CHALLENGES AND FUTURE POTENTIAL APPLICATIONS OF CFD IN RESTORATION HYDRAULICS

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INTRODUCTION

This paper focuses on emerging hydrodynamics and sediment transport questions in restoration infrastructure that can potentially be addressed by CFD simulations. These include:

- Hydraulic downpull on spillway gates
- Depth and extent of scour downstream of hydraulic structures
- Role of pressure fluctuations in structure failure
- 3D simulations of vegetated flows
HYDRAULIC DOWNPULL

The hydraulic downpull is a downward hydrodynamic force on high head spillways gates that is caused by a localized flow acceleration, and associated pressure drop, at or near the gates lips.

Its accurate estimate is important for a proper design of the lifting (hoist) mechanism of the gates. A properly designed hoist mechanism can withstand the hydraulic downpull, the weight of the gate, and the weight of the fluid above it. Previous studies have shown the hydraulic downpull is affected by:

- Geometry of the gates
- Flow and velocity field underneath of the gates
EXAMPLE OF PAST CFD APPLICATIONS IN ESTIMATING HYDRAULIC DOWNPULL

Figure 3.4 Mesh around the gate

Figure 3.5 Mesh around gate and parts of upstream and downstream

Figure 3.22 Velocity magnitude distribution for (A) $\theta=26.5^\circ$, $y=0.4$, $Q=0.0947$ m$^3$/s, (B) $\theta=36.7^\circ$, $y=0.4$, $Q=0.0997$ m$^3$/s, (C) $\theta=44.7^\circ$, $y=0.4$, $Q=0.0955$ m$^3$/s, (D) $\theta=51.6^\circ$, $y=0.4$, $Q=0.0953$ m$^3$/s
\[ D_p = \gamma_w \cdot K_L \cdot A \cdot H \]

where

\( D_p \) = Downpull force on the gate
\( \gamma_w \) = Specific weight of water
\( K_L \) = Downpull force coefficient
\( A \) = Cross-sectional area
\( H \) = Operating head on the

Uysal (2014)
Potential Application: HYDRAULIC DOWNPULL @ C43
Reservoir outflow structures

Outflow structures (S471 & S473)
Estimated Downpull forces > 20,000 lbf
SCOUR DOWNSTREAM OF STRUCTURES

- Currently we use estimated velocities from CFD simulation to infer scour potential.
- Depth and extent of scour downstream of hydraulic structures is not directly estimated.
Another Erosion Potential Check: Location of the Hydraulic Jump

Application of CFD to estimate sedimentation in channel Bend

Scour takes place on the outer bank side

Deposition is observed near inner bank
Model Verification and Analysis
Water depth changes at representative sections

Advection-Dispersion Eqn. and Van Rijn (1987) Model are used for modeling sediment transport

\[ C_{b*} = 0.015 \frac{d_{50}^1 T^{1.5}}{a D_*^{0.5}} \]
Equilibrium Con.
Equilibrium bed load rate
\[ Q_{b*} = 0.053 (R_g)^{0.5} \left( \frac{d_{50}^{15} T^{2.1}}{D_*^{0.3}} \right) \]
Non Dim. Excess shear stress
\[ \tau = \tau - \tau_{cr} = \left( \frac{(u^*)^2 - (u_{cr})^2}{(u^*)^2} \right) \]
\[ R = \rho_f / \rho - 1 \] is the reduced gravity.

the non-dimensional particle-size diameter is \( D_0 = d_{50} R_g k \)

- The newly developed model predicts well the change of water depth in various sections along the channel.
- Sparlat-Allmaras (SA) model with total load give a slightly better predictions compared with other simulation results.
- Without considering the bed slope effect, the outer bank scour inner bank deposition are over-predicted.

For \( \theta > 20^\circ \) triangular Shape
Short sand bar observed near inner bank
Maximum scour \( \theta \sim 50^\circ \)

J. Zeng (2006)
The stability of concrete slabs or rock blocks at plunge pool bottom of spillways (or at joints locations for segmented culverts) depends on the instantaneous pressure field.

This pressure propagates under lining elements through concrete fissures, open or failed joints, can generate an uplift force that can lead to dislodging of the lining.
Dynamic Pressure Field Analysis with DES model for S-375

Pressure fields in the culvert barrel at the times when the minimum (right) and maximum (Left) fluctuations occurred at a point 11 feet from the Gate

J. Zeng et al. (2009)
Pressure Fluctuations at Selected Locations

Pressures fluctuations can reach 11 psi

J. Zeng et al. (2009)
Damage analysis—Sand/soil erosion

The seepage and inner negative pressure lead to the loss of the sand/soil foundation after the joint failure.

J. Zeng et al. (2009)
FLOW PAST A CIRCULAR PATCH OF VEGETATION

-Von Karman vortex street is qualitatively similar to that observed past solid cylinders

SVF=20% (89 cylinders)

SVF=10% (44 cylinders)

Chang & Tsai (NHPC, Taiwan)
G. Constantinescu (Univ. of Iowa)
(RiverFlow 2016)
Flow past a surface-mounted porous cylinder

- MIT experiment for an emergent patch (Nepf, 2012)
- Solid Volume Fraction (SVF) = 13%
- 37 cylinders
- $H/D = 0.55$, $d/D = 0.06$, $H = 0.12$ m
- $Re = 30,000$, $Re_D = 60,000$
- Flat bed & Equilibrium scour

Main questions:

- What drives scour within and around the patch?
- Do necklace vortices form and do they play an important role in development of scour hole?

Chang & Tsai (NHPC, Taiwan)
G. Constantinescu (Univ. of Iowa)

(RiverFlow 2016)
Flow past a surface-mounted porous cylinder

Equilibrium bathymetry

Maximum scour occurs inside porous cylinder

No significant scour in front of porous cylinder

Bed friction velocity (FB)  Mean Bed friction vel Fluctuations at the bed (FB)

Chang & Tsai (NHPC, Taiwan)
G. Constantinescu (Univ. of Iowa)

(RiverFlow 2016)
CONCLUSIONS AND SUMMARY

CFD can be a powerful tool in addressing emerging restoration hydraulics issues, including:

• Hydraulic downpull on spillway gates - K-epsilon or K-Omega models
• Depth and extent of scour downstream of hydraulic structures
  - Implement Empirical/semi-empirical sediment transport equations in a CFD solver
  - Large Eddies Simulations (LES)
• Role of pressure fluctuations in structure failure - Detached Eddies Simulations (DES)
• 3D simulations of vegetated flows
  - Detached Eddies Simulations (DES)