Numerical Study of Erosion-proof of Loose Sand in an Overtopped Plunging Scour Process– FLOW3D

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The 2009 Joint ASCE-ASME-SES Conference on Mechanics and Materials
June 24-27, 2009 • Blacksburg, VA

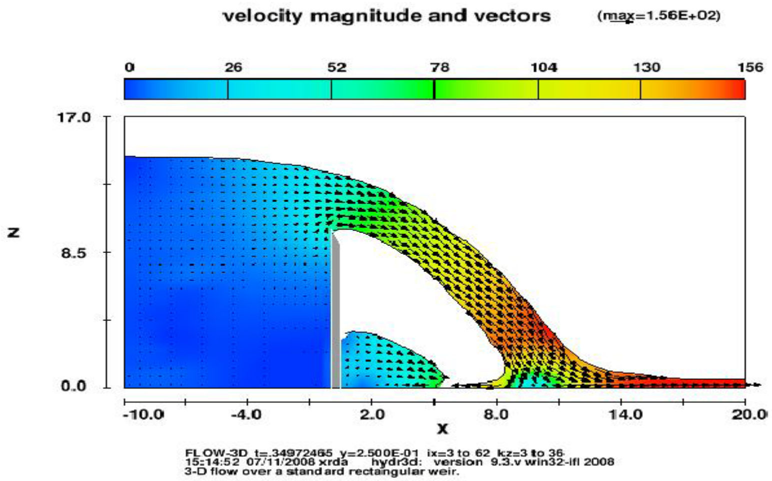
Objectives

Failure of floodwalls during Hurricane Katrina, August 23, 2005. Nearly every levee in metro New Orleans was breached. Eventually 80% of the city became flooded (*http://en.wikipedia.org/wiki/Hurricane_Katrina*).

Scouring caused by overtopping flow. This leads to the loss of lateral support that gives rise to failure of floodwall system under hydrostatic pressure from the other side of the wall (*IPET, 2007*).

Main goal: investigate levee back side erosion caused by overtopping, and ultimately provide improved technologies for retrofitting and construction of the nation's hurricane and flood protection system.

1. FLOW3D for a scour/erosion study



- Predict the behavior of packed/suspended sediment with one fluid mode.
- 3 dimensional prognostic solver.
- Contain a variety of optional turbulent models.
- Actual conditions are easy to apply.

Model introduction

- Model at a Glance

<u>Fluid field</u>

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \bullet \nabla \vec{u} = -\nabla p + \nabla \bullet \tau + g - K\vec{u}$$

<u>***K***: drag coeff.</u>

pure flow

Mean fluid viscosity does not rise, rather, the sediment particles begin to interact with one another to cause solid-like behavior.

$$K = \begin{cases} 0 & \text{if } f_S < f_{S,CO} \\ \left[\dfrac{f_{S,CR} - f_{S,CR}}{f_{S,CR} - f_S}\right]\left[\dfrac{f_{S,CR} - f_{S,CR}}{f_{S,CR} - f_S} - 1\right] \bullet f_d & \text{if } f_{S,CO} < f_S < f_{S,CR} \\ \infty & \text{if } f_S > f_{S,CR} \ (\text{fluid flow ceases}) \end{cases}$$

- f_S : solid fraction.
- $f_{S,CO}$: cohesive solid fraction.
- $f_{S,CR}$: critical solid fraction.
- f_d : drag factor.

Sediment particles are completely bound together in a solid-like mass.

(cont.)

Movement of suspended sediment

$$\frac{\partial c_s}{\partial t} + \vec{u} \bullet \nabla c_s = D\nabla^2 c_s - \vec{u}_{lift} \bullet \nabla c_s - \vec{u}_{drift} \bullet \nabla c_s$$

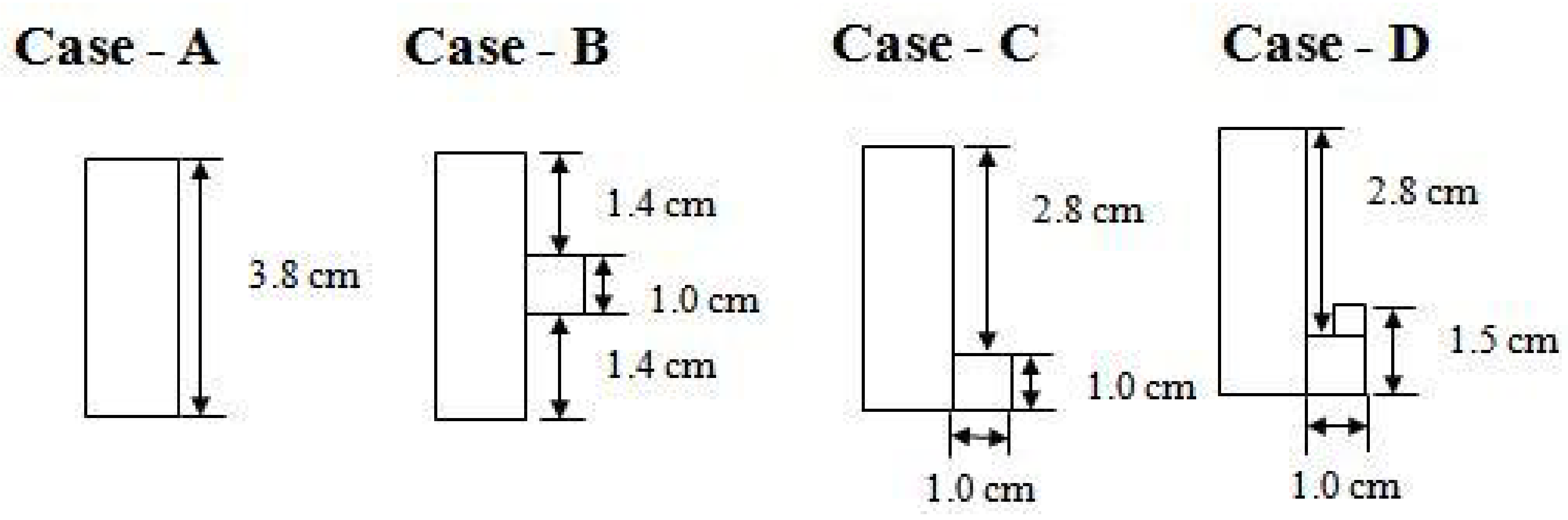
$\vec{u}_{lift}, \vec{u}_{drift}$: local lifting, drifting velocity.

c_s : local concentration.

D : diffusion coefficient.

2. Simulations of FLOW3D

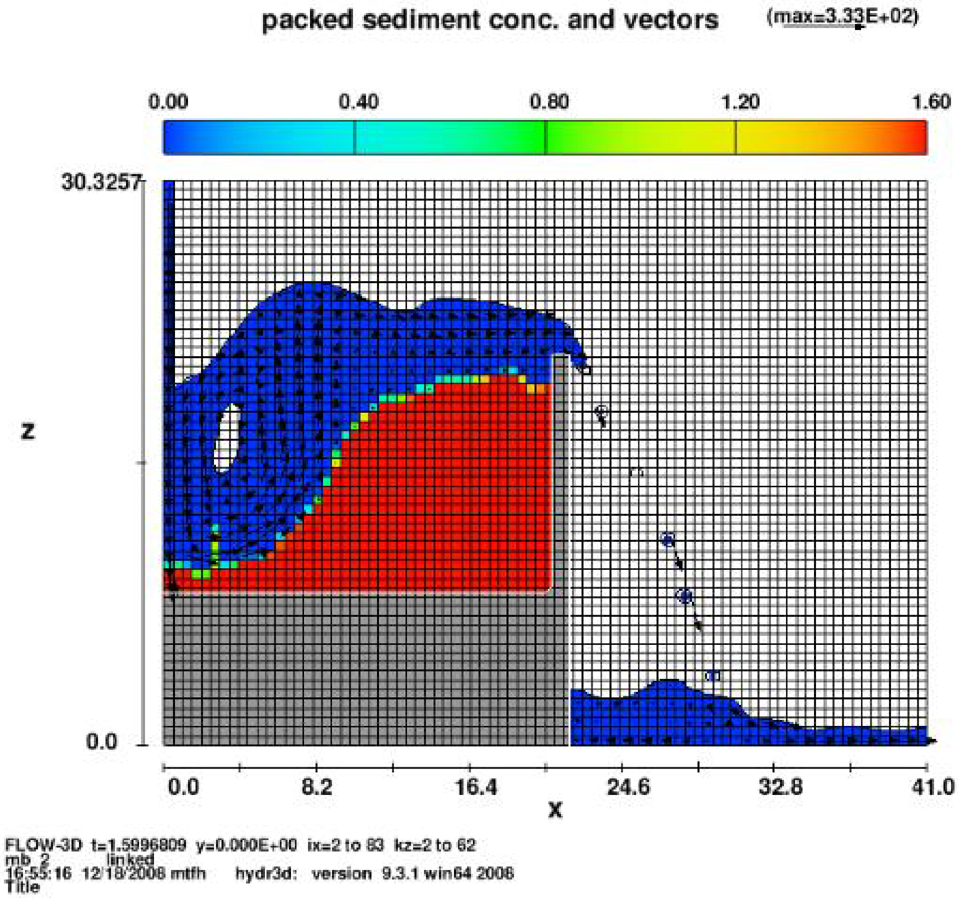
Four cases:



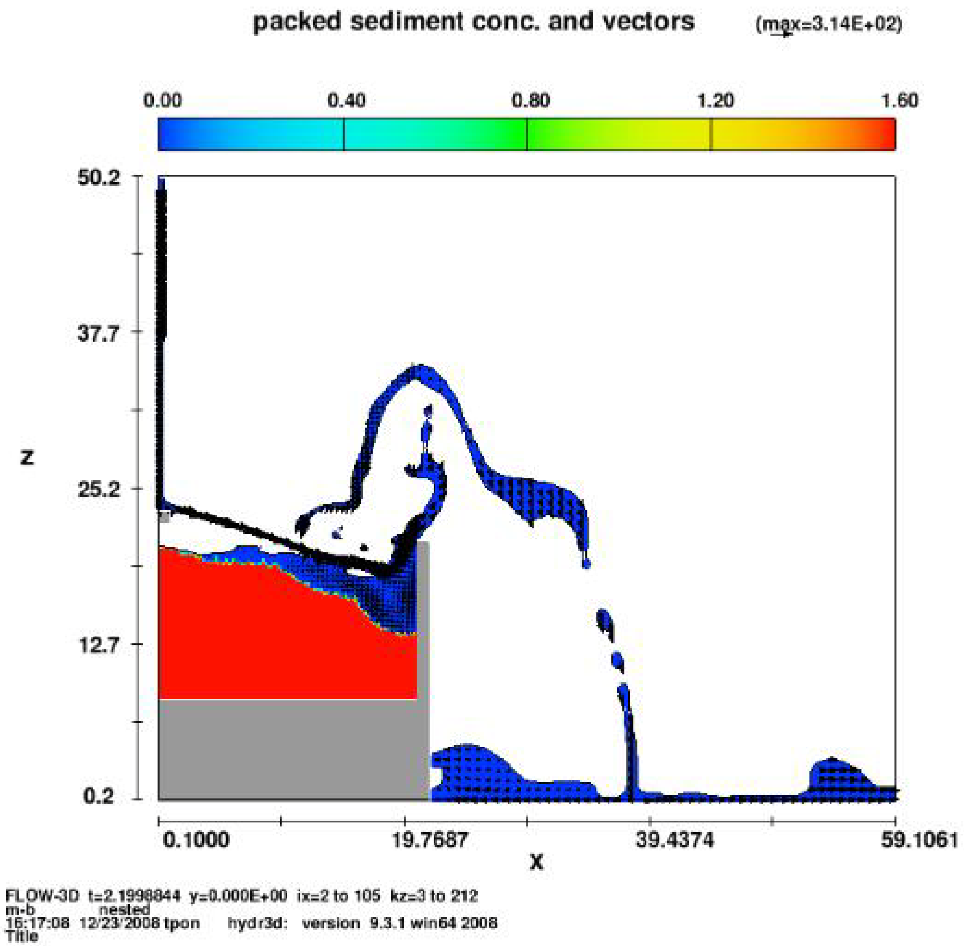
(cont.)

- Input parameters for an erosion simulation
  - Average particle diameter: 0.071 cm
  - Density of the sediment particles: 2.67 kg/m^3
  - Critical shields number: 0.00043
  - Critical sediment fraction
  - Cohesive sediment fraction
  - Sediment drag factor
  - Angle of repose: 22^0

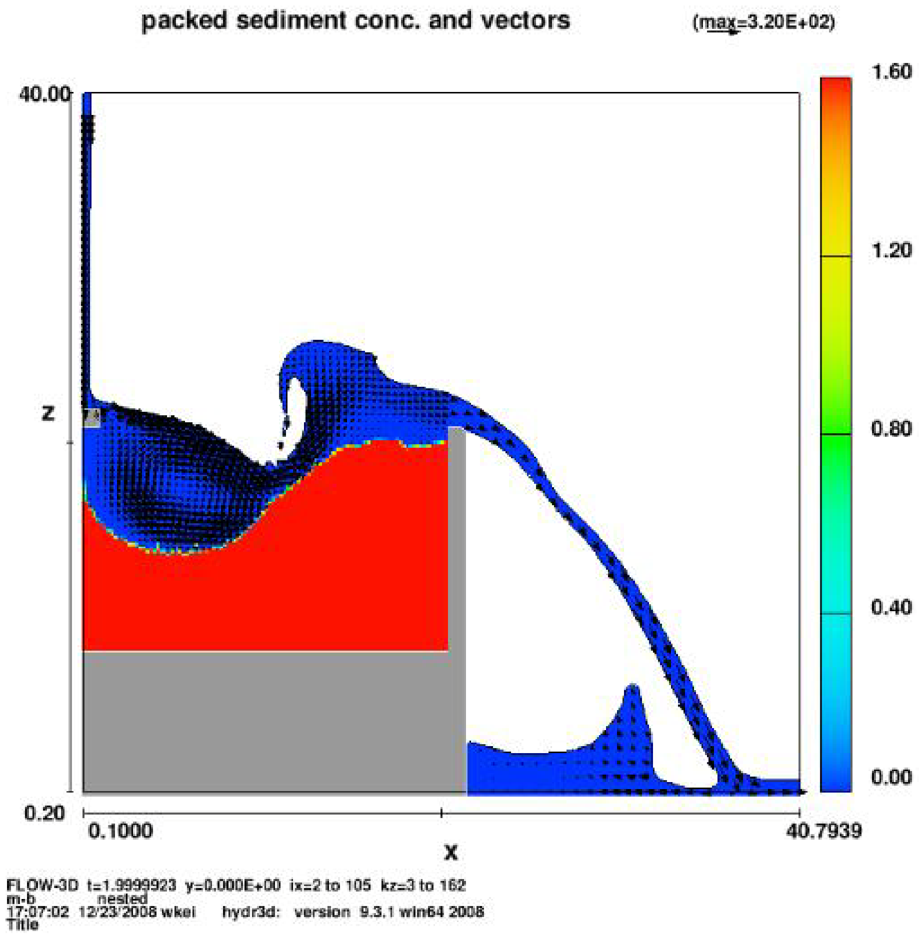
Case A:


packed sediment conc. and vectors
(max=3.33E+02)
0.00
0.40
0.80
1.20
1.60
30.3257
z
0.0
0.0
8.2
16.4
24.6
32.8
41.0
x
FLOW-3D t=1.5996809 y=0.000E+00 ix=2 to 83 kz=2 to 62
mb_2 linked
16:55:16 12/18/2008 mtfh hydr3d: version 9.3.1 win64 2008
Title

Case B:

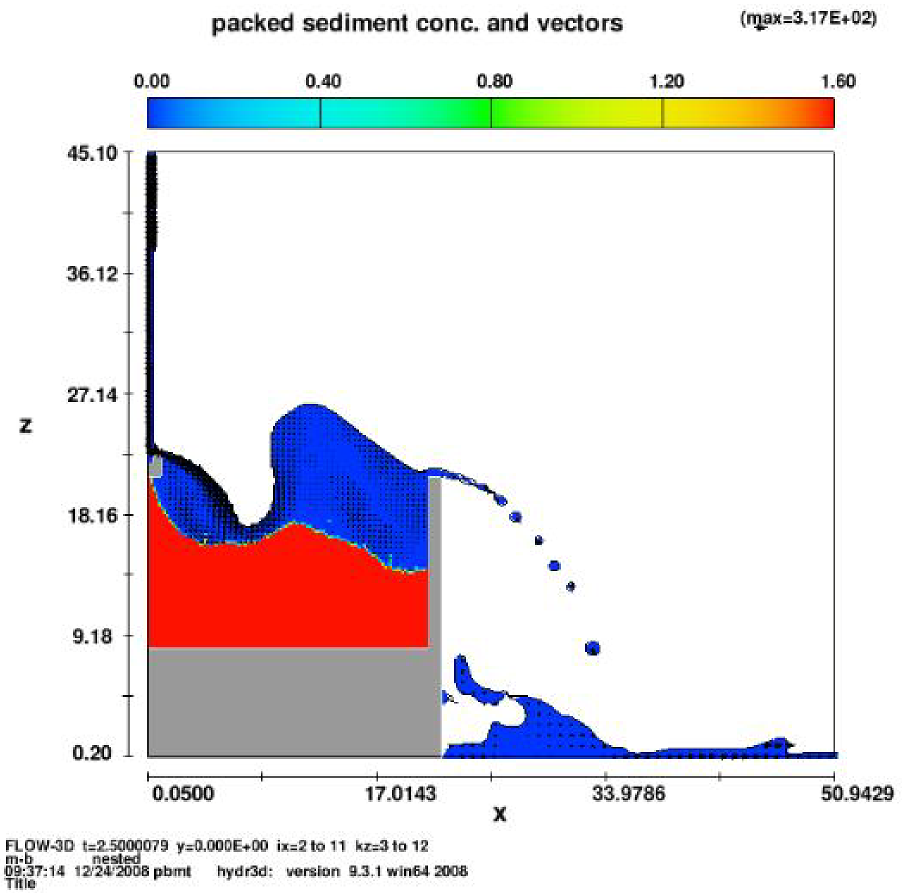

packed sediment conc. and vectors
(max=3.14E+02)
0.00
0.40
0.80
1.20
1.60
50.2
37.7
25.2
12.7
0.2
z
0.1000
19.7687
39.4374
59.1061
x
FLOW-3D t=2.1998844 y=0.000E+00 ix=2 to 105 kz=3 to 212
m-b nested
16:17:08 12/23/2008 tpon hydr3d: version 9.3.1 win64 2008
Title

Case C:



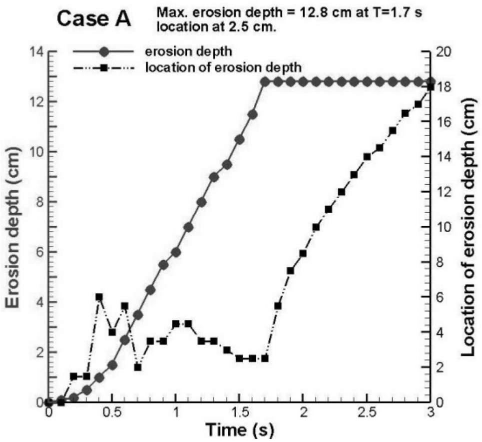
packed sediment conc. and vectors
(max=3.20E+02)
40.00
z
0.20
0.1000
40.7939
x
1.60
1.20
0.80
0.40
0.00
FLOW-3D t=1.9999923 y=0.000E+00 ix=2 to 105 kz=3 to 162
m-b nested
17:07:02 12/23/2008 wkei hydr3d: version 9.3.1 win64 2008
Title

Case D:

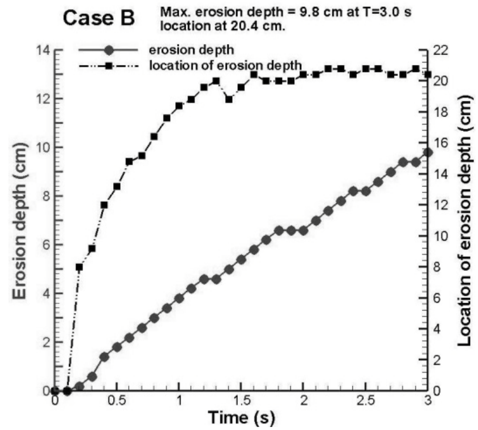

packed sediment conc. and vectors
(max=3.17E+02)
0.00
0.40
0.80
1.20
1.60
45.10
36.12
27.14
18.16
9.18
0.20
z
0.0500
17.0143
33.9786
50.9429
x
FLOW-3D t=2.5000079 y=0.000E+00 ix=2 to 11 kz=3 to 12
m-b nested
09:37:14 12/24/2008 pbmt hydr3d: version 9.3.1 win64 2008
Title

Simulations of erosion depth/location vs. time

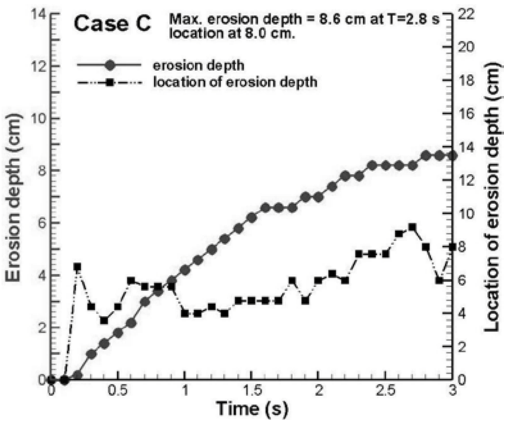
(A)



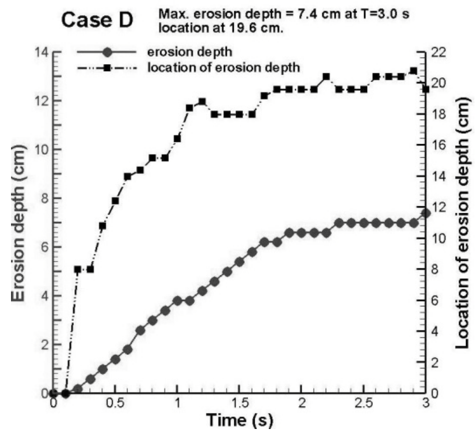
(B)



(C)



(D)

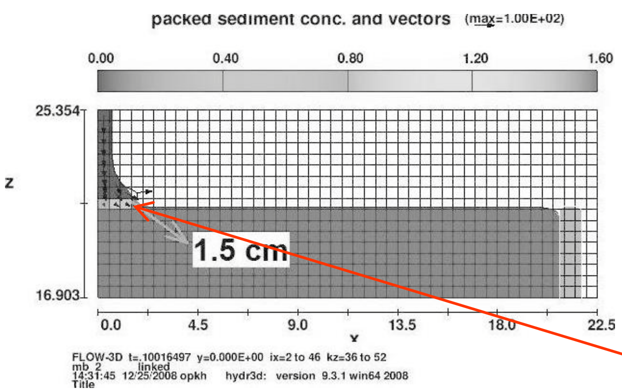


Comparison with experiments

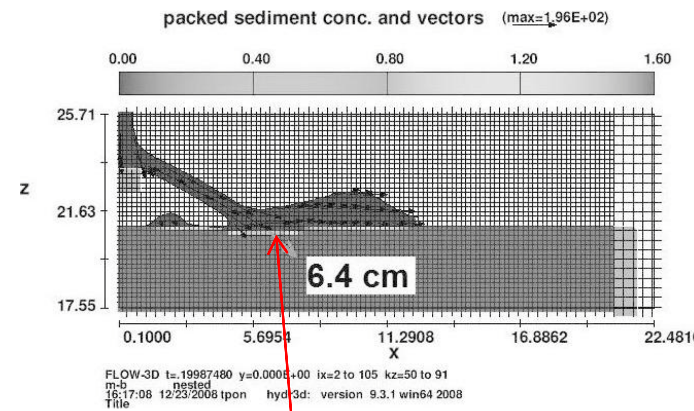
	Case A		Case B		Case C		Case D	
	Num.	**Exp.**	**Num.**	**Exp.**	**Num.**	**Exp.**	**Num.**	**Exp.**
Max. erosion depth (cm)	**12.8**	**12.8**	**9.8**	**9.9**	**8.6**	**10.1**	**7.4**	**8.8**
Time (s)	**1.7**	**1.65**	**3.0**	**2.66**	**2.8**	**2.66**	**3.0**	**1.5**
Location (cm)	**2.5**	**5**	**20.4**	**10**	**8.0**	**7.5**	**19.6**	**19.5**

(cont.) Erosion area analysis

Case A



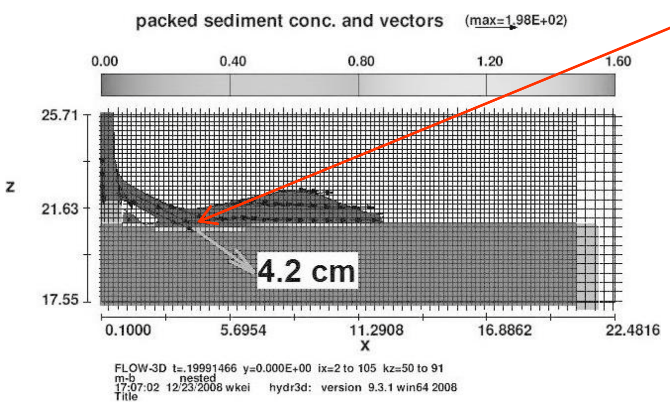
Case B



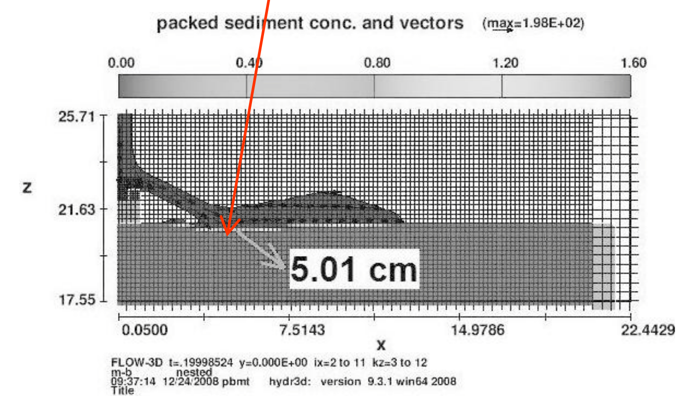
High pressure fluctuation takes place near the stagnation point where the scour hole initiates and expands.

Stagnation point

Case C



Case D



3. Conclusions

- FLOW3D's sediment scour model is a straightforward approach to modeling erosion and deposition of sediment for fully three-dimensional flows.
- Predictions show the scoured domain in agreement with the observations. Therefore, the modeling results can provide useful message to help improve the floodwall surface structure design. Properly designed floodwall surface structure could reduce the erosion rate as much as 400%.

4. Grant Acknowledgement

- Department of Homeland Security-through Southeast Region Research Initiative (SERRI), USA.

Thanks a lot for your attention!

Any questions?