Risk-Based Approach for Bridge Scour Prediction: Applications for Design

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National Hydraulic Engineering Conference
August 2014
Iowa City, Iowa

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NCHRP Project 24-34

- **Project Time Line:** May 2010 - March 2013
- **Research Team:** P.F. Lagasse (PI), M. Ghosn (Co-PI), P.A. Johnson (Co-PI), L.W. Zevenbergen, P.E. Clopper
- **NCHRP Report 761** "Reference Guide for Applying Risk and Reliability – Based Approaches for Bridge Scour Prediction" (Published September 2013)
- **Final Report** – Web Only Document (TRB)

NCHRP 24-34 Objectives

- Develop a risk/reliability-based methodology to link scour estimates to a probability
- Statistical procedures should be consistent with LRFD approaches used by structural and geotechnical engineers

Results Applicable to Design

- Detailed analysis of available data sets to establish bias and COV for commonly used scour equations (HEC-18 Pier Scour, FDOT Pier Scour, HEC-18 Contraction Scour, NCHRP 24-20 Abutment Scour)
- Integration of HEC-RAS and Monte Carlo simulation techniques (rasTOOL™)
- 27-element matrix considering 3 levels of hydrologic uncertainty, 3 bridge size ranges, and 3 pier size ranges (3x3x3 = 27 combinations)

Results Applicable to Design (cont'd)

- **"Scour Factor"** tables for conditional (single event) probability of exceedance for Q_{100} scour design event
- Required 300,000 HEC-RAS/Monte Carlo simulations and 1.2M off-line scour calculations
- A procedure was developed for determining unconditional probability over selected service life of bridge
- Five example applications using scour factor tables for a variety of actual bridge conditions

Design Steps

1. Perform hydrologic and hydraulic analyses, and calculate scour (e.g., contraction, pier, abutment scour)
2. Identify category for bridge size, hydrologic uncertainty, and pier size
3. Look up scour factors from appropriate table
4. For a selected level of reliability, apply equation bias and scour factors, and then determine total design scour

Example Bridge

Example Bridge Conditions

- **Bridge length = 1,715 ft**
- **Q_{100} = 401,000 cfs**
- **Hydraulic model : HEC-RAS**
- **Pier type/geometry : 11 ft. dia. drilled shaft**
- **Abutment type/location – spill-through on floodplain behind levee (abutment scour considered negligible)**

Q_{100} Design Scour Depths

Table 7.5.2. 100-Year Design Scour Depths.				
Pier Scour (ft)	Contraction Scour (ft)	Total Scour (ft)	Abutment Total Scour (ft)	
			Left	Right
44.1	2.3	46.4	0.0	0.0

Bridge Size and Pier Size

Table 6.1 Bridge and Pier Geometry for Typical Bridges.

	Bridge Length (ft)		**Pier Size (ft)**		
Bridge Size	Range	Monte-Carlo	Small	Medium	Large
Small	< 100	50	1	2	3
Medium	100 – 300	180	1.5	3	4.5
Large	> 300	1200	3	6	9

Hydrologic Uncertainty (95% Confidence Limits)

- Q_{100} = 401,000 cfs
- Q_{upper} = 458,000 cfs
- Q_{lower} = 350,000 cfs

Discharge COV (lognormal) = 0.006

Table 7.5.3. Hydrologic Uncertainty as Function of Annual Exceedance Probability.				
Annual Exceedance		Discharge COV (lognormal)		
p(X>x)	T (years)	**Low**	Medium	High
0.04	25	0.009	0.014	0.018
0.02	50	0.010	0.015	0.019
0.01	**100**	**0.011**	0.016	0.021
0.005	200	0.012	0.017	0.022
0.002	500	0.013	0.018	0.023

Select Appropriate Scour Factor Table

- We have a ***large bridge*** with ***low hydrologic uncertainty*** and ***large piers***

- This combination leads us to Table B.21 in the 27-element matrix

Scour Factor Table (B.21)

Table B.21	Large Bridge - Low Hydrologic Uncertainty - Large Pier					
	Pier Scour (HEC-18)	Pier Scour (FDOT)	Contraction Scour	Total Scour (HEC-18)	Total Scour (FDOT)	Abutment Scour
Design Scour (ft)	17.93	15.90	5.29	23.22	21.19	10.96
Expected Scour (ft)	12.19	11.89	4.95	17.14	16.84	8.28
Bias	0.68	0.75	0.93	0.74	0.79	0.76
Std. Dev. (ft)	1.97	2.13	1.93	2.93	2.96	3.24
COV	0.16	0.18	0.39	0.17	0.18	0.39
Design Scour β	2.91	1.89	0.18	2.08	1.47	0.83
Non-Exceedance	0.9982	0.9704	0.5711	0.9811	0.9296	0.7961
Scour factors based on Monte Carlo results						
β = 0.5 (0.6915)	0.74	0.81	1.08	0.80	0.86	0.87
β = 1.0 (0.8413)	0.79	0.88	1.30	0.86	0.93	1.05
β = 1.5 (0.9332)	0.85	0.95	1.52	0.93	1.01	1.24
β = 2.0 (0.9772)	0.90	1.02	1.77	1.00	1.09	1.43
β = 2.5 (0.9938)	0.95	1.08	2.04	1.08	1.18	1.66
β = 3.0 (0.9987)	0.99	1.13	2.37	1.16	1.26	1.96

Scour Factor Table (B.21)

- For 1st design iteration select a high reliability index (Beta = 3.0)
- Beta = 3.0 has a probability of non-exceedance of 0.9987 for Q_{100})

Scour Factors for Beta = 3.0

Table 7.5.6. 100-Year Scour Results for $\beta = 3.0$ (Using Monte Carlo Results).

	Pier Scour	Contraction Scour	Total Scour	Abutment Total Scour	
				Left	Right
Design Scour (ft)	44.1	2.3	**46.4**	0.0	0.0
Bias	0.68	0.93			
Expected Scour (ft)	30.0	2.1	32.1		
Scour Factor	0.99	2.37			
Component Scour for $\beta = 3.0$ (ft)	43.7	5.5			
Difference from Expected (ft)	13.7	3.4	14.1		
Total Scour for $\beta = 3.0$ (ft)			**46.2**		

PNE = 0.9987

Scour Factors for Beta = 2.0

Table x.x. 100-Year Scour Results for β = 2.0 (Using Monte Carlo Results).

	Pier Scour	Contraction Scour	Total Scour	Abutment Total Scour	
				Left	Right
Design Scour (ft)	44.1	2.3	**46.4**	0.0	0.0
Bias	0.68	0.93			
Expected Scour (ft)	30.0	2.1	32.1		
Scour Factor	0.90	1.77			
Component Scour for β = 2.0 (ft)	39.7	4.1			
Difference from Expected (ft)	9.7	2.0	9.9		
Total Scour for β = 2.0 (ft)			**42.0**	**9% reduction**	

PNE = 0.9772

Scour Factors for Beta = 1.0

Table y.y. 100-Year Scour Results for $\beta = 1.0$ (Using Monte Carlo Results).

	Pier Scour	Contraction Scour	Total Scour	Abutment Total Scour	
				Left	Right
Design Scour (ft)	44.1	2.3	**46.4**	0.0	0.0
Bias	0.68	0.93			
Expected Scour (ft)	30.0	2.1	32.1		
Scour Factor	0.79	1.30			
Component Scour for $\beta = 1.0$ (ft)	34.8	3.0			
Difference from Expected (ft)	4.8	0.9	4.9		
Total Scour for $\beta = 1.0$ (ft)			**37.0**	**20% reduction**	

PNE = 0.8413

Implementation of Risk Analysis in Design

- **FHWA risk analysis recommendations (HEC-18 Fifth Edition, 2012):**

Table 2.1. Hydraulic Design, Scour Design, and Scour Design Check Flood Frequencies.

Hydraulic Design Flood Frequency, Q_D	Scour Design Flood Frequency, Q_S	Scour Design Check Flood Frequency, Q_C
Q_{10}	Q_{25}	Q_{50}
Q_{25}	Q_{50}	Q_{100}
Q_{50}	Q_{100}	Q_{200}
Q_{100}	Q_{200}	Q_{500}

Implementation of Risk Analysis in Design

- **Conditional Probability:** Need additional scour factor tables for scour design flood frequencies Q_{25}, Q_{50}, Q_{200}, and Q_{500} to fully implement FHWA risk analysis recommendations of HEC-18 (2012)
- **Unconditional Probability:** Need streamlined integration procedure to determine reliability over service life of bridge

THANK YOU !

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