Identifying Number MPC-354

Project Title:

Geotechnical Limit to Scour at Spill-through Abutments

University:

The University of Wyoming

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Description of Research Problem:

Most cases of abutment failure attributable to scour show a geotechnical failure of the spill slope of earthfill embankment associated with the abutment. The abutment column typically remains standing. Figure 1 illustrates two typical examples. Because spill-slope failure increases the flow area through a bridge waterway, and deposits material in the scour area, the maximum scour depth attainable at an abutment, and damage sustained by an abutment, appears to be limited by the geotechnical stability of an abutment's earthfill embankment. However, the relationship between scour and geotechnical stability of a spill-slope or embankment has never been investigated. The proposed study will be the first to investigate the relationship.

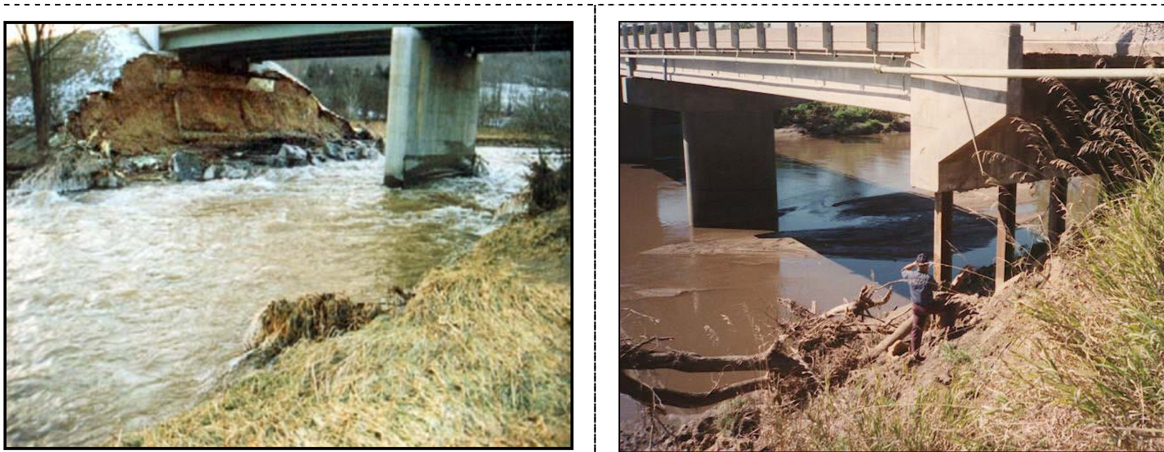
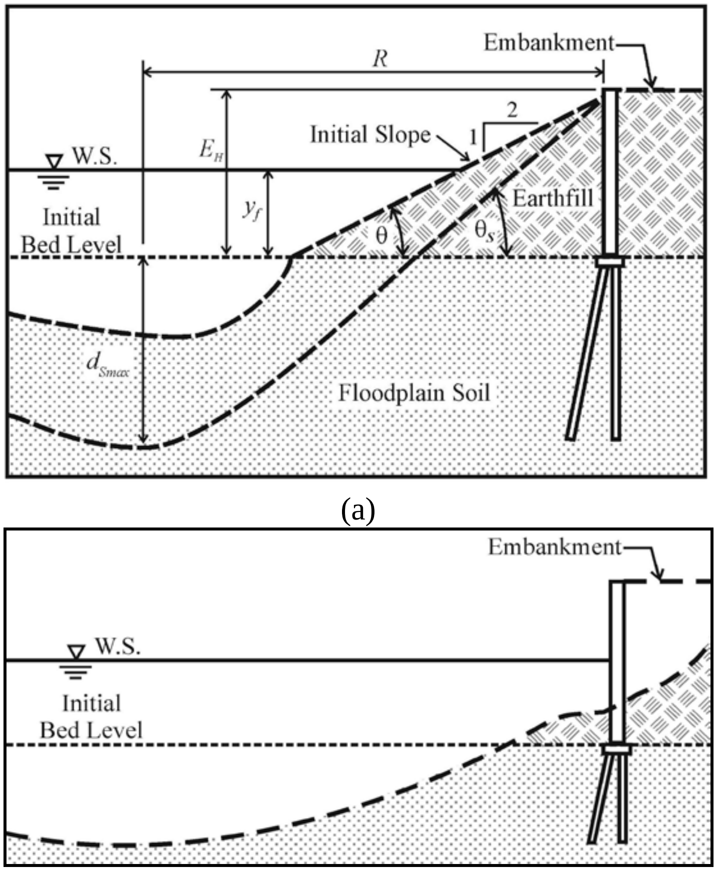


Figure 1. Abutment failure due to scour typically is attributable to the geotechnical failure of the abutments spill-slope, as illustrated by these two examples.

The project addresses the research question that scour at spill-through abutments is best characterized as largely a geotechnical design concern and less of a hydraulics concern, because the geotechnical strength of the spill-slope limits the extent of scour. The actual depth of flow-induced scour leading to embankment failure can be unremarkable. Typically, scour depths at spill-through abutments are modest, at least when viewed after the flood event that caused the scour, and when other factors such as channel morphology effects are excluded. Though numerous illustrations of scour at spill-through abutments show failed embankment and channel bank, methods currently available for estimating scour do not address the geotechnical aspects of scour at spill-through abutments

When scour causes the spill-slope to become unstable, spill-slope soil slides into the scour region and the flow transports it away. Further deepening leads to more slope instability and erosion, until eventually, the erosion extends to the abutment column (Figure 2a, b). Still further erosion breaches the embankment, increasing the flow area, and relaxing flow velocities through the bridge waterway.



(b)

Figure 2. Deepening scour destabilizes the embankment face, causing the slope to fail and to erode back to a limiting condition. When the slope erodes back past the abutment column, the embankment breaches, and scour attains an equilibrium state: the scour limit for an embankment face eroded back to an extent defined in terms of angle for embankment-slope stability, θS, and column position (a); and, embankment failure beyond this limit leads to embankment breaching and flow relaxation (b)

The leading design guides, and bridge-monitoring guides, inadequately characterize scour at bridge abutments. For example, the recent FHWA publication NIH (2009) "Stream Instability, Bridge Scour and Countermeasures," for instance inaccurately portrays an abutment structure and its flow field, and says nothing about how abutments actually are built, and possibly fail subject to scour. Figure 3 is taken from the publication. A similar comment can be made for the FHWA design guide HEC-18 (Richardson et al. 2001).

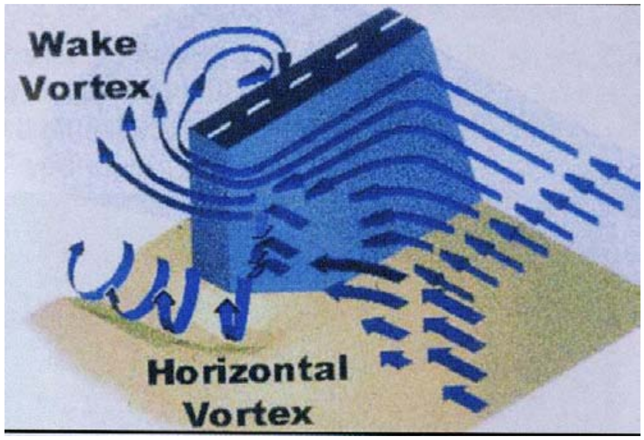


Figure 3. This sketch portrays an unrealistic, or at least very uncommon, view of abutment scour; taken from NHI (2009) "Stream Instability, Bridge Scour and Countermeasures"

Research Objectives:

The project has the following principal objectives:

1. Comprehensively define the essential geotechnical aspects associated with scour of spill-through abutments;
2. Show that the stability of an abutment's spill-slope limits scour depth; and,
3. Formulate a practical method relating abutment scour depth to the shear strength of the abutment's earthfill embankment. The relationship would provide a useful check on scour depth estimated using existing (and largely inadequate) methods for scour-depth prediction (e.g., as in HEC-18 recommended by the Federal Highway Administration).

The information and insights obtained from the project will significantly enhance understanding of abutment scour, and improve abutment design.

Research Approach / Methods:

The research entails diagnosis of a set of field cases of scour at abutments, focused laboratory tests conducted with a large flume, and formulation of a practical design method. Specifically, the project comprises the following tasks:

1. Review pertinent literature on abutment scour;

2. Investigate selected field cases of abutment scour to determine the geotechnical failure modes of spill-slope failure;

3. Formulate an approach for evaluating the geotechnical limit to maximum scour depth at a spill-through abutment. The approach will involve one or more formulations of abutment scour from a geotechnical perspective;

4. Carry out a select number of flume experiments to verify, in a controlled manner, the formulated relationship (or set of relationships) between scour depth and the shear strength of compacted earthfill spill-slope;

5. Determine if riprap on a spill-slope aids or hinders the geotechnical stability of a spill-slope. Riprap protects the spill-slope against erosion by water, but, by adding weight and not strength, may hasten spill-slope instability;

6. Recommend a practical design relationship for use in assessing abutment scour depths; and,

7. Provide a comprehensive final report to be written and submitted to the MPC Program

Literature Review

The project entails completion of an incisive review of the literature on abutment scour so as to develop a concise summary on the state-of-practice regarding current design methods. The PI's background expertise in the topic area will facilitate the review. Particular focus of the review will be design recommendations presently in FHWA's HEC-18 publication, and reports prepared by the National Cooperative Highway Research program (NCHRP).

Case-Study Evaluation

A set of case-studies of abutment scour will be assembled and investigated in terms of the geotechnical aspects of scour and spill-slope erosion or failure. This task entails working with the Wyoming Dept of Transportation

(WYDOT), other state DOTs, and the Lakewood office of the Federal Highway Administration (FHWA). Principal Investigator Robert Ettema has good working relationship with design engineers at FHWA and WYDOT.

Preliminary Formulation of Geotechnical Limit

The formulation will provide an estimate to the limit of the abutment scour possible at an abutment. It will do so for several modes of spill-slope failure. A preliminary formulation has been developed, as outlined below. Figure 2a, b illustrates the geotechnical limit for a spill-slope. As scour deepens, it reduces the stability of the earthfill embankment at the abutment, adjusting the embankment slope to its equilibrium slope. When the slope is exceeded, embankment material slides into the scour region (Figure 2a) and the flow transports it away. Further deepening leads to more slope instability and erosion, until eventually, the erosion extends to the abutment column. Because the cross section of flow increases (Figure 2b), further erosion results in breaching of the embankment and relaxation of the flow around the abutment.

It is possible to formulate the geotechnical limit to maximum scour depth. Figure 2 illustrates this limit. As indicated in Figure 2a, and found in the flume experiments, the location of deepest scour, dSmax, was a radial distance, R, out from the abutment column. For the present study (and many abutment embankments), the constructed embankment slope was 2 horizontal to 1 vertical, such that the requirement for embankment slope stability, when the slope extends back to the abutment column, is

$$\theta_S = \tan^{-1}\left(\frac{E_H + d_{S\max}}{R}\right) \tag{1}$$

where EH is embankment height. Adjusting Eq. (1), gives an estimate for the limiting values of dSmax;

$$d_{S\max} = R\tan\theta_S - E_H \tag{2}$$

The flume experiments, augmenting case-study field observations, are needed to show how R varies with the abutment length.

The maximum scour depth at the abutment should not exceed the limit given by Eq. (2). Note that this limit can actually be attained, especially when θS is large, such as for an earthfill embankment formed of a compact stiff clay. A larger scour depth leads to breaching of the embankment and flow relaxation through the bridge waterway (Figure 2b). The limiting scour-depth analysis should be further investigated for a range of earthfill materials, along with varying combinations of compacted embankment earthfill and floodplain soils. The preliminary formulation of Eqs (1) and (2) is somewhat simplified, but is nonetheless indicative of how to estimate a limiting scour depth.

It could be noted for an analysis of abutment geotechnical stability that riprap presence does not enhance geotechnical stability. Riprap adds weight to the slope, but does not increase the shear strength of the earthfill forming the embankment.

For abutments on footing foundations, a limiting maximum scour-depth coincides with the undermining of the footing and the possible geotechnical collapse of the earthfill embankment behind the abutment column. This limit also could be formulated, at least in approximate terms. A formulation is not given here, but the photographs of failed abutments show such a geotechnical collapse, and directly indicate how the formulation might be formulated.

Flume Experiments

The flume experiments will be proof-of-concept tests involving a hydraulic model of a spill-through abutment and embankment formed of compacted soil whose laboratory-scale shear strength will be varied. The flume constructed with the aid of MPC funds (Grant: NDSU48510ETMA) will be used for the experiments. The abutment and embankment will be replicated at a length scale of 1:30 to 1:40, placed on a simulated, erodible floodplain subject to scour. Flow will be recirculated through the flume, enabling the scour to develop until the replicated spill-slope fails. Scour depth will be related to the shear strength of the replicated embankment, and the relationship used to verify the preliminary formulation presented above, or an advanced version of the formulation.

Final Report

The final report will be a well-illustrated documentation of the projects results. It will include example design calculations using the formulation described above.

MPC Critical Issues Addressed by the Research:

1. Infrastructure Longevity (better abutments)

2. Improved Infrastructure Design (better and safer abutments)

3. Environmental Impacts of Infrastructure (abutment effects on flow and erosion)

4. Low-Cost Safety Improvements (effective placement of scour countermeasures).

Contributions / Potential Applications of Research:

The research findings facilitated by the flume, aiding the numerical model results, will lead to improved estimation of scour depth at bridge abutments, and thereby to improved design of bridge waterways. Also it will help in the design and placement of effective scour countermeasure methods.

Potential Technology Transfer Benefits:

The insights and design information obtained from the project will be of interest to bridge designers, as well as to bridge inspection personnel, working for State Departments of Transportation or other entities. The Wyoming Technology Transfer Center (T2/LTAP) will ensure the dissemination of the findings of this study.

Time Duration:

July 1, 2010 - June 30, 2011

Total Project Cost:

$50,143

MPC Funds Requested:

$26,506

Source of Matching Funds:

University of Wyoming: $23,637

Contributions / Potential Applications of Research:

The literature review which will be conducted will insure that the findings of similar projects will be considered in the development of the methodology of this study.

TRB Keywords: Safety, Rural Transportation, Transportation Systems, Safe Travel, Public Services, Safe Driving

References

National Highway Institute (2009), "Stream Instability, Bridge Scour and Countermeasures." Federal Highway Administration, US Dept of Transportation, McLean, VA.

Richardson, E. and Davis, S. (2001), "Evaluating Scour at Bridges," Report FHWA-NHI-01-
001, Federal Highway Administration, Hydraulic Engineering Circular No. 18, McLean, VA.