determined that streambed elevations may be effectively obtained with this device. The board is manually pulled across the river on a steel guide cable attached to posts on opposite sides of the river. As the river rises, the cable may be raised on the posts to maintain the proper cable to river height for the board frame.

Preliminary Scour Equation Evaluation

Two of the bridges (Kuenzli and Keitzke) included in this project were evaluated utilizing the revised pier scour equation from the Fourth Edition of HEC-18 (Richardson and Davis, 2001) and compared to results obtained using the equation from the Third Edition (Richardson and Davis, 1995). As shown in Table 1, the depth of scour obtained with the Fourth Edition equation is significantly less than the value obtained by the Third Edition equation. Furthermore, the scour rating code, Item 113[5] is less severe for these bridges, yielding a rating of 3(C) using the Third Edition equation, which is indicative of a calculated depth of scour below the bottom of the footing.

For the Keitzke Bridge, the Fourth Edition equation predicted a scour depth less than the footing depth and a scour code rating of either 3(C) or 5, depending on the results of a structural analysis of the foundation.

For the Kuenzli Bridge, the Fourth Edition equation yielded a scour depth significantly less than the Third Edition equation. However, the calculated depth of scour was still below the bottom of footing, so the scour rating would still remain critical at 3(C).

From a sensitivity analysis conducted on the Keitzke Bridge, the scour consistently decreased as particle size increased until a particle size of approximately 0.4 feet was reached. As shown in Figure 6, for particle sizes greater than 0.4 feet, the results predicted a constant scour depth of 7.5 feet. Evidently, this is due to limitations associated with the K_4 factor in the equation. The minimum value of K_4 is 0.4.

[5] Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges (FHWA, 1995)

Similar results were obtained for the other two bridges, Keystone Avenue and Mayberry Drive. In light of these preliminary results, the scour code for other NDOT bridges may be revised to less severe ratings, pending re-evaluation utilizing the revised equation in the Fourth Edition of HEC-18. Moreover, calibration of the scour equation to the bed conditions of the Truckee River could result in additional bridges being classified as non-scour critical. Mueller and Jones (1999) concluded that the coefficients (e.g., K_4) based on laboratory data do not provide sufficient reductions in computed scour depths to compare favorably with observed depths. Additionally, they recommend further research to improve on scour predictions in nonuniform coarse bed material. Therefore, it is likely that the scour rating for other bridges will be reduced further following additional research and refinement of the scour coefficients.

ACCESS PLAN AND GEOTECHNICAL INVESTIGATION

A major component of the detailed geotechnical investigation will involve the development of a soil profile of the bed material with depth for a few locations along the Truckee River. By classifying the soil profile with depth, the significance of bed armoring for protecting the bed from scour can be determined.

Accessing the Truckee River to obtain large quantities of bed material to quantify particle size distributions is a significant task due to physical and environmental constraints. It was decided to utilize soil profile information for particle size characterization at the riverbank in lieu of adjacent to the pier. This will greatly reduce the impact to the river, simplifies permitting, and reduces the cost and time frame for soil sampling. A pit approximately 10 to 12 feet deep should be sufficient to characterize the soil at a level below the spread footings of the piers.

The bridge sites were evaluated for ease of access and it appeared that all of the riverbanks near the selected bridges are accessible. However, the access routes still need to be evaluated for equipment safety. Additionally, right-of-way (ROW), soil classification techniques, and environmental permitting need to be addressed. The access plan will consist of the following elements.

1. Perform an equipment safety review.
2. Conduct a preliminary environmental impact review.
3. Identify the ROW, access easements, and property owners along the access areas.
4. Determine the techniques and procedures to be used for classifying soil.
5. Conduct a preliminary field review by all affected parties.
6. Assess the bridge site for accessibility and select final bridges for monitoring.
7. Prepare access plans and reports for each selected bridge site including:
    - Base topography, boundaries, existing improvements and vegetation areas
    - Identify on plan areas of disturbance, fill, excavation an best management practices
    - Prepare a traffic control plan
    - Prepare permit applications and supporting reports for the United States Army Corps of Engineers and the City of Reno
8. Process permits through the appropriate agencies
9. Perform the geotechnical investigation and classify the particle size distributions.

LONG-TERM MONITORING PLAN

The long-term scour monitoring plan will consist of measuring pier scour with fixed and portable devices over an extended period of time. The flow in the Truckee River will be monitored using the United States Geological Survey (USGS) gauging stations that are already in place at various sites along the Truckee River. Fixed scour monitoring devices installed at the selected bridge sites will be monitored continuously to monitor changes in scour depth over time.

Detailed measurements of the channel cross sections at the selected bridge sites will be collected. These channel cross sections will be compared to any available historical records of channel cross sections at the same site. Channel cross sections at each of the selected bridge sites will be measured approximately every four months or immediately following significant flow events in order to monitor changes in overall channel geometry with time.

CALIBRATE EXISTING EQUATIONS FOR CONDITIONS IN THE TRUCKEE RIVER

The experimental data collected during this study will be used in an effort to calibrate the existing scour models presented in HEC-18 (Richardson and Davis, 2001) for the conditions that are observed in the Truckee River. Current methods tend to substantially overestimate the depth of scour around bridge piers in the Truckee River. For example, appropriate values for parameters such as the correction factor K_4 used to account for armoring by bed material will be determined using the data collected during this study.

CONCLUSIONS

The proposed research project will help NDOT identify how to improve the existing methods for predicting scour depth at bridge crossings along the Truckee River. Further, the results of this project will provide valuable experimental data that can be incorporated into modeling studies of the resuspension and deposition of sediments in the Truckee River and other rivers having similar characteristics. The erosion and scour of sediments around bridge piers and abutments is important to the fields of hydraulic, geotechnical, and bridge engineering. Improved prediction is needed to ensure the stability of these structures.

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Figure 1. Kietzke Lane Bridge Piers

Figure 2. Kuenzli Street Bridge Pier

Figure 3. Keystone Avenue Bridge

Figure 4. Mayberry Drive Bridge

Table 1. Comparison of Local Pier Scour Equations

Bridge / Equation	K_4	Scour Depth, Y_s (ft)	Footing Depth (ft)	Scour Code Rating *
Keitzke/HEC-18, Third Edition	0.79	14.8	8.5	3(C)
Keitzke/HEC-18, Fourth Edition	0.40	7.5	8.5	5 or 3(B)
Kuenzli/HEC-18 Third Edition	1.00	22.6	9.8	3(C)
Kuenzli/HEC-18 Fourth Edition	0.48	10.5	9.8	3(C)

* 3(B) indicates that the bridge is "scour critical" but scour is within the limits of the footings; 3(C) indicates that the bridge is "scour critical" and scour is below the base of the spread footing; 5 indicates that the bridge foundations are stable.

Figure 5. Sounding Board Testing

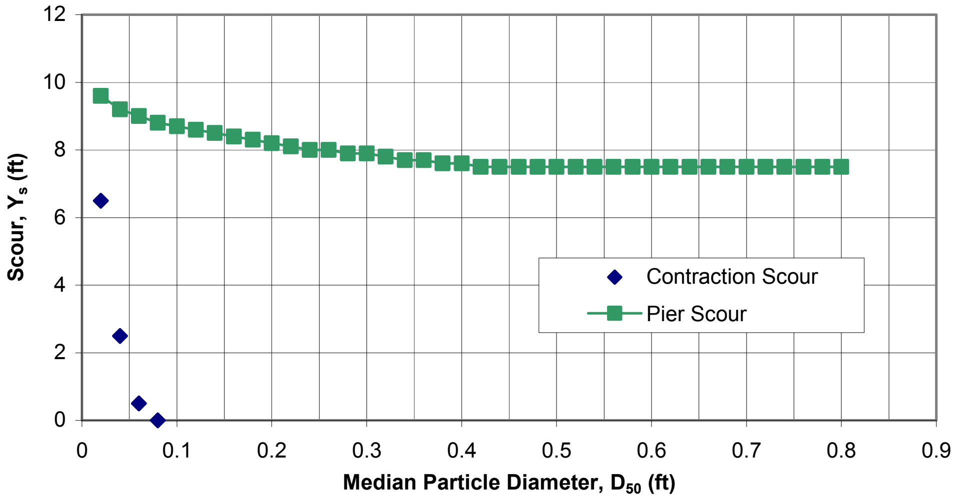

Figure 6. Scour Sensitivity for the Keitzke Bridge