A MODIFIED INDEX FOR ASSESSMENT OF POTENTIAL SCOUR AT BRIDGES OVER WATERWAYS

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ABSTRACT

A modified potential-scour index has been developed to assess the potential for scour at bridges over waterways. The modified index is based on a potential-scour index used by the U.S. Geological Survey (USGS) Maryland District (the Maryland index) and the original prototype potential-scour index developed by the USGS Tennessee District. The modifications were made to (1) improve the technical content of the Maryland index, and (2) provide a more extensive set of index variables for assessment of potential scour at bridges.

This report demonstrates and describes problems that were encountered when using the Maryland index in a study of county-maintained bridges in Maryland from 1993 to 1995. The modifications made to specific index variables and ranking values in the Maryland index are presented and discussed.

A comparison of potential-scour ratings from the Maryland index, as applied to two bridges, is presented. This comparison indicates that the modified potential-scour index yields potential-scour ratings that most consistently reflect scour conditions observed at these bridges.

INTRODUCTION

During 1993-95, the U.S. Geological Survey (USGS) Maryland District conducted channel-stability assessments at 1,191 county-maintained bridges over waterways in Maryland. Data were collected at each site to describe physical characteristics of the bridge and stream channel and to assess ongoing channel processes (Simon and others, 1989). Potential scour was assessed by use of a potential-scour index that was based on a prototype index developed by the USGS Tennessee District in 1988 (the Tennessee index). The potential-scour index assigns numerical rankings to specific characteristics of the bridge and stream channel to develop a potential-scour rating. The potential-scour index used for assessing bridges and stream channels in Maryland (the Maryland index) is shown in figure 1.

The Maryland index yields a maximum potential-scour rating of 63 and a minimum of 12. A greater ranking value represents lesser scour potential for each index variable. Each of the 13 index variables and their respective rankings are described in Simon and others (1989) and Doheny and others (1996).

Both the Tennessee index and the Maryland index provide a means for prioritizing bridges and stream channels for further study. However, review and comparison of potential-scour ratings for selected bridges using the Maryland index reveal that bridges with little or no observed scour sometimes have potential-scour ratings that indicate greater potential for scour than bridges with large scour holes and footing exposures. A tendency also is shown where bridges with many piers or bents can have potential-scour ratings that indicate greater scour potential than single-span bridges regardless of the observed-scour conditions. Some additions and modifications to specific index variables and ranking values in the Maryland index can help to correct these and other discrepancies.

This report demonstrates and describes problems that were encountered when using the Maryland index to assess potential scour at bridges over waterways. Modifications made to specific index variables and ranking values are presented and discussed. A comparison of potential-scour ratings using the modified potential-scour index also is presented.

POTENTIAL-SCOUR INDEX

[Index variables and ranking values for calculation of potential-scour rating; potential-scour rating equals sum of assigned ranking values]

1. Type of bed material

manmade	bedrock	cobble boulder	gravel cobble	gravel	sand	unknown alluvium	silt clay
5	5	4.5	4.25	4	3	2	1

2. Protected channel bed (with protected channel banks)

yes	no	1 channel bank	2 channel banks
4	3	2	1

3. Stage of channel evolution

I	II	III	IV	V	VI
5	4	2	1	3	5

4. Percentage of channel constriction at the bridge

0-5	6-25	26-50	51-75	76-100
5	4	3	2	1

5. Number of piers or bents in stream channel

0	1-2	3 or more
3	2	1

6. Percentage of debris blockage (horizontal (6), vertical (7), total (8))

0-5	6-25	26-50	51-75	76-100	
5	4	3	2	1	(values are divided by 3)

9. Bank erosion for left bank and right bank

none	light fluvial	heavy fluvial	mass wasting
3	2	1.5	1

10. Location of high-flow meander-impact point from bridge (in feet)

>100	51-100	26-50	0-25
4	3	2	1

11. Skew for each pier or bent (default value = 14)

no	yes
0	-1

12. Mass wasting at left or right bank pier or bent

no	yes
4	1

13. High-flow angle of approach (in degrees)

0-10	11-25	26-40	41-60	61-90
4	3.5	3	2	1

Figure 1. Potential-scour index used for assessing bridges and stream channels in Maryland.

PROBLEMS ENCOUNTERED USING THE MARYLAND INDEX

The problems encountered when using the Maryland index can best be demonstrated by use of an example. Two channel-stability assessments conducted at county-maintained bridges in Maryland were selected for demonstration on the basis of varying channel characteristics and scour conditions.

Bridge WO703 spans Pusey Branch on Whitesburg Road in Worcester County, Maryland. The flow is nontidal and mostly pooled. The channel bed is composed mainly of silt. The channel banks are gently sloped with greater than 50-percent woody-vegetative cover on three of the four channel banks. The bridge has four bents in the stream channel that are all skewed to the flow because of their alignment and a 20-degree high-flow angle of approach toward the right bank. The bents also have submerged debris rafts on the upstream side of the bridge. The bridge has vertical abutments that are in contact with the flow when the stream is flowing at full channel capacity. The stream channel widens into a large pond on the downstream side of the bridge before constricting to the original width about 150 feet downstream from the bridge. Small scour holes were observed at two of the bents and the right abutment during the channel-stability assessment.

Bridge W1011 spans Little Conococheague Creek on Ashton Road in Washington County, Maryland. The flow is nontidal, with mostly riffled flow approaching the bridge. The channel bed is composed mainly of gravel and cobbles. The channel banks are gently sloped, except for the upstream, right bank. All channel banks have little or no woody-vegetative cover. The bridge is a single span with vertical abutments that are projected into the stream channel and are skewed to the flow. The high-flow angle of approach is 35 degrees toward the right bank. The upstream channel is greater than twice as wide as the bridge opening when the stream is flowing at full channel capacity. Local scour and exposure of footings were observed on both abutments. The right abutment footing (when facing in a downstream direction) is exposed vertically to a maximum of 2.6 feet under the bridge. The left abutment footing is exposed vertically to a maximum of 1.0 foot under the bridge. The datum for these exposures is based on the top of the footing.

Despite the fact that scour conditions observed at bridge W1011 are much more severe than those observed at bridge W0703, the Maryland index produces a potential-scour rating indicating greater scour potential at bridge W0703 than for bridge W1011. A listing of the index variables and respective ranking values for both bridges are shown in table 1.

The index variables that contribute most to reducing the potential-scour rating for bridge W0703 relative to bridge W1011 are the type of bed material, the number of piers or bents in the stream channel, and the skew for each pier or bent. The difference in ranking values for the pier-related index variables are greater than the difference in potential-scour ratings between these two bridges. The scour conditions observed at bridge W1011 are a result of abutment scour rather than pier scour. However, the Maryland index does not consider the potential for abutment scour.

Table 1. Index variables, ranking values, and potential-scour ratings for bridges W0703 and W1011 using the Maryland index

Index variable	Ranking value	
	Bridge W0703	Bridge W1011
Type of bed material	1.00	4.25
Protected channel bed	3.00	1.00
Stage of channel evolution	3.00	3.00
Percentage of channel constriction at bridge	5.00	1.00
Number of piers or bents in stream channel	1.00	3.00
Percentage of debris blockage (horizontal)	1.00	1.67
Percentage of debris blockage (vertical)	1.33	1.67
Percentage of debris blockage (total)	1.33	1.67
Bank erosion on left bank	2.00	3.00
Bank erosion on right bank	2.00	1.50
Location of high-flow meander-impact point	1.00	1.00
Skew for each pier or bent	10.00	14.00
Mass wasting at left bank pier or bent	4.00	4.00
Mass wasting at right bank pier or bent	4.00	4.00
High-flow angle of approach	3.50	3.00
Potential-scour rating	43.16	47.76

MODIFICATIONS TO INDEX VARIABLES AND RANKING VALUES

All index variables and ranking values in the Maryland index were reviewed for potential modification. All data variables that were measured during the channel-stability assessments were reviewed for possible inclusion in a modified potential-scour index.

Modifications or additions to the Maryland index were deemed necessary for index variables relating to (1) pier or bent skew, (2) abutment scour, (3) type of bank material, (4) bank erosion, (5) percentage of woody-vegetative cover, and (6) mass wasting at left or right bank pier or bent. Adjustments to the ranking values of index variables were made for the (1) high-flow angle of approach, (2) percentage of debris blockage at the bridge opening, and (3) location of a high-flow meander-impact point from the bridge.

A modified potential-scour index was constructed to incorporate all modifications and additions. The modified potential-scour index yields a maximum potential-scour rating of 105 and a minimum rating of 24. A greater ranking value represents lesser scour potential for each index variable. The modified potential-scour index is shown in figure 2. All modifications and additions made to the Maryland index in constructing the modified potential-scour index are discussed in the following sections.

Pier or Bent Skew

Significant modifications were made to the method of ranking pier or bent skew in the Maryland index. The Maryland index deducts one point from the potential-scour rating for every pier or bent in the stream channel that is skewed to the flow. The magnitude of the skew is not considered. Field experience has demonstrated that the magnitude of skew on a pier or bent can be a determining factor in the presence of scour. Analysis of potential-scour ratings has also shown that the method of deducting a point for each pier that is skewed to the flow places a bias on the potential-scour ratings for multiple-span bridges. For example, a newly built bridge with 12 piers in the stream channel that are each skewed 5 degrees to the flow and have no observed scour can have a potential-scour rating indicating greater scour potential than a bridge with 1 severely skewed pier in the stream channel with scour and the footing exposed.

In order to improve the method of ranking pier or bent skew, the magnitude of skew must be considered while removing the bias on potential-scour ratings for multiple-span bridges. The following modifications have been made to the Maryland index to improve the method of ranking for pier or bent scour:

(1) The index variable for "Number of Piers or Bents in Stream Channel" has been retained with no modification to the ranking values.

(2) An index variable has been added for "Number of Piers or Bents in Stream Channel With Skew." A ranking value of 3 is assigned if the bridge has no piers or bents in the stream channel with skew. A ranking value of 2 is assigned if one or two piers in the stream channel are skewed to the flow. A ranking value of 1 is assigned if three or more piers or bents are skewed to the flow.

(3) An index variable has been added for "Largest Skew Angle on any Pier or Bent in the Stream Channel." Incremental ranges of skew magnitude were developed to incorporate the full range of skew magnitudes that were measured in the field. A ranking value of 5 is assigned if the largest skew magnitude is in the range of 0 to 5 degrees. The ranking values decrease incrementally for incrementally increasing magnitudes of maximum skew on any pier or bent, as shown in figure 2.

(4) The index variable "Skew for Each Pier or Bent," which deducts one point for every skewed pier or bent in the stream channel, has been removed.

POTENTIAL-SCOUR INDEX

[Index variables and ranking values for calculation of <u>potential-scour rating</u>; potential-scour rating equals sum of assigned ranking values]

1. <u>Type of bed material</u>

manmade	bedrock	cobble boulder	gravel cobble	gravel	sand	unknown alluvium	silt clay
5	5	4.5	4.25	4	3	2	1

2. <u>Percentage of channel constriction at the bridge</u>

0-5	6-25	26-50	51-75	76-100
5	4	3	2	1

3. <u>Stage of channel evolution</u>

I	II	III	IV	V	VI
5	4	2	1	3	5

4. <u>Protected channel bed (with protected channel banks)</u>

yes	no	1 channel bank	2 channel banks
4	3	2	1

5. <u>Number of piers or bents in stream channel</u>

0	1-2	3 or more
3	2	1

6. <u>Number of piers or bents in stream channel with skew</u>

0	1-2	3 or more
3	2	1

7. <u>Largest skew angle on any pier or bent in stream channel (in degrees)</u>

0-5	6-15	16-25	26-40	41-60	61 or greater
5	4	3	2	1	0

8. <u>Location of abutments (score for both abutments)</u>

setback	even with bank	projected into flow
3	2	1

9. <u>Skew angle on abutments (in degrees, score for both abutments)</u>

0-5	6-15	16-25	26-40	41-60	61 or greater
5	4	3	2	1	0

Figure 2. Modified potential-scour index to be used for assessing bridges and stream channels.

10. Type of bank material, left bank (score for upstream and downstream)

manmade	bedrock	cobble boulder	gravel cobble	silt clay	sand
3	3	2.5	2	1.5	1

11. Type of bank material, right bank (score for upstream and downstream)

manmade	bedrock	cobble boulder	gravel cobble	silt clay	sand
3	3	2.5	2	1.5	1

12. Bank erosion for left bank (score for upstream and downstream)

none	light fluvial	heavy fluvial	mass wasting
3	2	1.5	1

13. Bank erosion for right bank (score for upstream and downstream)

none	light fluvial	heavy fluvial	mass wasting
3	2	1.5	1

14. Percentage of woody-vegetative cover-left bank (upstream and downstream)

76-100	51-75	26-50	6-25	0-5
3	2.5	2	1.5	1

15. Percentage of woody-vegetative cover-right bank (upstream and downstream)

76-100	51-75	26-50	6-25	0-5
3	2.5	2	1.5	1

16. High-flow angle of approach (in degrees)

0-5	6-15	16-25	26-40	41-60	61 or greater
5	4	3	2	1	0

17. Percentage of debris blockage (percent of total area blocked)

0-5	6-25	26-50	51-75	76-100
5	4	3	2	1

18. Mass wasting at left or right bank pier, bent, or abutment

no	yes
4	1

19. Location of high-flow meander-impact point from bridge (in feet)

>100	76-100	51-75	26-50	0-25
5	4	3	2	1

Figure 2.--Continued.

Abutment Scour

The potential for abutment scour is not considered in the Maryland index. Only the number of piers or bents in the stream channel and the number of piers or bents skewed to the flow are considered. In Maryland, about 60 percent of the 1,191 county-road bridges assessed for channel stability are single-span bridges. Because single-span bridges have no piers or bents, the only structural elements potentially vulnerable to scour on these bridges are the abutments and wingwalls. For purposes of channel-stability assessments, wingwalls are considered to be part of the respective abutment. To accurately rank single-span bridges and multiple-span bridges for potential scour, both abutment scour and pier or bent scour must be considered.

The potential for abutment scour is related to the abutment locations in reference to the channel banks and the skew to the flow on each abutment. The following index variables have been added to the Maryland index to consider potential for abutment scour:

(1) An index variable has been added for "Location of Abutments." The location of a spillthrough abutment is the location of the toe of the spillthrough slope. The location of a vertical abutment is the toe location of the vertical wall of the abutment. If the abutment toe is set back from the channel bank, a ranking value of 3 is assigned. If the abutment toe is even with the channel bank, a ranking value of 2 is assigned. If the abutment toe is projecting into the stream channel, a ranking value of 1 is assigned.

(2) An index variable has been added for "Skew Angle on Abutments." A ranking value of 5 is assigned if the magnitude of abutment skew is in the range of 0 to 5 degrees. The ranking values decrease for incrementally increasing magnitudes of abutment skew as shown in figure 2.

Type of Bank Material

The Maryland index does not consider the type of bank material on each channel bank. The type of bank material can determine the erodibility of a channel bank. Therefore, an index variable has been added to the Maryland index for "Type of Bank Material." The predominant type of bank material will be ranked for both the upstream and downstream reaches of each bank according to relative erodibility. If a channel bank is manmade or composed predominantly of bedrock, a maximum ranking value of 3 is assigned. The ranking values for other types of bank material decrease incrementally with increased erodibility as shown in figure 2.

Bank Erosion

The Maryland index addresses bank erosion by ranking the most severe, predominant type of erosion in either the upstream or downstream reach for the left and right channel banks. Bank erosion can be considered in more detail by considering both the upstream and downstream reaches of each channel bank. Therefore, the index variable "Bank Erosion for Left Bank and Right Bank" has been separated into two index variables entitled "Bank Erosion for Left Bank" and "Bank Erosion for Right Bank." The predominant type of bank erosion will be ranked for both the upstream and downstream reaches of each bank by use of these index variables. The ranking values used in the Maryland index have not been modified.

Percentage of Woody-Vegetative Cover

The Maryland index does not consider the percentage of woody-vegetative cover on the channel banks. Woody-vegetative cover can stabilize a channel bank because extensive root systems hold bank material in place. As the percentage of woody-vegetative cover increases on a channel bank, so does the extent of the root system to protect the channel bank from erosion. The Maryland index has been modified to include two new index variables--

"Percentage of Woody-Vegetative Cover on Left Bank" and "Percentage of Woody-Vegetative Cover on Right Bank". The percent range of woody-vegetative cover will be ranked for both the upstream and downstream reaches of each channel bank using these index variables. If a channel bank is estimated to have woody-vegetative cover in the range of 76 to 100 percent, a maximum ranking value of 3 is assigned. The ranking values decrease incrementally as the incremental ranges for percentage of woody-vegetative cover decrease, as shown in figure 2.

High-Flow Angle of Approach

A high-flow angle of approach is a measure of the direction of flow relative to a channel bank at the bridge. Concentration of flow toward one side of a stream channel can cause local scour and lead to pier- and abutment-footing exposures (Doheny, 1993). In the Maryland index, the ranking values for the high-flow angle of approach are reduced by a total of 1 point between magnitudes of 0 and 40 degrees. Field experience has demonstrated that high-flow angles of approach in the range of 10 to 15 degrees can be factors in local scour and footing exposures on piers and abutments. The range of ranking values in the Maryland index seems to underestimate the severity of the high-flow angle of approach. Therefore, the range of ranking values has been adjusted to deduct more points within smaller ranges as the magnitude of the high-flow angle of approach increases.

Percentage of Debris Blockage at Bridge Opening

The index variable "Percentage of Debris Blockage" in the Maryland index has been simplified to consider the percentage of total cross-sectional area blocked in the bridge opening instead of considering the percentage of horizontal, vertical, and total debris blockage separately. The range and magnitude of ranking values included in the Maryland index have not been modified.

Mass Wasting at Left or Right Bank Pier or Bent

The Maryland index assigns ranking values based on the presence or absence of mass wasting on a channel bank and a pier or bent located on that channel bank. Mass wasting on a channel bank in relation to the abutment location on that channel bank is not considered. An abutment located on a channel bank or projected into the stream channel could be at risk if mass wasting is occurring along the channel bank in either the upstream or downstream reach. Therefore, the index variable for "Mass Wasting at Left or Right Bank Pier or Bent" has been modified and expanded to include the abutments. The index variable "Mass Wasting at Left or Right Bank Pier, Bent, or Abutment" will also consider the presence or absence of mass wasting on a channel bank and the location of an abutment in relation to that channel bank. If no mass wasting is present in the upstream or downstream reach of a channel bank, or an abutment is set back from the channel bank, a ranking value of 4 is assigned. If mass wasting is present in the upstream or downstream reach of a channel bank and an abutment is located along the channel bank or projected into the stream channel, a ranking value of 1 is assigned. The method of applying the index variable to piers or bents has not been modified from that used in the Maryland index.

Location of High-Flow Meander-Impact Point From Bridge

The ranges of ranking values used in the Maryland index for the index variable "Location of High-Flow Meander-Impact Point From Bridge" have been modified to provide consistent intervals of distance from the bridge. A ranking was introduced for the intervals of 76 to 100 feet and 51 to 75 feet from the bridge instead of one ranking for the interval of 51 to 100 feet from the bridge. The maximum ranking value was increased from 4 points to 5 points.

COMPARISON OF POTENTIAL-SCOUR RATINGS FOR TWO COUNTY-MAINTAINED BRIDGES IN MARYLAND USING THE MODIFIED POTENTIAL-SCOUR INDEX

The results of modifying the Maryland index can be demonstrated by comparing the potential-scour ratings for the two channel-stability assessments considered earlier to ratings calculated using the modified potential-scour index. Potential-scour ratings were developed for the same two bridges using the modified potential-scour index. A listing of the index variables and respective ranking values for both bridges are shown in table 2.

Table 2. Index variables, ranking values, and potential-scour ratings for bridges W0703 and W1011 using the modified potential-scour index

Index variable	Ranking Value	
	Bridge W0703	Bridge W1011
Type of bed material	1.00	4.25
High-flow angle of approach	3.00	2.00
Location of high-flow meander-impact point	1.00	1.00
Percentage of channel constriction at bridge	5.00	1.00
Percentage of debris blockage (total)	4.00	5.00
Stage of channel evolution	3.00	3.00
Protected channel bed	3.00	1.00
Type of bank material, left bank, upstream	1.50	1.50
Type of bank material, right bank, upstream	1.50	1.50
Type of bank material, left bank, downstream	1.50	1.50
Type of bank material, right bank, downstream	1.50	1.50
Bank erosion on left bank, upstream	3.00	3.00
Bank erosion on right bank, upstream	2.00	1.50
Bank erosion on left bank, downstream	2.00	3.00
Bank erosion on right bank, downstream	3.00	2.00
Mass wasting at left bank pier, bent, or abutment	4.00	4.00
Mass wasting at right bank pier, bent, or abutment	4.00	4.00
Number of piers or bents in stream channel	1.00	3.00
Number of piers or bents in stream channel with skew	1.00	3.00
Largest skew angle on any pier or bent	3.00	5.00
Location of left abutment	2.00	1.00
Location of right abutment	2.00	1.00
Skew angle on left abutment	5.00	2.00
Skew angle on right abutment	3.00	2.00
Percentage of woody-vegetative cover, left bank, upstream	2.50	1.00
Percentage of woody-vegetative cover, right bank, upstream	2.00	1.50
Percentage of woody-vegetative cover, left bank, downstream	3.00	1.00
Percentage of woody-vegetative cover, right bank, downstream	3.00	1.00
Potential-scour rating	71.50	62.25

The difference in ranking values for the pier-related and channel-constriction index variables are the same when using either the Maryland index or the modified potential-scour index. However, with the addition of index variables for abutment locations, abutment skew, and woody-vegetative cover on the channel banks, the modified potential-scour index significantly reduces the potential-scour rating for bridge W1011 relative to bridge W0703. Therefore, the modified potential-scour index produces potential-scour ratings that are more consistent with the scour conditions observed at these bridges. This example also illustrates the need to consider the potential for abutment scour in addition to pier scour.

SUMMARY AND CONCLUSIONS

A modified potential-scour index was developed to assess the potential for scour at bridges over waterways. The modified potential-scour index is based on a potential-scour index originally used by the USGS Maryland District and the prototype index developed by the USGS Tennessee District. The modified potential-scour index provides a more extensive set of index variables for assessment of potential scour at bridges than the Maryland index or the Tennessee index.

The Maryland index places significant emphasis on the presence of pier or bent skew and does not consider the magnitude of pier or bent skew, or the potential for abutment scour. The modified potential-scour index includes new index variables for the number of piers or bents in the stream channel with skew, the magnitude of pier or bent skew, abutment locations, abutment skew, the type of bank material composing the channel banks, and the percentage of woody-vegetative cover on the channel banks. The modified potential-scour index also considers bank-erosion index variables in greater detail than the Maryland index.

A comparison of potential-scour ratings from the modified potential-scour index, as applied to two bridges, indicates that the modified potential-scour index produces potential-scour ratings that more consistently reflect scour conditions observed at these bridges. However, potential-scour ratings from any potential-scour index depend on numerous combinations of ranking values for many different index variables. The potential for scour at a bridge can depend on any one index variable or combination of index variables. The individual ranking values that compose the potential-scour rating must be analyzed to determine which index variables contribute the most to reducing the potential-scour rating.

REFERENCES CITED

Doheny, E.J., 1993, Relation of channel stability to scour at highway bridges over waterways in Maryland: Proceedings, American Society of Civil Engineers National Conference on Hydraulic Engineering, July 26-30, 1993, San Francisco, Calif., v. 2, p. 2243-2248.

Doheny, E.J., Helinsky, B.M., and McGregor, R.A., 1996, A technique for preliminary appraisal of potential and observed scour as applied to state-maintained highway bridges in Maryland: U.S. Geological Survey Open-File Report 95-135, 75 p.

Simon, A., Outlaw, G.S., and Thomas, Randy, 1989, Evaluation, modeling, and mapping of potential bridge-scour, West Tennessee: National Bridge-Scour Symposium, October 17-19, 1989, Federal Highway Administration, McLean, Va., 18 p.