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Possibilities of application of HEC RAS two-dimensional models for prediction of bridge pier scour

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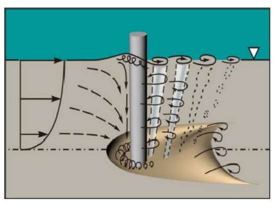
Introduction

- As a result of current intensive infrastructural development and construction in Montenegro, more roadways are being built over rivers.
- One of the most common causes of bridge failure is the bridge scour occuring at the foundation.
- Taking this effect into account is of crucial importance for bridge design and construction.
- Various methods for estimating scour depth around a bridge pier have been developed so far.
- Through the use of two-dimensional numerical flow models, suitable results can be obtained, that would be applicable for further analysis of erosion effects.

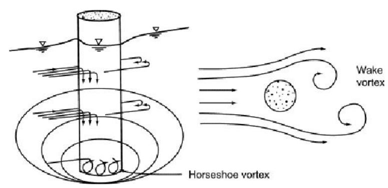
Erosion effects on bridge pier positioned in the streambed

Theoretical background

- Scour – the removal of sediment (soil and rocks) from stream beds and stream banks caused by moving water.
- Pier scour is closely related to the flow field at a pier – a three-dimensional unsteady flow field marked by interacting turbulence structures.
- The horseshoe vortex at the bridge pier base is the result of the current impact on the upstream pier surface (which represents an obstacle) and then the acceleration of the flow in front of the pier nose. The vortex moves the sediment from the foundation zone of the pier, and thus an erosion hole is formed.



The main flow features forming the flow field at a narrow pier of circular cylindrical form



Horseshoe and wake vortex around cylindrical bridge pier

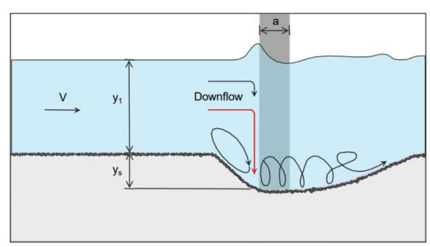
Theoretical background

- HEC18 methodology:

$$\frac{y_s}{a} = 2.0K_1K_2K_3\left(\frac{y_1}{a}\right)^{0.35} Fr_1^{\,0.43}$$

Where:

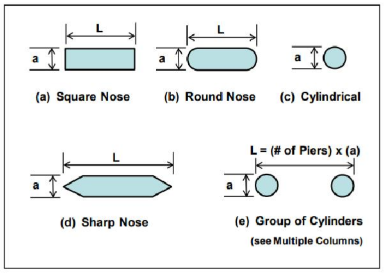
y_s	- scour depth (m)
y_1	- flow depth directly upstream of the pier (m)
K_1	- correction factor for pier nose shape
K_2	- correction factor for angle of attack of flow
K_3	- correction factor for bed condition
a	- pier width (m)
L	- length of pier (m)
Fr_1	- Froude number directly upstream of the pier = $V_1/(gy_1)^{1/2}$
V_1	- mean velocity of flow directly upstream of the pier (m/s)
g	- acceleration of gravity (9.81m/s^2)



Schematic presentation of variables in the equation

Theoretical background

- HEC18 methodology for scour prediction



Different pier shapes

Table 7.1. Correction Factor, K_1, for Pier Nose Shape.

Shape of Pier Nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Group of cylinders	1.0
(e) Sharp nose	0.9

Table 7.2. Correction Factor, K_2, for Angle of Attack, θ, of the Flow.

Angle	L/a=4	L/a=8	L/a=12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0

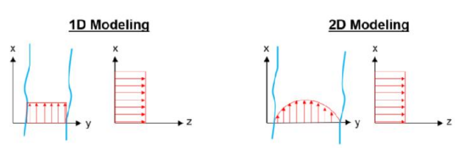
Angle = skew angle of flow
L = length of pier

Table 7.3. Increase in Equilibrium Pier Scour Depths, K_3, for Bed Condition.

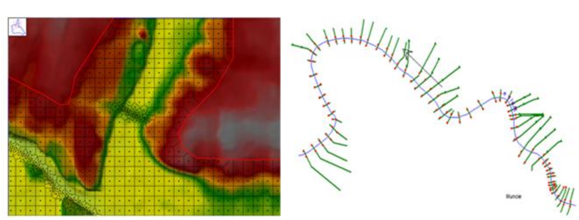
Bed Condition	Dune Height ft	K_3
Clear-Water Scour	N/A	1.1
Plane bed and Antidune flow	N/A	1.1
Small Dunes	$10 > H \geq 2$	1.1
Medium Dunes	$30 > H \geq 10$	1.2 to 1.1
Large Dunes	$H \geq 30$	1.3

Theoretical background

- 2D hydraulic models, thanks to suitable terrain data, provide the possibility to determine the direction of water flow when it is not possible to determine it in advance unambiguously.
- Application of 2D models: urban areas, wide floodplains, dam-break studies, areas around bridges...
- HEC RAS (Hydrological Engineering Center's River Analysis System) - modeling flow in open channels with possibility of building two-dimensional hydraulic models
- Solving the hydrodynamic equations along two dimensions.



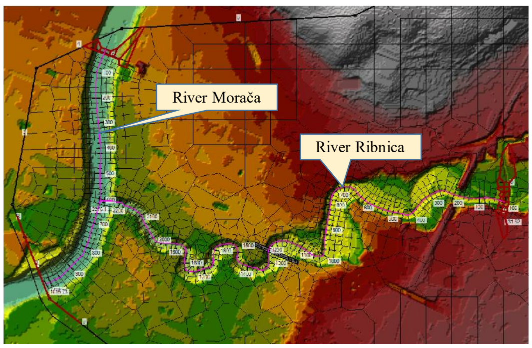
Difference between 1D and 2D models



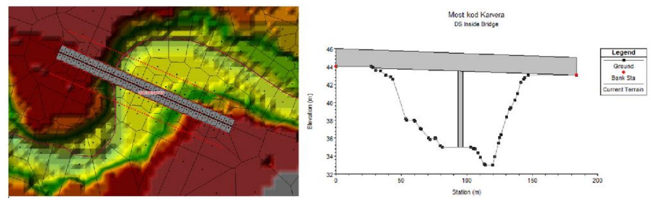
2D and 1D model in HEC RAS

Building the hydraulic model

- Two-dimensional model of part of the river Ribnica (right tributary of the river Morača in the urban zone of Podgorica)
- Input parameters: terrain data, external and internal boundary conditions, bridge geometry data...



Modeled part of the river



Bridge input data

Building the hydraulic model

- Debris buildup modeling – assumptions for debris accummulation geometry
- Prediction of the change in water surface from just downstream of the bridge to just upstream of the bridge – Yarnell equation :

$$H_{3-2} = 2K(K + 10\omega - 0.6)(\alpha + 15\alpha^4)\frac{V^2}{2g}$$

Where:

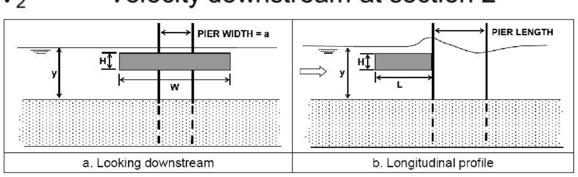
H_{3-2} - drop in water surface elevation from section 3 to section 2

K - Yarnell's pier shape coefficients

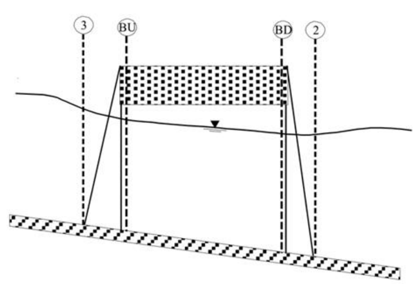
ω - ratio of velocity head to depth at section 2

α - obstructed area of the piers divided by the total unobstructed area at section 2

V_2 - velocity downstream at section 2



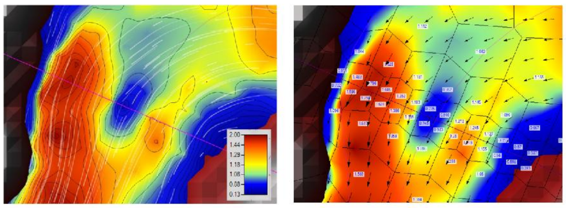
Rectangular debris formation



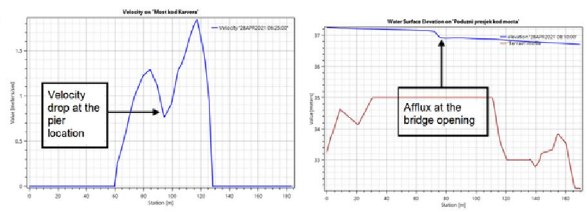
Cross section inside the bridge

Computation results

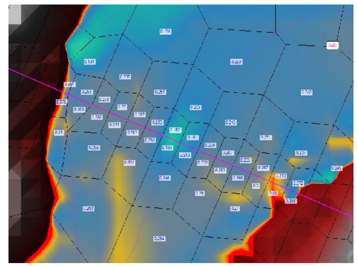
- Flow field around the pier



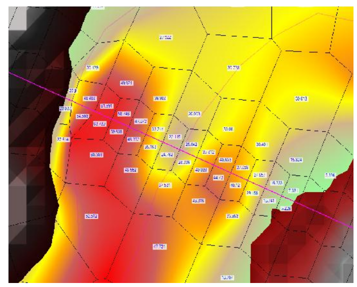
Map of streamlines around the bridge pier and velocity vectors with velocity values



Velocity distribution along the bridge cross section and longitudinal profile plot with water surface elevation



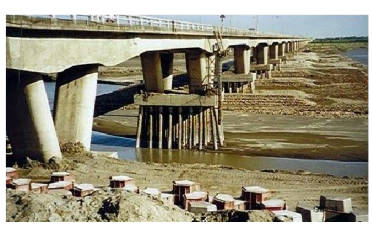
Froude number around the bridge pier



Shear stress distribution around the bridge pier

Conclusion

- Various empirical equations for evaluation of local scour around bridge piers have been developed.
- Most commonly used variables include: flow depths (in the bridge profile), flow velocities, shear stress, Froude number and Reynolds number as an indicator of turbulence...
- Twodimensional hydraulic analysis in specialised software for open flow modeling (such as HEC RAS) can provide useful and more realistic values of basic hydraulic flow parameters.
- Model calibration and verification are necessary in order to use the model for predictive purposes.



Scour holes compromise the integrity of a structure

Conclusion

THANK YOU FOR YOUR ATTENTION !