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:

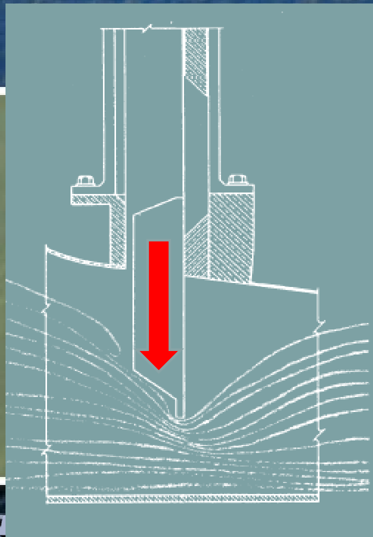
- Hydraulic downpull on spillway gates
- Depth and extent of scour downstream of hydraulic structures
- Role of pressure fluctuations in structure failure
- 3D simulations of vegetated flows

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

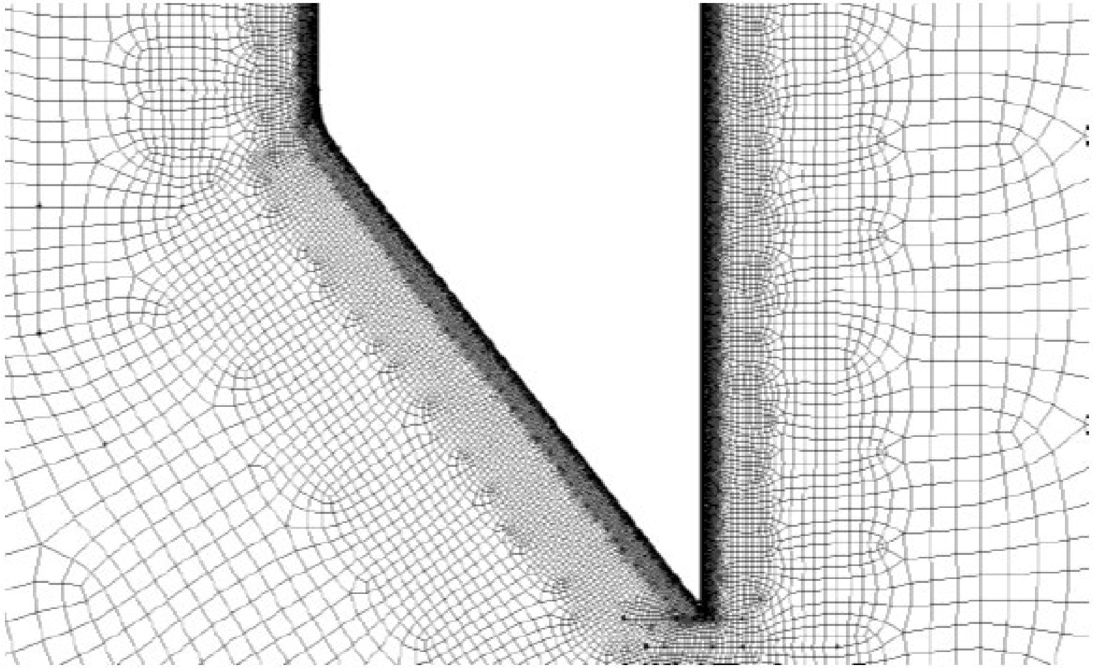


Figure 3.4 Mesh around the gate

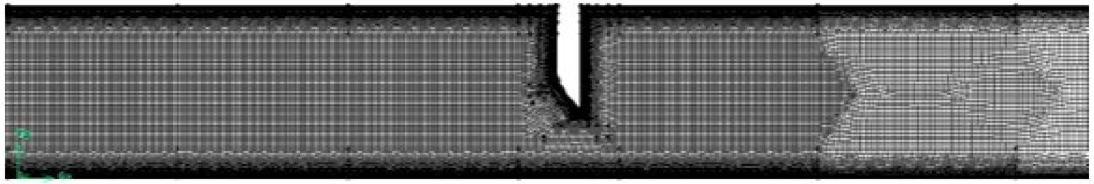


Figure 3.5 Mesh around gate and parts of upstream and downstream

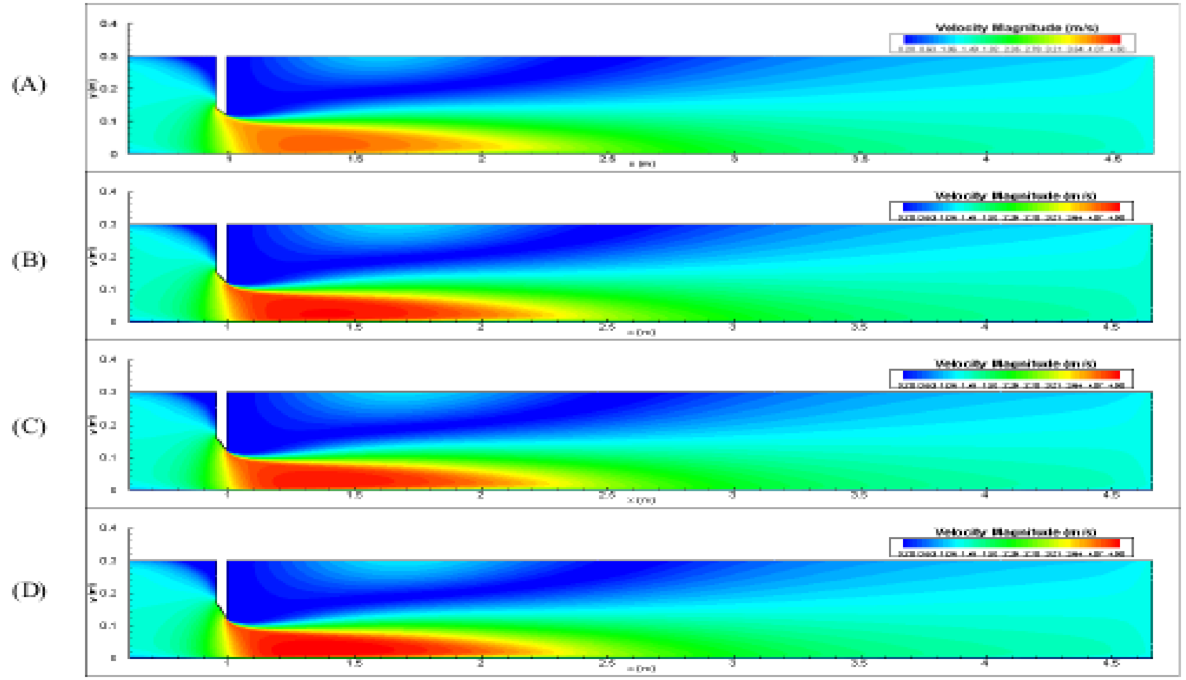


Figure 3.22 Velocity magnitude distribution for (A) θ=26.5°, y=0.4, Q=0.0947 m^3/s, (B) θ=36.7°, y=0.4, Q=0.0997 m^3/s, (C) θ=44.7°, y=0.4, Q=0.0955 m^3/s, (D) θ=51.6°, y=0.4, Q=0.0953 m^3/s

Uysal (2014)

$D_P = \gamma_w . K_L . A . H$

where

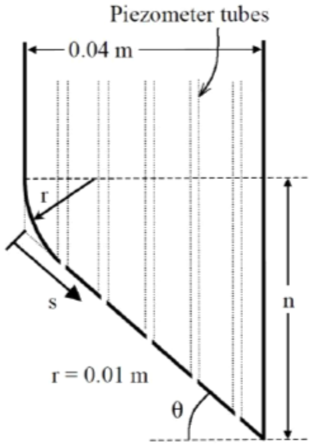
D_P = Downpull force on the gate

γ_w = Specific weight of water

K_L = Downpull force coefficient

A = Cross-sectional area (

H = Operating head on th



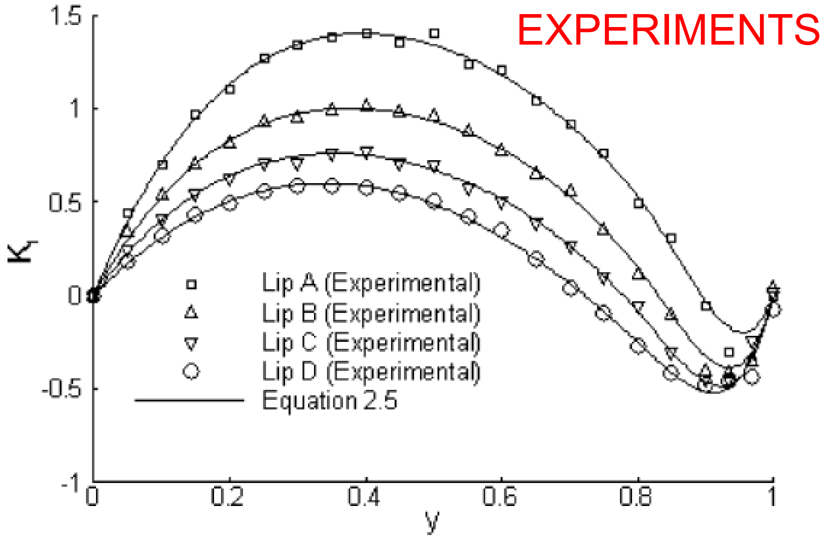


Figure 2.14 Downpull coefficient as a function of gate opening and gate lip angle (Aydin et al., 2003)

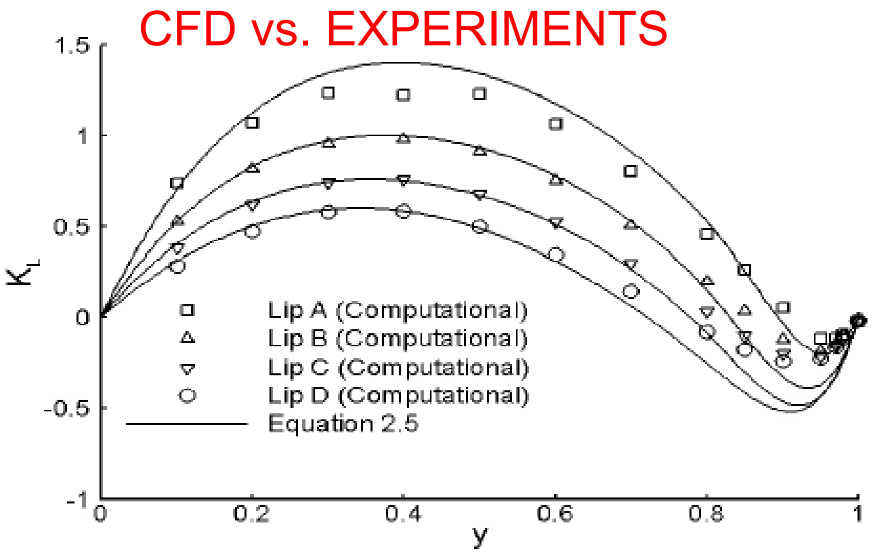


Figure 3.31 Downpull coefficient as a function of the gate lip angle and the gate opening (Computational and experimental comparison)

Table 2.1 Gate lip angles

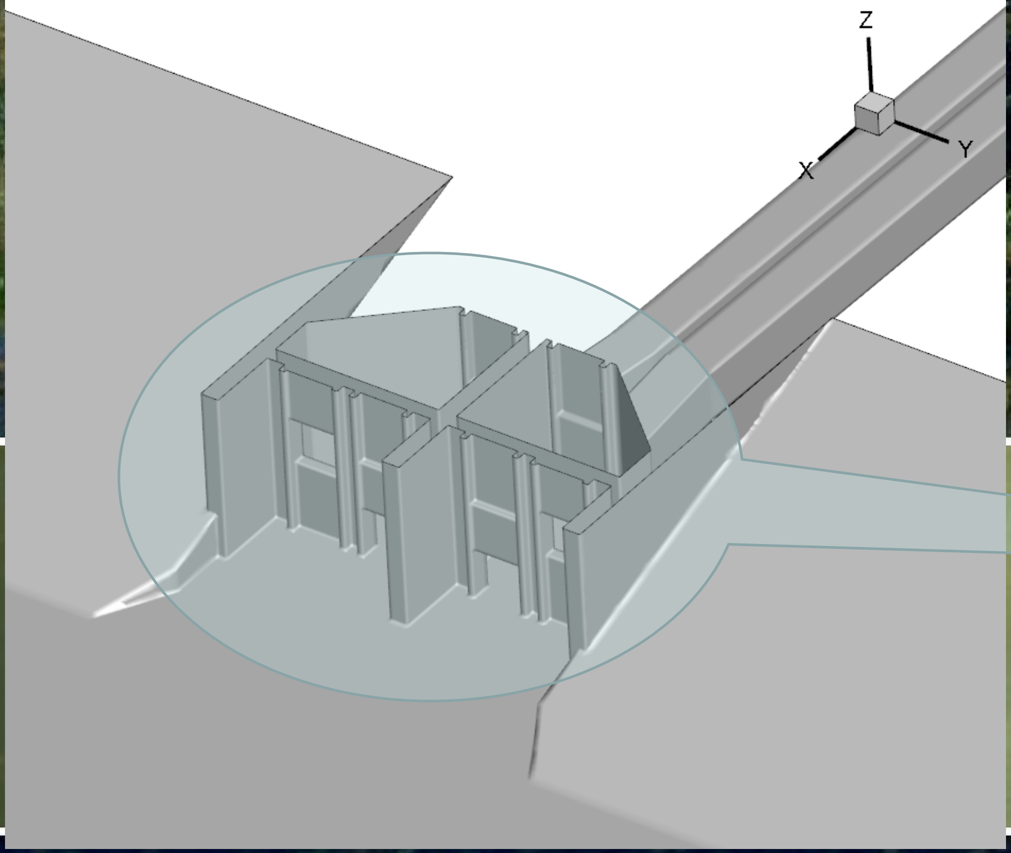
Lip Symbol	n (cm)	Lip angle, θ (degrees)
A	2	26.5
B	3	36.7
C	4	44.7
D	5	51.6

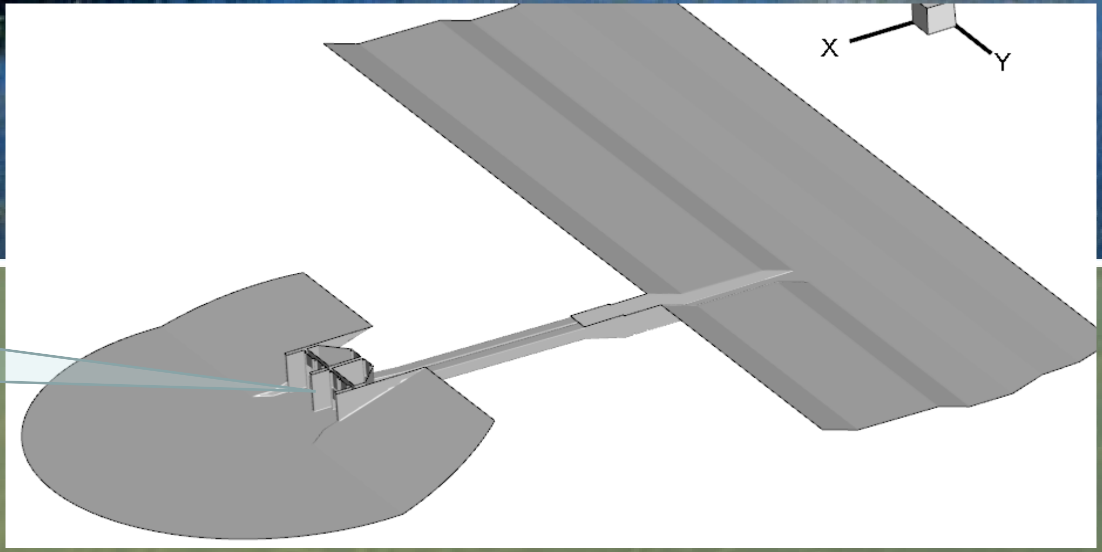
Uysal (2014)

Potential Application: HYDRAULIC DOWNPULL @ C43 Reservoir outflow structures

Outflow structures (S471 & S473)

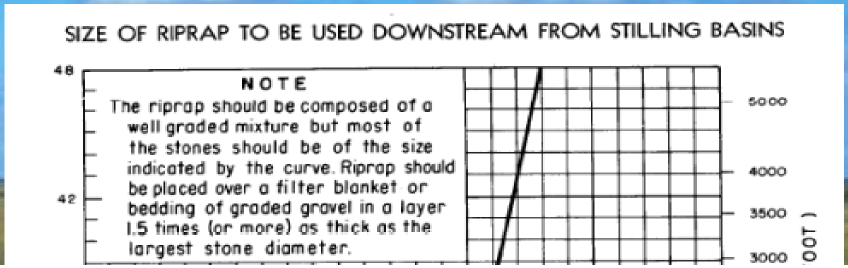
Estimated Downpull forces > 20,000 lbf

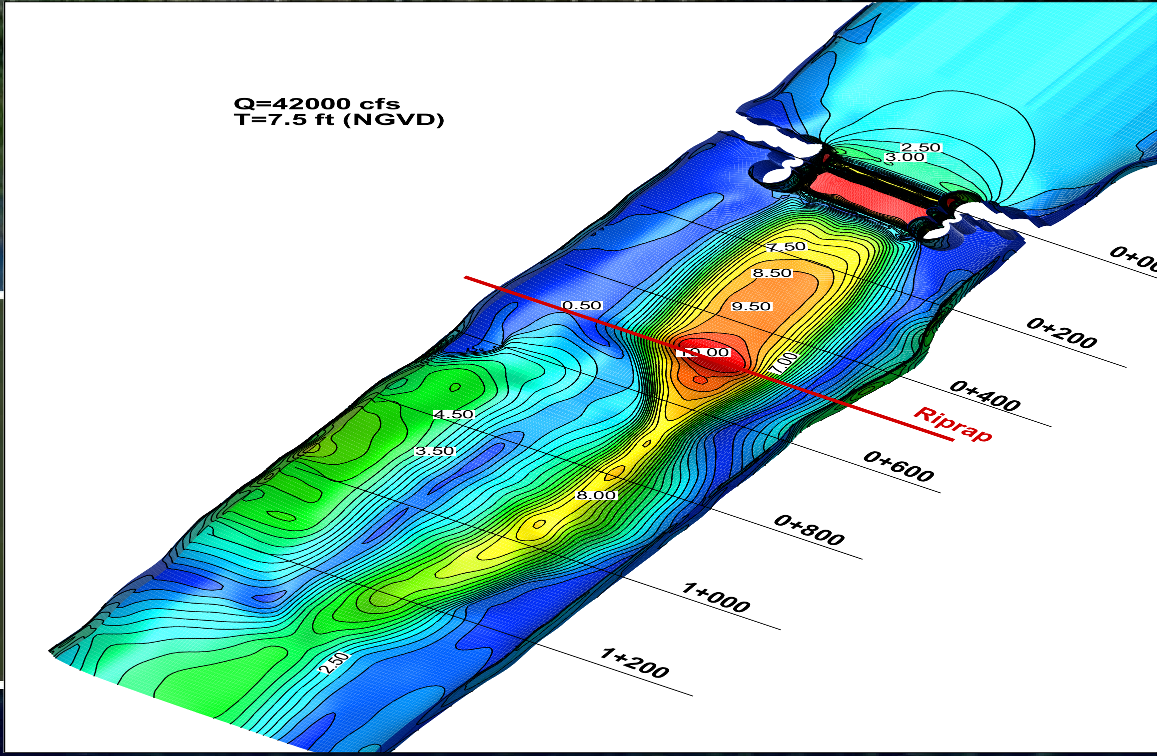


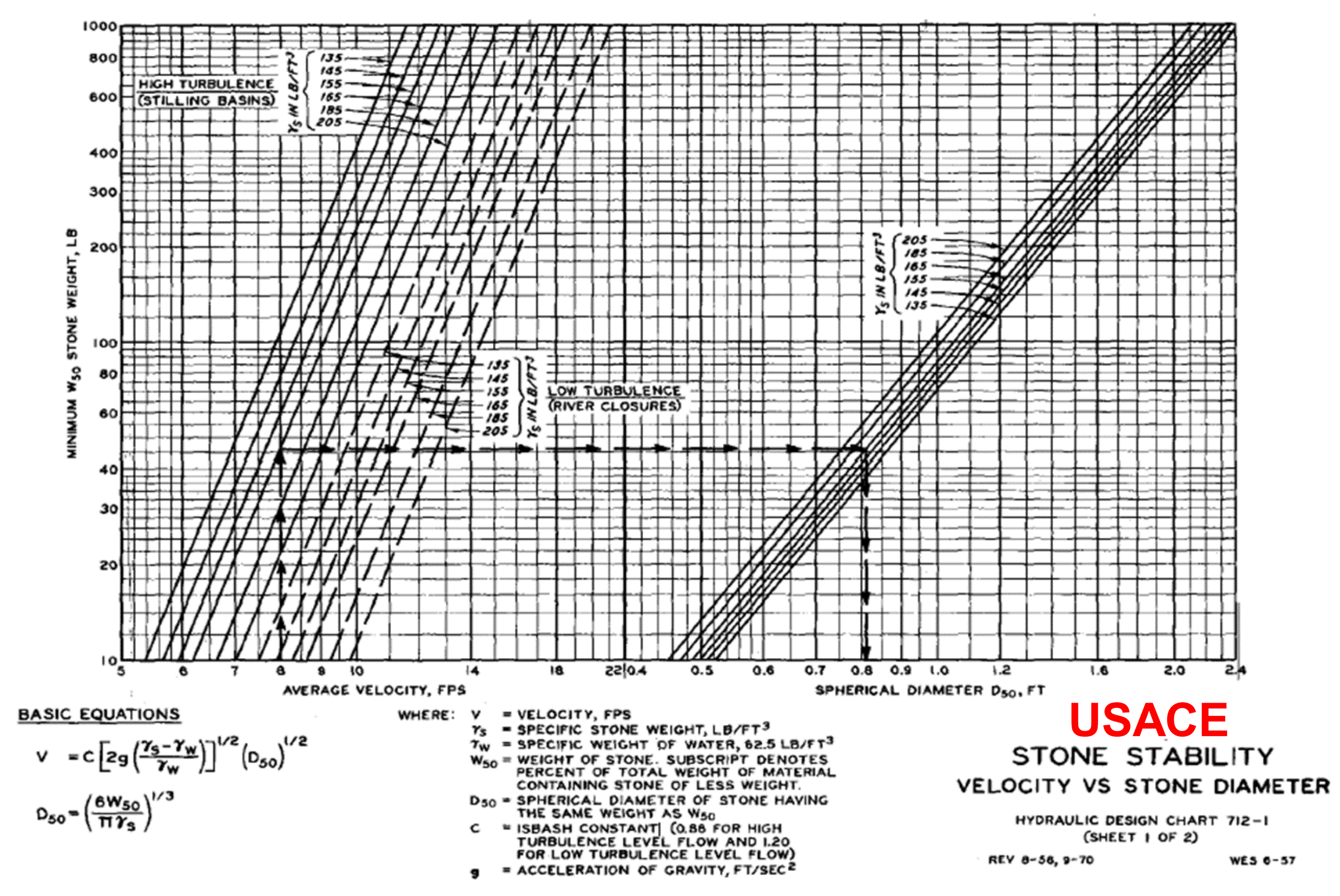


SCOUR DOWNSTREAM OF STRUCTURES

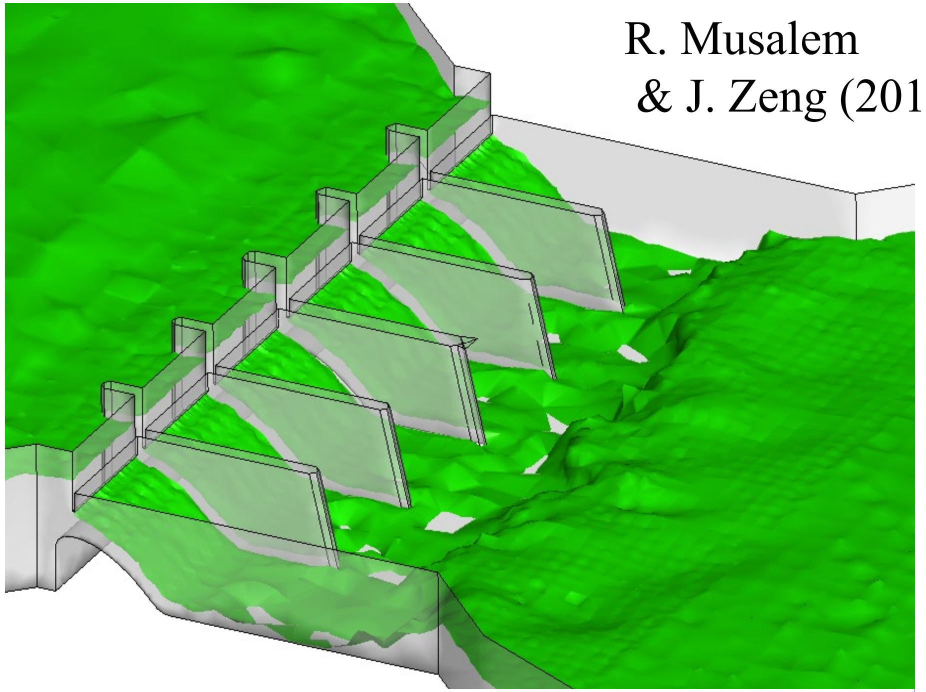
- Currently we use estimated velocities from CFD simulation to infer scour potential
- Depth and extent of scour downstream of hydraulic structures is not directly estimated



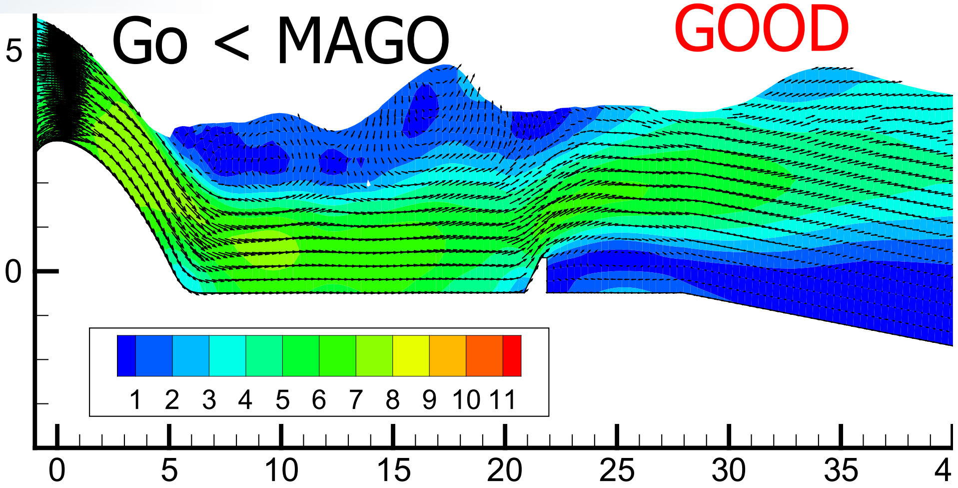


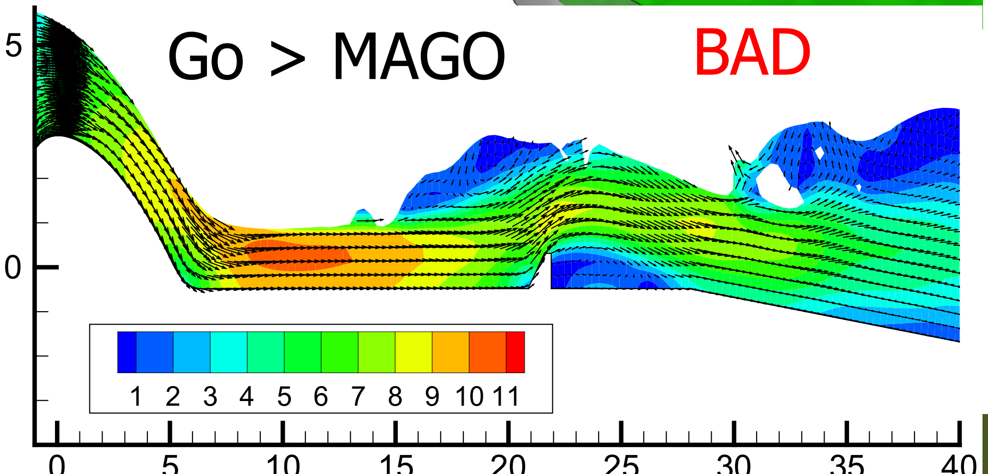


Another Erosion Potential Check: Location of the Hydraulic Jump

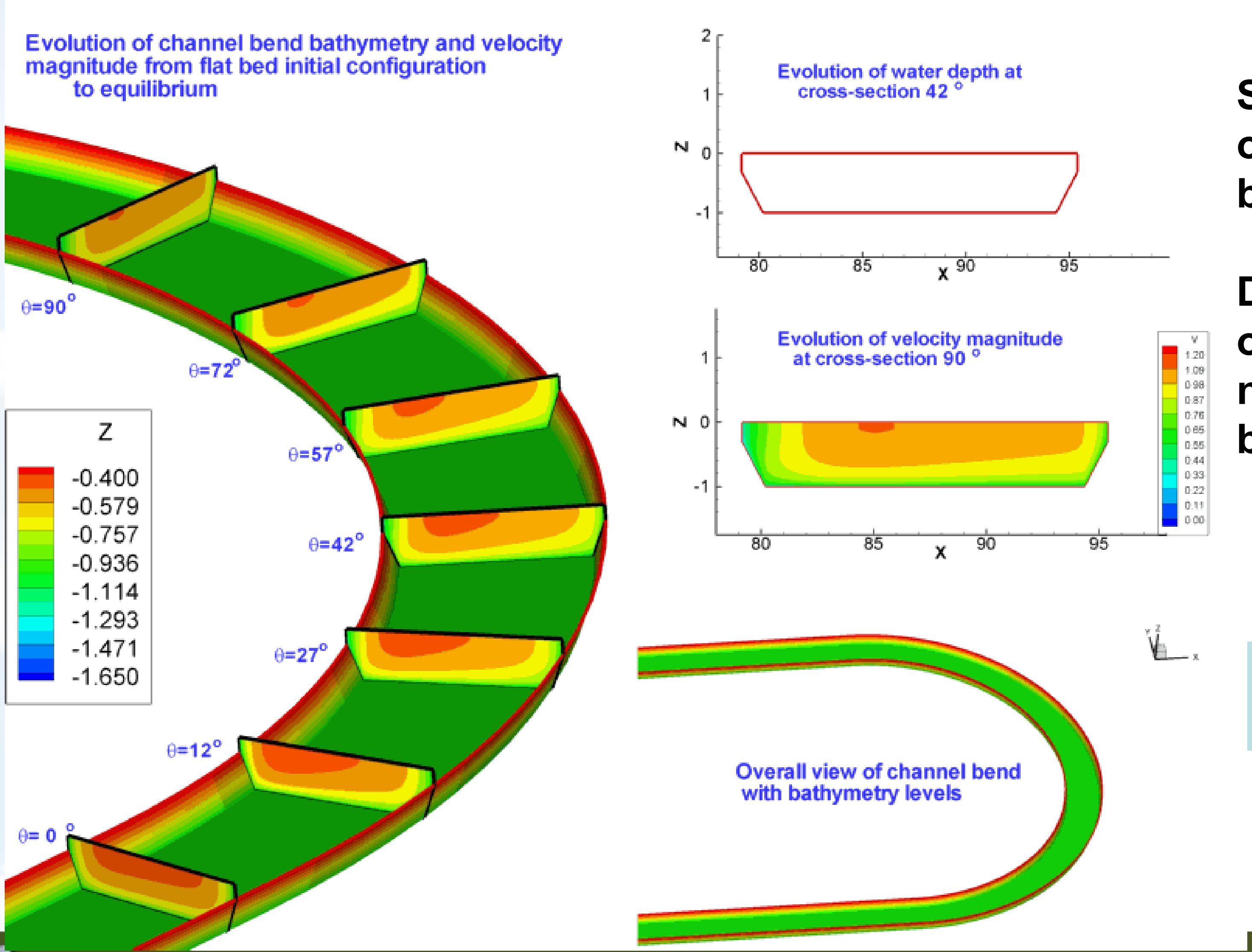


R. Musalem
& J. Zeng (2012)





Application of CFD to estimate sedimentation in channel Bend



Scour takes place on the outer bank side

Deposition is observed near inner bank

J. Zeng (2006)

Model Verification and Analysis

Water depth changes at representative sections

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

$$C_{b*} = 0.015\frac{d_{50}T^{1.5}}{aD_*^{0.5}}$$ Equilibrium Con.

Equilibrium bed load rate

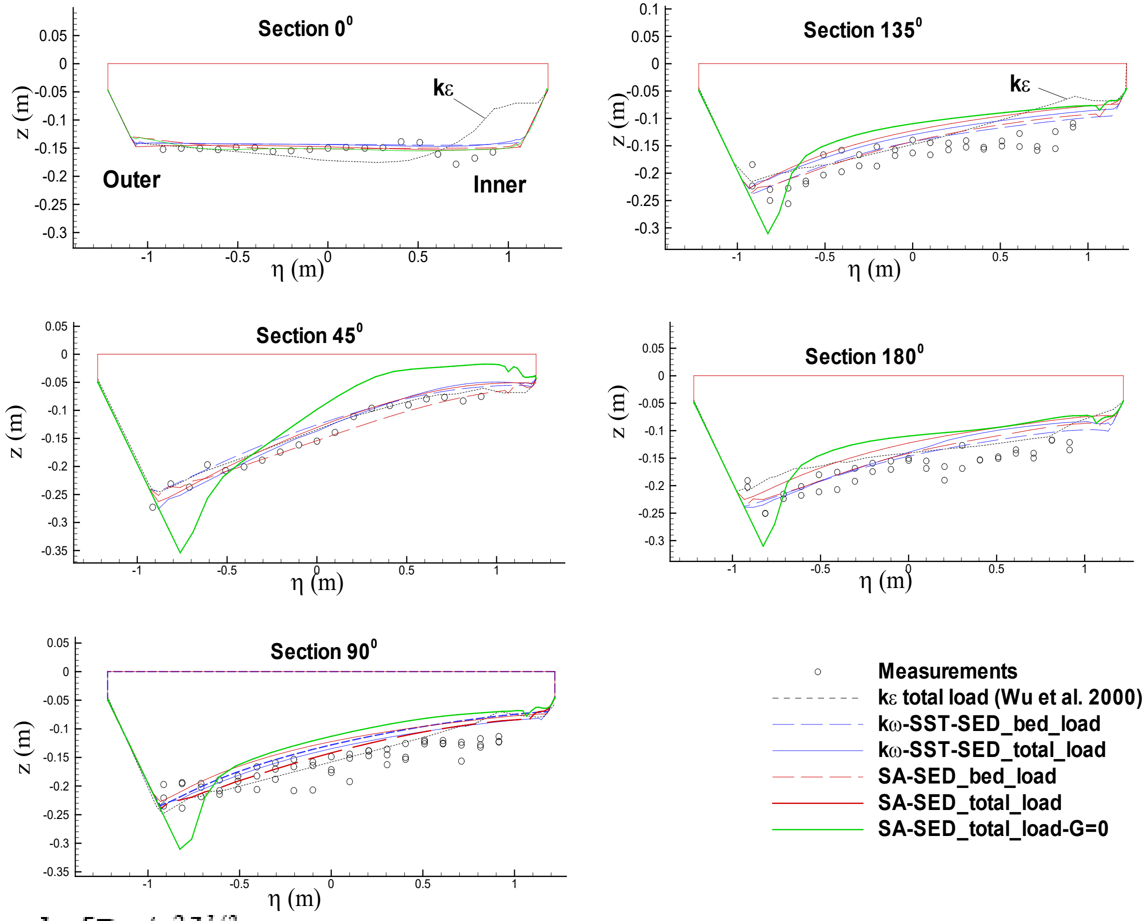
$$Q_{b*} = 0.053(Rg)^{0.5}\left(d_{50}^{1.5}T^{2.1}\right)/\left(D_*^{0.3}\right)$$

Non Dim. Excess shear stress

$$T = [\tau'_* - \tau_{cr}]/\tau_{cr} = [(u'_*)^2 - (u_{*cr})^2]/(u_{*cr})^2$$

$R = \rho_s/\rho - 1$ is the reduced gravity.

the non-dimensional particle-size diameter is $D_* = d_{50}[Rg/\nu^2]^{1/3}$.



For θ>20⁰ triangular Shape

Short sand bar observed near inner bank

Maximum scour θ~50⁰

- 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.

J. Zeng (2006)

Instantaneous Pressure Field: Role of fluctuating pressure in structure failure

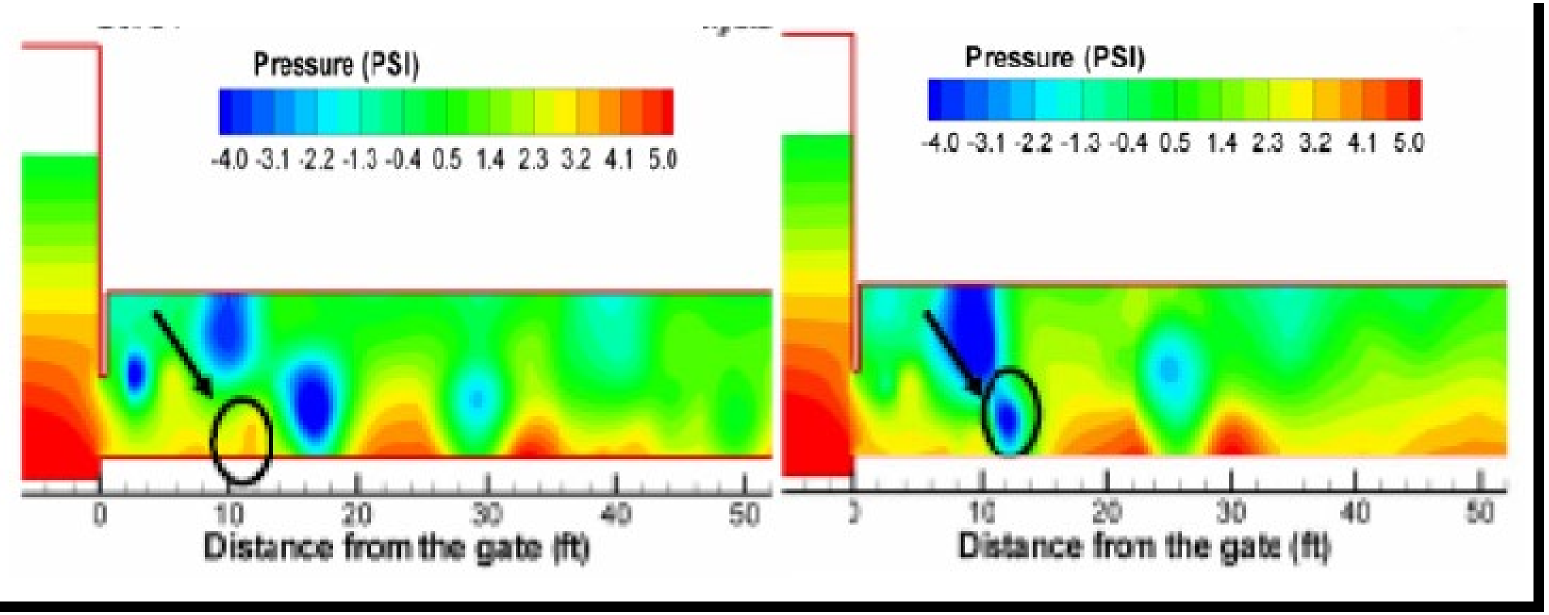
The stability of concrete slabs or rock blocks at plunge pool bottom of spillways (or at joints locations for segmented culverts) depends on the instantaneous pressure field

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.

California Department of Water Resources photos taken Tuesday, Feb. 7, 2017, show extensive damage to the Oroville Dam spillway and severe erosion to area adjacent to spillway structure. *(Kelly M. Grow/Department of Water Resources)*

A concrete section eroded on the middle section of the spillway. (Kelly M. Grow/California Department of Water Resources)

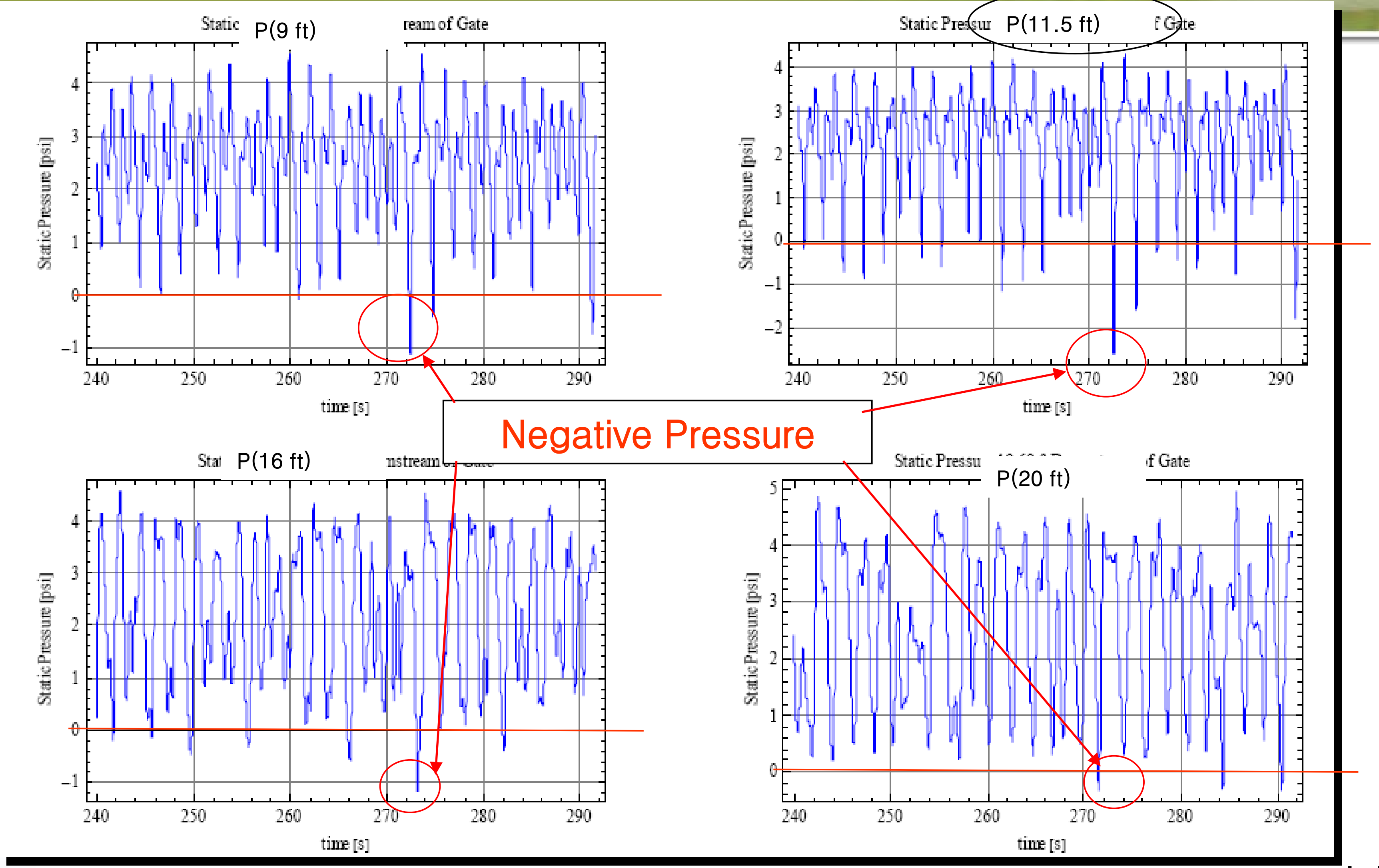
Dynamic Pressure Field Analysis with DES model for S-375



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)

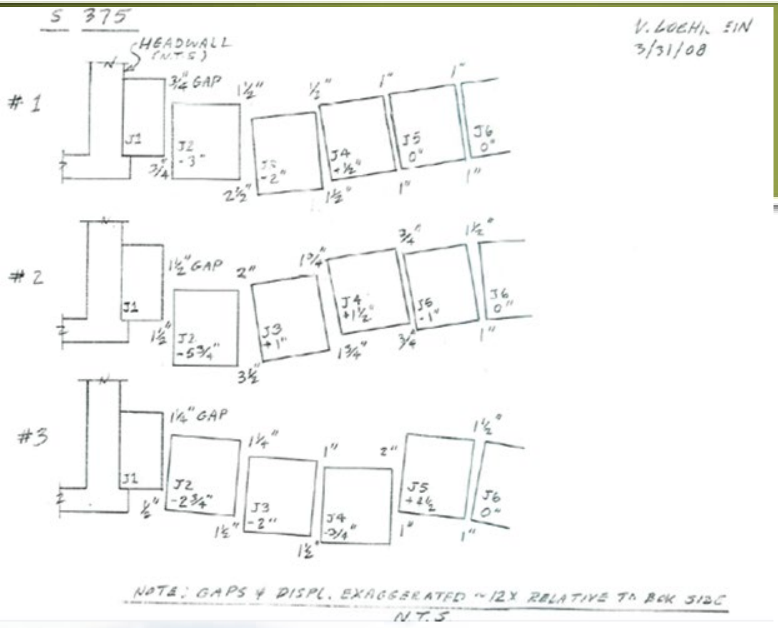
Pressure Fluctuations at Selected Locations

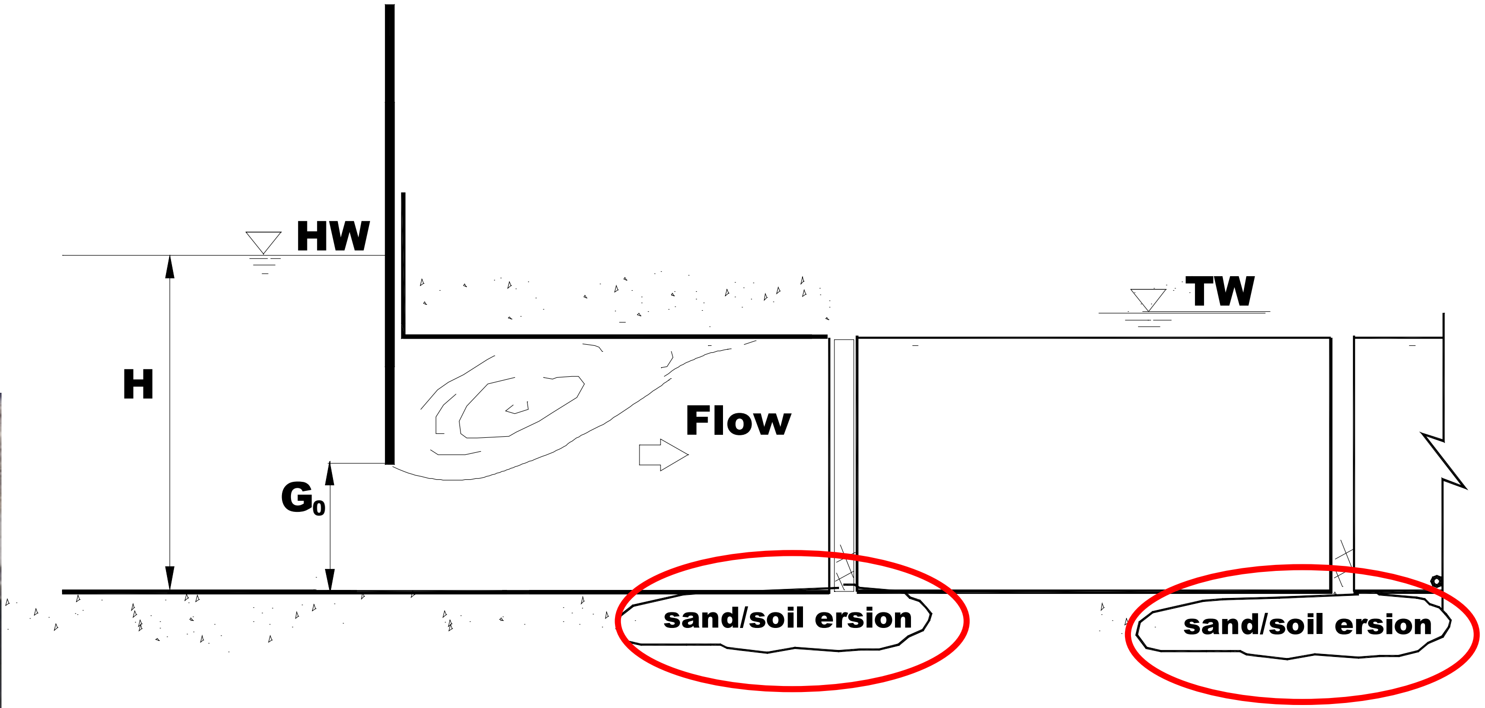


J. Zeng et al. (2009)

Pressures fluctuations can reach 11 psi

Damage analysis—Sand/soil erosion





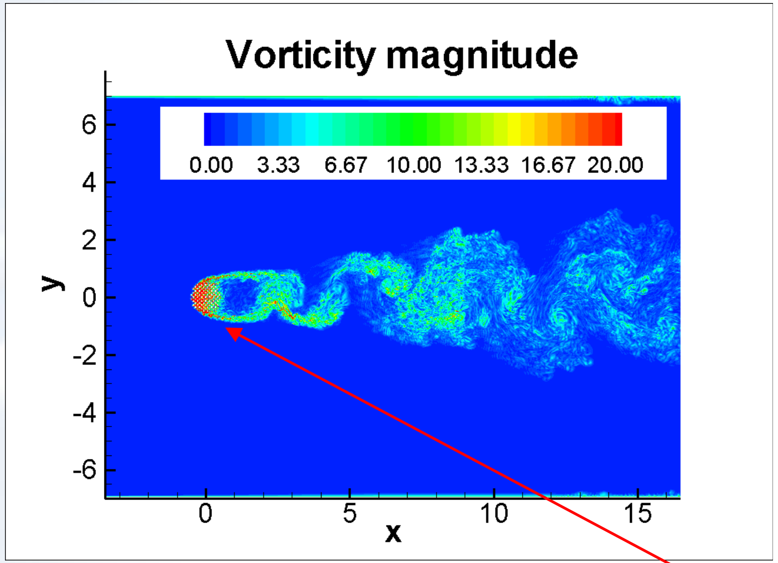
The seepage and inner negative pressure lead to the loss of the sand/soil foundation after the joint failure.

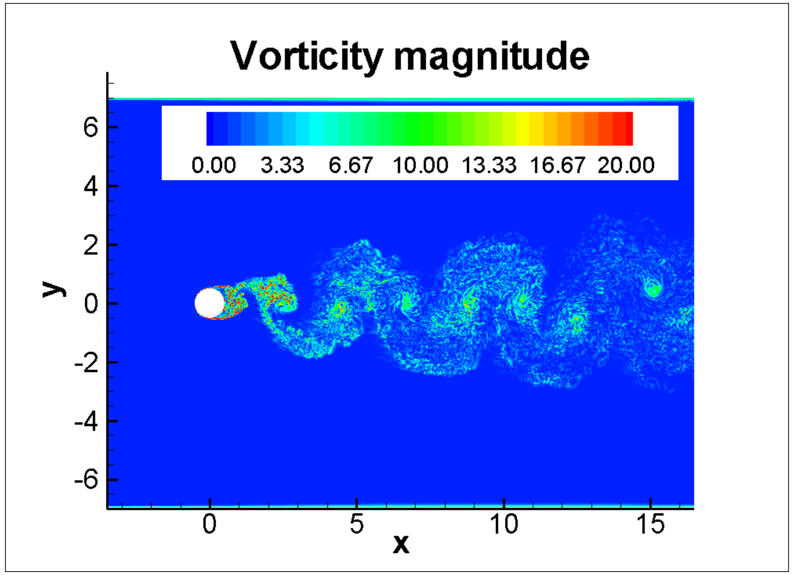
J. Zeng et al. (2009)

FLOW PAST A CIRCULAR PATCH OF VEGETATION

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

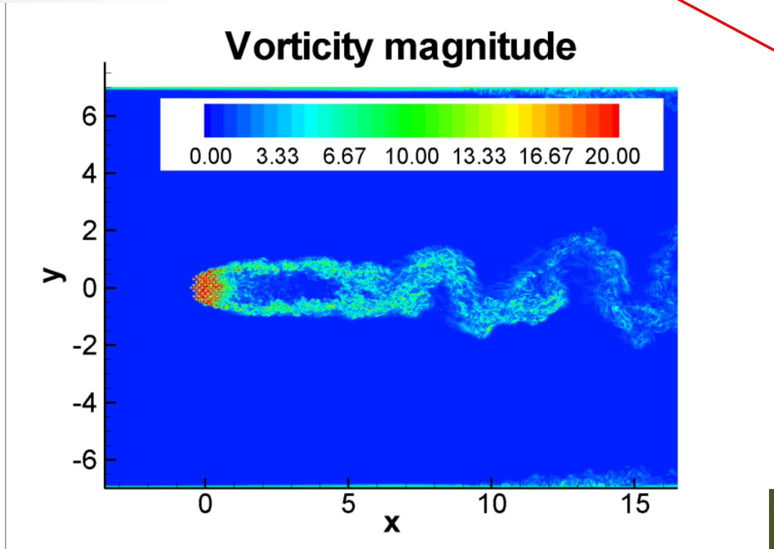
SVF=20%
(89 cylinders)

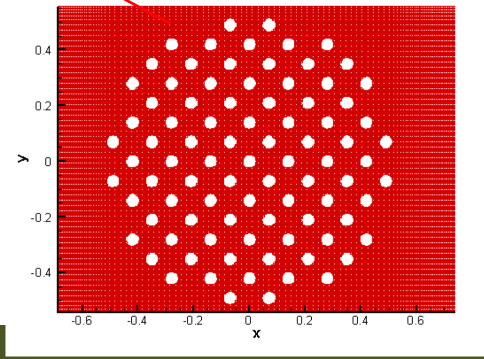




SVF=100% (solid cylinder)

SVF=10%
(44 cylinders)



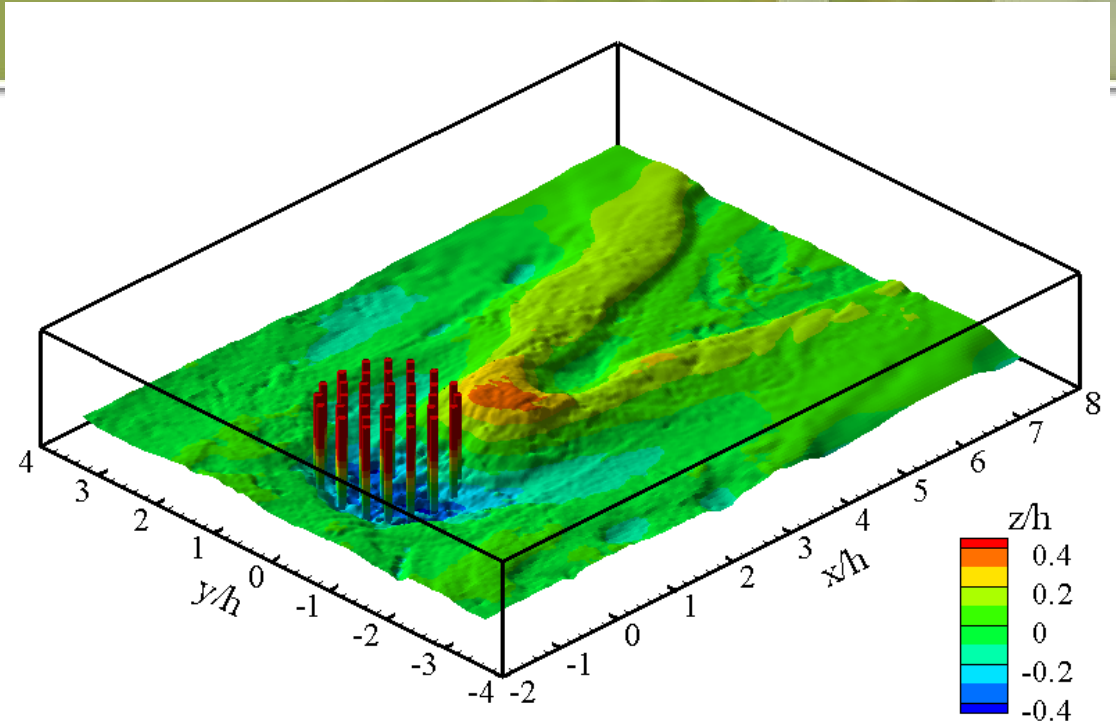


Chang & Tsai (NHPC, Taiwan)
G. Constantinescu (Univ. of Iowa)

IIHR Hydroscience & Engineering

(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?

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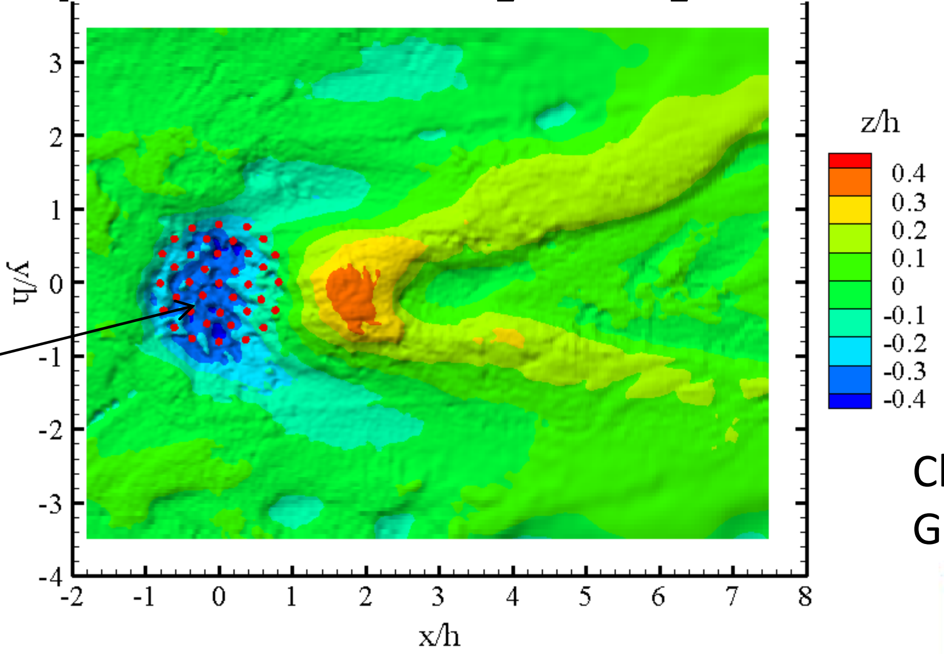
Flow past a surface-mounted porous cylinder

Equilibrium bathymetry



SVF=13%

Maximum scour occurs inside porous cylinder

No significant scour in front of porous cylinder

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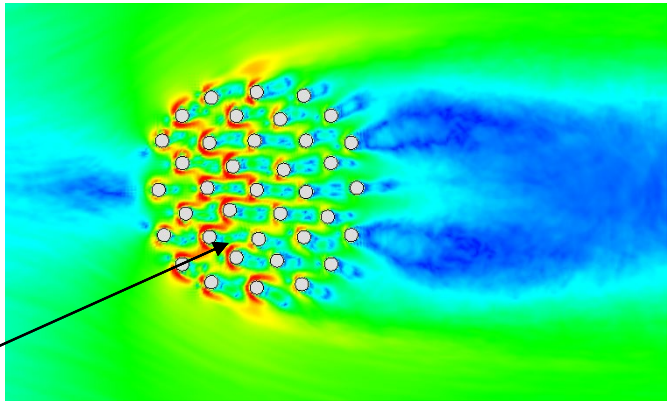

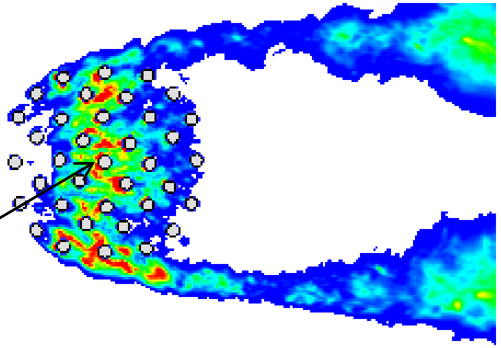

Bed friction velocity (FB) **Mean Bed friction vel Fluctuations at the bed (FB)**

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)