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ASSESSING BRIDGE VULNERABILITY AND RISK DUE TO STREAM INSTABILITY

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ABSTRACT

The FHWA recommends that stream stability analyses begin with a Level 1 assessment. Following data collection and observations at the bridge, the user must determine whether the relative risk is low or not. If it is low, then no action is needed. If the risk is greater than low, then a Level 2 analysis is recommended. In this paper, the relative risk of failure due to stream channel instability at a bridge is assessed as a simple function of vulnerability and criticality. Vulnerability is based on a stream stability assessment and the National Bridge Inventory (NBI) ratings for channel condition for a particular bridge. Criticality is determined indirectly as a function of the bridge importance, using data extracted from the NBI. Relative risk is then qualitatively determined by combining vulnerability and criticality. An example is provided in which the relative level of risk is used to determine the need for a Level 2 analysis.

INTRODUCTION

Bridge scour, including pier, abutment, and contraction, have been heavily researched over the past several decades. Relatively simple equations have been developed to estimate scour depths, although much work still remains to refine those equations and improve confidence. Stream instabilities, such as widening, lateral migration, and downcutting, on the other hand, have received less attention in the scour literature for various reasons. The Federal Highway Administration's manual for assessing stream stability, HEC-20 (Lagasse et al., 2001), recommends that stream stability analyses begin with a Level 1 assessment. Following data collection and observations at the bridge, the user must determine whether the risk is low. If so, then no action is needed. If the risk is greater than low, then a hydrologic, hydraulic, and scour analysis is needed (Level 2). However, no method is given for determining the level of risk, even in a relative sense. Thus, a systematic approach to this decision-making process is needed to provide sufficient justification to decide whether the risk is low or otherwise. Given the importance of stream channel stability to the safety of bridges over water, the difficulty in assessing or quantifying stream channel stability, and the expense of conducting full hydrologic, hydraulic, and scour studies, this study focuses on the use of a simplified assessment to determine the relative risk of bridge loss due to stream channel instability as a basis for making this important decision. Data from the National Bridge Inventory, as well as a stream stability assessment, are used.

ASSESSING STREAM CHANNEL STABILITY

Based on substantial field observations, Johnson (2006) described the characteristics of bridge-stream intersections across the United States and developed recommendations for addressing and improving channel stability at bridges, including: (1) controlling water and sediment discharges at the catchment level; (2) revegetating channel banks with woody vegetation; (3) reshaping the channel cross-section to a more stable, configuration; (4) removing disturbances from the stream channel, such as cattle and (5) using structures to control flow near channel beds and banks. Johnson found that the physiographic setting of the bridge-stream intersection is a factor in the solution of at least the first three suggestions in this list and suggested that attention to the physical characteristics of bridge-stream intersections in the various physiographic regions can lead to sustainable solutions for stabilizing channels at bridge-stream intersections

The Federal Highway Administration's Hydraulic Engineering Circular 20 (HEC-20) (Lagasse et al. 2001) provides guidelines for bridge owners and inspectors to assess channel stability and potential stability-related problems in the vicinity of bridges and culverts. A three-level approach is suggested. If the results of the qualitative Level 1 assessment suggest that the channel may be unstable in either the vertical or lateral direction, then the user is guided to continue to the more quantitative Level 2. Based on those results, the user may or may not be instructed to continue to Level 3. To assist in the determination of the need to go on to Level 2 in HEC-20, Johnson et al. (1999, 2005) developed a rapid stability assessment method based on geomorphic and hydraulic indicators that have been included in the most recent revision of HEC-20. This method is based on observations at bridges in 13 physiographic regions of the continental United States. The method provides an assessment of channel stability conditions as they affect bridge foundations. It is intended as a rapid assessment of conditions for the purpose of documenting conditions at bridges and for judging whether more extensive geomorphic studies or complete hydraulic and sediment transport analyses are needed to assess the potential for adverse conditions developing at a particular bridge in the future, as advised in the Federal Highway Administration guidelines (see Lagasee et al., 2001).

RELATIVE VULNERABILITY AND RISK

Vulnerability indices (VI) and vulnerability assessments have been developed for a variety of purposes and have been used by several U.S. government agencies to rank and assess a wide variety of threats, both natural and human. In this paper, vulnerability is assessed using data from the National Bridge Inventory along with ratings of stability from the stream channel stability assessment method developed by Johnson (2005) to provide a current picture of the state of the stream channel in the vicinity of the bridge. The most relevant NBI data is the Channel Condition (Item 61 in the FHWA coding system (FHWA, 1995)). The rating for channel condition ranges from 0-9, with 0 the worst condition (bridge closed because of channel failure) and 9 being the best condition (no noticeable or noteworthy deficiencies). The reason to use both the stability assessment rating as well as the NBI rating is that they are based on different sets of factors, thus giving a more complete picture of the overall condition. In the stability assessment rating, the higher the resulting rating, the more unstable the channel. For the NBI items, the higher the number, the better the conditions are at the bridge. Given this difference in ratings and also given that the factors scaled differently, the ranges of values for each factor were reduced to similar scales.

Using the reduced ratings, the vulnerability was computed. The resulting vulnerability is categorized as given in Table 1.

Table 1. Categories of vulnerability.

Category	Description
Low	A loss event due to stream channel instability is unlikely.
Moderate	Given continuing stream conditions, a loss event occurrence is moderate and more likely to occur than not.
High	Continuing stream instabilities will likely cause a significant loss event.
Very High	Given the current conditions, continuing stream instability will almost certainly lead to a loss event.

Criticality is defined here as the impact or consequences of loss. In risk analyses, losses are typically quantified in terms of costs, such as costs associated with loss of life, replacement costs, costs of services interrupted, and environmental costs. However, for the purpose of deciding on the need to conduct a Level 2 analysis, relative risks are sufficient. Thus, criticality was assessed in this study using NBI data as surrogates for costs, as these data are readily available. NBI items that are related to costs (Stein et al., 1999), and thus criticality, include detour length, functional class, average daily traffic (ADT), number of spans, structure length, and overall width. As with the vulnerability factors, the criticality factors have different units and ratings. In order to have consistent scales, the criticality factors were transformed to reduced scales. The categories of criticality are given in Table 2.

Table 2. Categories of criticality.

Category	Description
Low	Costs of failure are low.
Moderate	Costs of failure are moderate.
High	Overall loss is high and somewhat costly.
Very High	Overall loss is very high and costly.

Combining the vulnerability and the criticality leads to a relative approximation of risk. A risk and decision matrix can then be constructed based on these factors. The result is a matrix of decisions, including: (1) the levels of vulnerability and loss are too high to ignore and must be made a high priority to be controlled or eliminated; (2) the risks may be unacceptable, however, following further investigation, the bridge owner may choose to accept these risks; and (3) these risks may be accepted upon the bridge owner's review.

EXAMPLE USING RISK-LOGIC MATRIX FOR DECISION-MAKING

As an example of using the method described in this paper, a bridge over Bentley Creek in north-central Pennsylvania is presented, along with the results of the vulnerability, criticality, and risk-logic decision. The Bentley Creek watershed lies within the glaciated Appalachian Plateau physiographic region of north-central Pennsylvania in the Susquehanna River Basin. The channel bed material is primarily gravel and cobbles. The stream banks are noncohesive sand and gravel. In 1972, Hurricane Agnes destabilized large portions of the channels in the watershed, causing a significant increase in bank erosion and subsequent movement of large quantities of sediment through the channel. In addition, the channel was straightened along several reaches to facilitate road construction. As a result, the channels were further destabilized and erosion rates continued to increase. To maintain flood flow through the bridge openings along the channels, the Pennsylvania Department of Transportation dredges the area beneath and immediately upstream of the bridges, creating a potential sediment trap during subsequent high flow events. Sediment has been observed to accumulate beneath one of the two-span bridges to a depth of more than 1.5 meters during a single storm, nearly filling the left span with sediment. Because most overbank flood events deposit an abundance of material beneath the bridges, dredging must be conducted on almost an annual basis at the majority of the six bridges along Bentley Creek. Upstream, channel degradation and bank erosion are actively occurring. The eroded sediment is then carried downstream where it deposits at the bridges because of gentler gradients and backwater conditions during high flows. The specific bridge used in this example is PA Route 4013 over Bentley Creek about 0.8 km south of the town of Bentley Creek in Bradford County.

According to a stability assessment and other relevant factors and Table 1, the Bentley Creek bridge has a Very High vulnerability rating due to a highly unstable channel, a meander bend at bridge, continued dredging, and a poor stability assessment rating. Based on Table 2, the criticality is determined as moderate. This is primarily due to a moderate ADT (average daily traffic) and a long detour length. For a very high vulnerability and moderate criticality, the risk-logic matrix yielded a level 3A, meaning that the levels of vulnerability and loss are too high to ignore and must be made a high priority to be controlled or eliminated. Thus, the decision for a HEC-20 Level 1 analysis is that the relative risk is greater than low and, thus, a Level 2 analysis is required.

CONCLUSIONS

In this paper, a method was described to systematically document the factors related to risk and provide justification for the need for a Level 2 analysis using HEC-20 for stream channel stability considerations. The analysis was completed for a bridge in Northern Pennsylvania where channel stability problems threaten the sustainability of the structure. The results showed that the combination of a moderate ADT, a long detour length, and a highly unstable channel resulted in a high level of risk, thus providing a compelling argument for a Level 2 analysis. The majority of data used in this analysis are readily available. The stream stability assessment needed to determine vulnerability is based on a rapid assessment method provided in HEC-20 and Johnson (2005).

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