Risk-costs for Scour at Unknown Bridge Foundations

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Abstract

A risk method sets priorities for bridge foundation information gathering. Scour failure risk is the product of failure cost and the probability of failure. The method is based on data (much of which is subjective) in the National Bridge Inventory, NBI. Risk determines the ranking of bridges for foundation data gathering in support of scour evaluation; high risks could vanish if substantial foundations are discovered.

Summary and Conclusions

Risks are the expected value of losses associated with rebuilding, additional running costs over detours, and lost time. Losses depend upon an assumption of how long a failed bridge will take to be repaired. This time is assumed to be inversely related to traffic volume. Losses are based on a bridge failure outcome.

Risks weight the economic outcome with a failure probability. The methods assume the unknown foundations are poor to begin with. Subjective failure probabilities are calculated as a function of overtopping frequency,

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substructure and channel conditions noted by inspectors. The logic is exact at the limits of possibilities and will accurately identify higher and lower risks.

Application of the method to an example subset of NBI[4] bridges gives reasonable risk ranked results. The method is sensitive to traffic and detour length.

The red book economic parameters[5] of the method are: value of lost time; occupancy rate; detour speed; running costs; and, bridge rebuilding costs.

The items of the method within the NBI data base are: functional class (#26); ADT (#29): substructural condition (#60); channel protection (#61); waterway adequacy (#71); year built (#27); width (#52); length (#49); and detour length (#19).

The conclusions are:

1. The NBI data base plus a few economic parameters generates a risk ranked list of bridges based on failure by scour. The risks assume that the unknown foundations are poor (shallow or susceptible to scour).

2. Subjective determinations are needed to cope with the limitations of the NBI data base which was designed for national defense purposes, is utilized for maintenance, and now is being applied to scour.

3. The NBI data base now considers scour with the inclusion of item 113. The risk-based method can prioritize projects for information gathering pending item 113 updates.

4. The risk-based method adapts to the case where the foundations are known in order to generate rankings that are related to provision of countermeasures.

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[4]FHWA, Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, Bridge Division, 1988.

[5]AASHTO, A Manual on User Benefit Analysis of Highway and Bus Transit Improvements, 1977.

5. Timely implementation of this method should be sought for rationally directing scarce information gathering and analyzes resources. Computerization is indicated.

The Model

The model logic is shown in Figure 1:

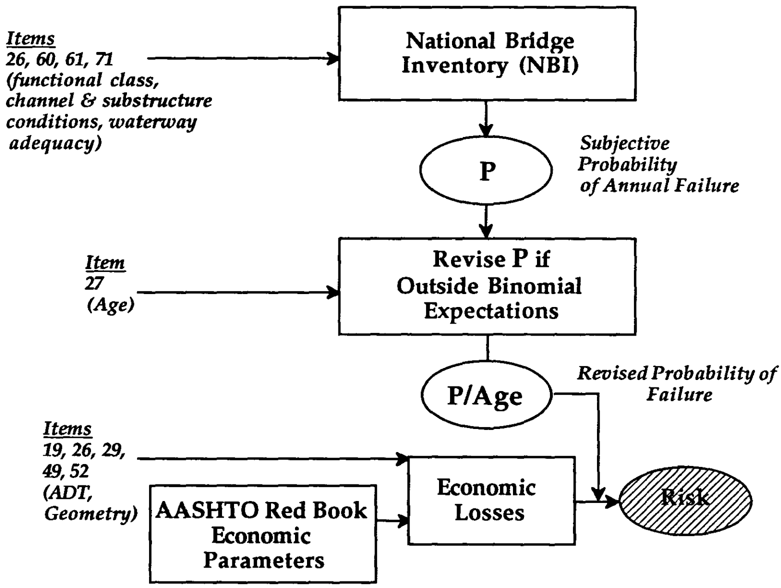

Figure 1. Flowchart for Risk Methodology in Unknown Foundation Prioritization

The risk is calculated as the product of the probability of scour failure given generally inadequate foundations and the losses associated with failure. Risk is the expected value of the loss. The three categories of costs used in the model include:

1. Rebuilding cost;
2. Additional running cost; and
3. Additional time cost.

Property damage, injury, and death costs can be high but when weighted by probability, their risks are negligible compared with the other risks. Risk is calculated as:

$$\text{Risk} = KP\,[\underbrace{C_1\,WL}_{\text{Rebuilding Cost}} + \underbrace{C_2\,DAd}_{\text{Running Cost}} + \underbrace{(C_3O(1 - T/100) + C_4\,T/100)\,DAd/S]}_{\text{Time Cost}}$$

where:

Risk	=	risk of scour failure, \$/year;
K	=	risk adjustment factor;
P	=	annual probability of failure (based on NBI items 26, 60, 61, 71), year^{-1};
C_1	=	rebuilding cost, \$60/ft^2;
W	=	bridge width, ft (NBI item 52);
L	=	bridge length, (NBI item 49);
C_2	=	cost of running vehicle (\$0.25/mi);
D	=	detour length, mi (NBI item 19);
A	=	ADT (NBI item 29);
d	=	duration of detour, days (based on ADT-NBI item 29);
C_3	=	value of time per adult in passenger car, \$7.05/hr (1991);
O	=	average occupancy rate, 1.56 adults;
T	=	average daily truck traffic, % of ADT (NBI item 109);
C_4	=	value of time for truck, \$20.56/hr (1991); and
S	=	average detour speed, 40 mph.

Subjective Probabilities

The subjective probability of scour failure is estimated based on waterway adequacy (NBI item 71) functional classification (NBI item 26), substructure condition (NBI item 60), and channel protection (NBI item 61). The waterway adequacy and functional classification are used to determine the overtopping frequency, as described in NBI instructions.

If one knows the overtopping frequency, say 0.01, one also knows the frequency that the bridge opening is full of water. This full condition also represents maximum depth since higher flow will be accommodated by embankment overtopping without large depth increases. The logic derives the frequencies of less than full flow depths using USGS regional regression equations and proportionalities implied by Manning's equation.

With the probability of failure given scour vulnerability and depth, and the probability of depth given overtopping frequency, the probability of failure given overtopping frequency and scour vulnerability is determined as follows:

$$P\,(F|(OT \text{ and } SV)) = \sum_{D} P\,(D|OT)\; P\,(F|(SV \text{ and } D)$$

where:

F = failure;
OT = overtopping frequency;
SV = scour vulnerability; and
D = dimensionless depth.

The above expression weights failure over the five depth ranges, eliminating depth as a variable. The probability results are given in Figure 2.

Bridge age (calculated from NBI item 27-year built) is used as a reality check on the probability of scour failure. The reciprocal of the probability of scour failure is the mean time to scour failure. The mean time is compared to the age of the bridge; demonstrated longevity is used to reduce failure probability.

Example

The methodology was applied to 78 bridges over water within one mid-Atlantic Seaboard county. The bridges were then sorted from high to low risk, ranging from $1.5 million to $635. This ranking is depicted in Figure 3. Many of the high risk bridges have high ADTs and long detour lengths, both of which influence running costs and time loss costs. The six highest risk bridges have ADTs over 10,000 and 17 of the 24 highest risk bridges have detour lengths of 10 miles or more. In this example, running costs and time loss costs dwarf rebuilding costs for most of the high risk bridges; ADT and detour length are important parameters.

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	Overtopping Frequency (items 26, 71)			
Scour Vulnerability (Items 60 & 61)	***Remote (0.01)***	***Slight (0.02)***	***Occas. (0.20)***	***Freq. (0.50)***
0 (Bridge failure)	**1.00**	**1.00**	**1.00**	**1.00**
1 (Bridge closed)	**1.00**	**1.00**	**1.00**	**1.00**
2 (Extremely vulnerable)	**0.37**	**0.40**	**0.59**	**0.71**
3 (Unstable foundations)	**0.20**	**0.22**	**0.37**	**0.49**
4 (Action required)	**0.10**	**0.11**	**0.21**	**0.29**
5 (Fair condition)	**0.04**	**0.05**	**0.12**	**0.18**
6 (Satisfactory condition)	**0.01**	**0.02**	**0.06**	**0.11**
7 (Good condition)	**0.002**	**0.01**	**0.03**	**0.06**
8 (Very good condition)	**0.002**	**0.002**	**0.01**	**0.03**
9 (Excellent condition)	**0.002**	**0.002**	**0.002**	**0.01**
N (Not over water)	**0.002**	**0.002**	**0.002**	**0.002**

Figure 2. Probability of Failure Given Overtopping Frequency and Scour Vulnerability

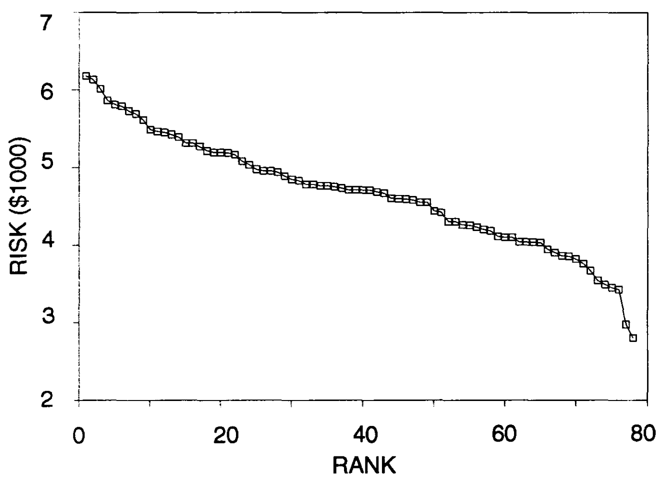

Figure 3
Risk Versus Rank