Current Applications of Three Dimensional Computational Fluid Dynamics Analysis to Hydraulic Problems in FHWA R&D at Argonne's Transportation Research and Analysis Computing Center

National Hydraulic Engineering Conference

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www.anl.gov

www.tracc.anl.gov

Argonne: One of DOE's Largest Research Facilities

Argonne computer clusters are in a controlled environment .

TRACC Phoenix and Zephyr clusters are here.

Many clusters, including 800,000 core Mira supercomputer, are here.
Computations span scales from molecular dynamics to astrophysics

in the middle: hydraulics

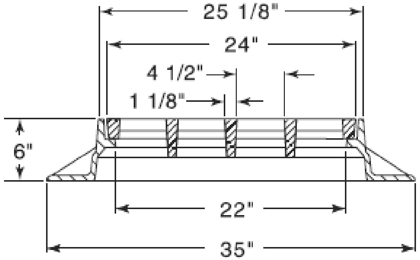
Current Hydraulics CFD Work at TRACC

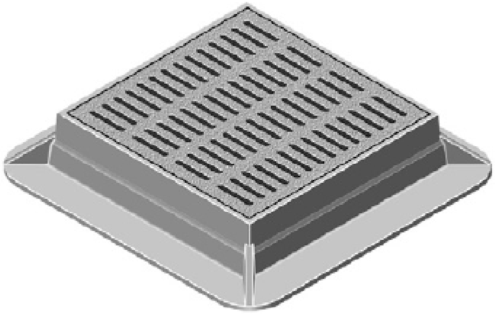
- Other Presentations

- Rockery Wall under Flood Conditions
- Riprap Onset of Motion
- Hydraulic Performance of Grates

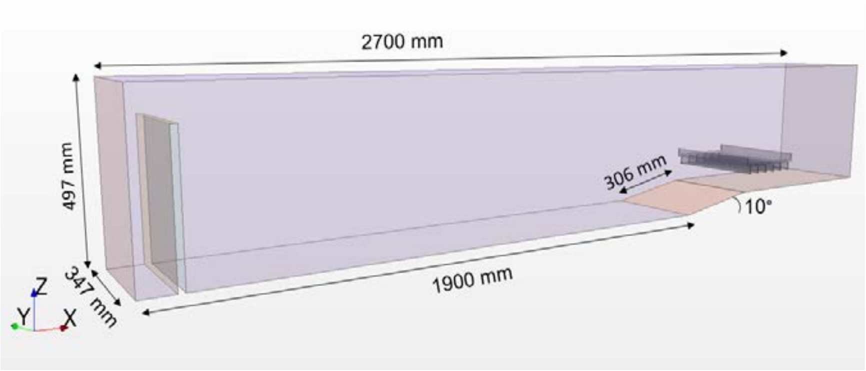
- This Presentation

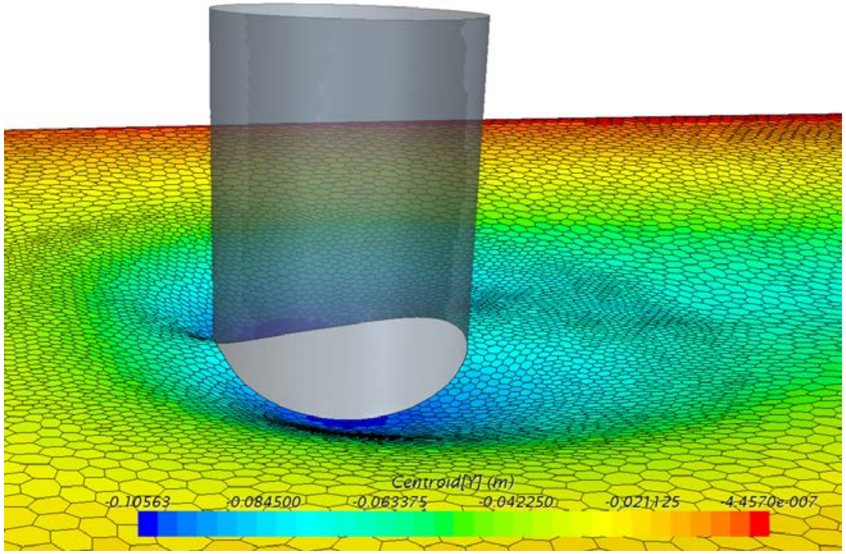
- Tsunami Flume Modeling
- Pier Extensions to Prevent Scour
- 3D Scour Modeling Update

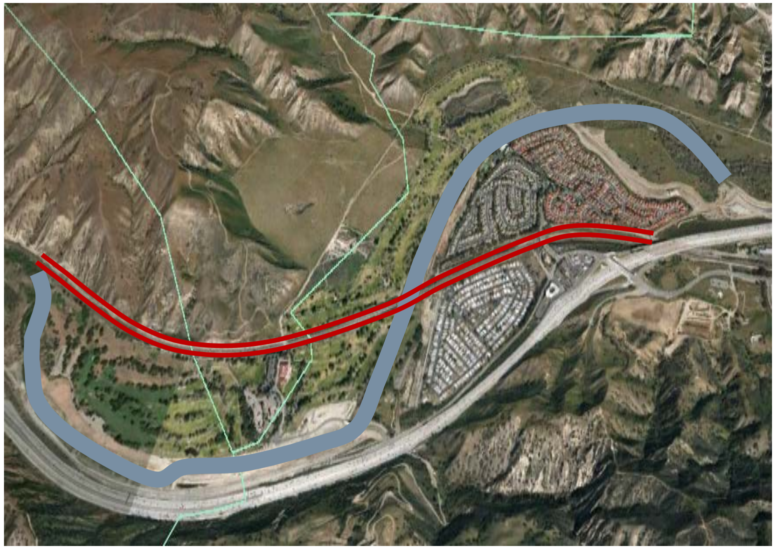




Argonne TRACC is Doing More Full Field Scale Modeling





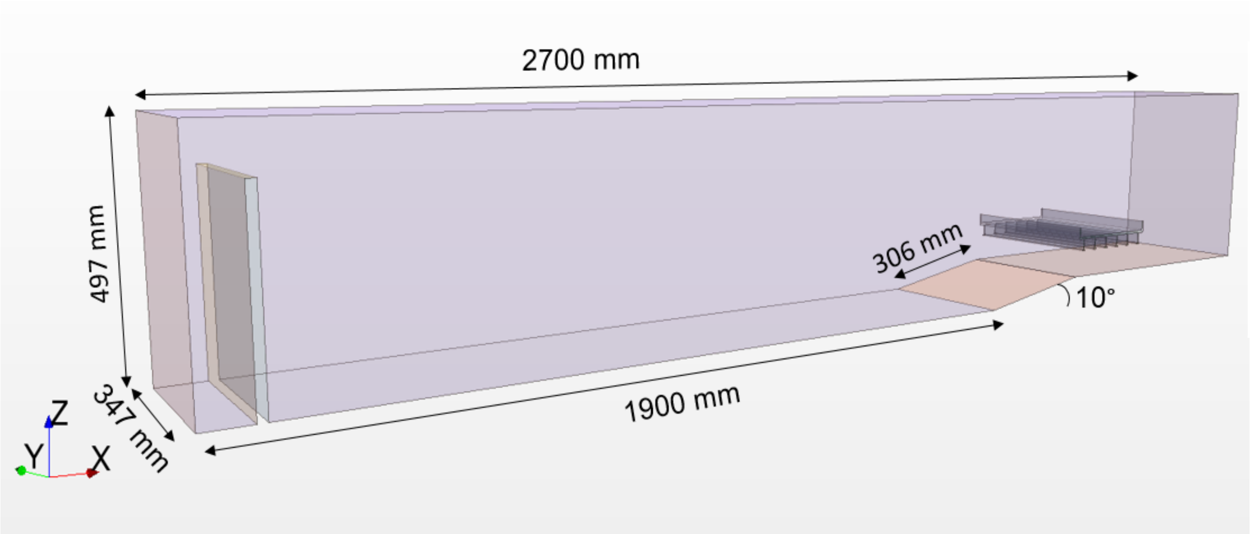


Additional Software Capabilities are Available Each Year

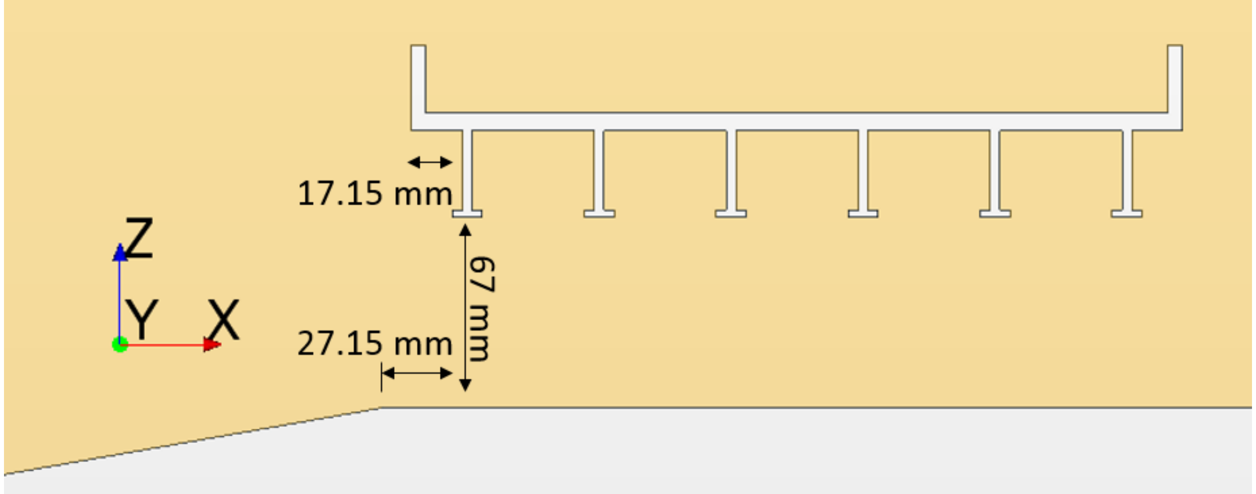
- Basic 3D flow analysis – force distribution on piers & bridge decks, shear on river beds
- Compute water force on objects, then answer questions:
  - Will it break, if so, how will it break – answer that with computational structural mechanics software (a fluid structure interaction , FSI, problem)
  - Will it move (riprap or structures), if so, what moves, where and how far
- Mesh morphing and new overset mesh capabilities allow relative motion of objects in a flow flied during solution (examples follow)
- Dynamic Fluid Body Interaction (DFBI) computes response of a rigid body to fluid forces, moves the body, and adjusts the mesh

- All of these new capabilities allow a much broader class of problems to be solved

Modeling a Tsunami Wave Flume – Basis for Real World, Full Scale Model



Parameter	Value
Time-step	0.001 s
Inner Iterations	10
Number of Cells	1,2 million



View of Computational Mesh on Boundaries Showing Finer Mesh Near Water Surface and Bridge Deck

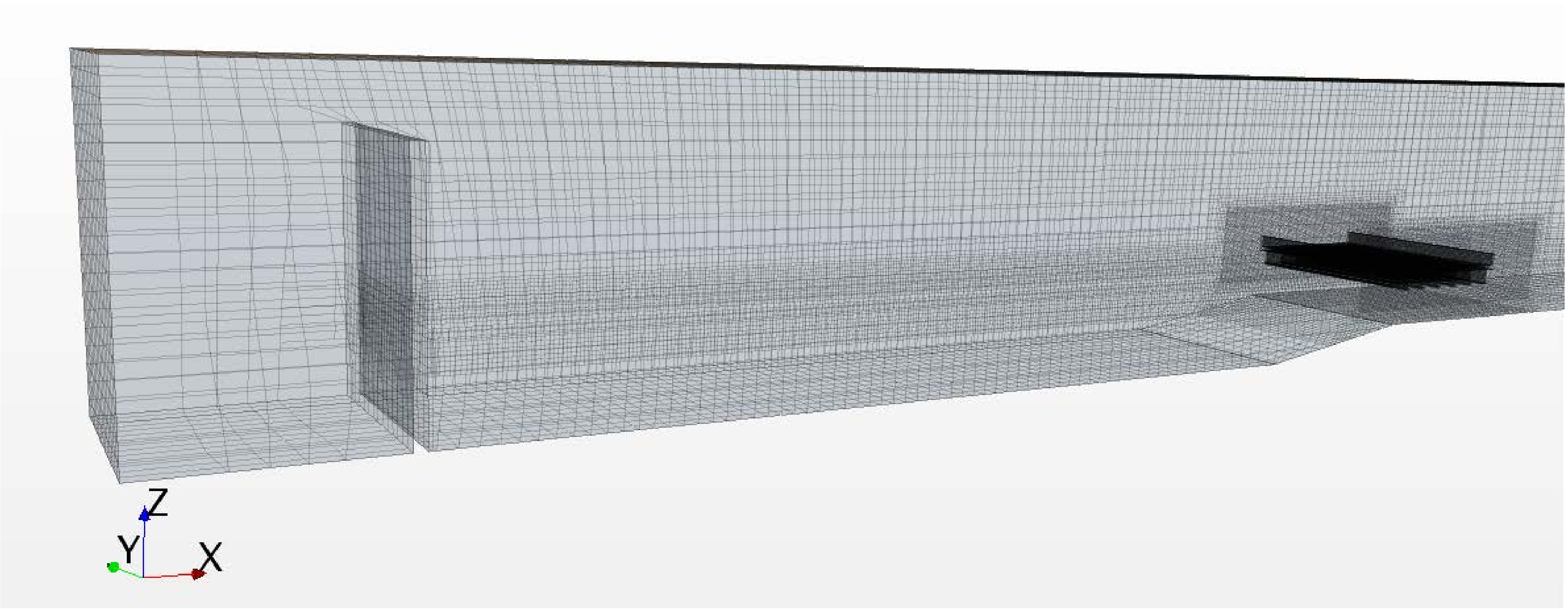
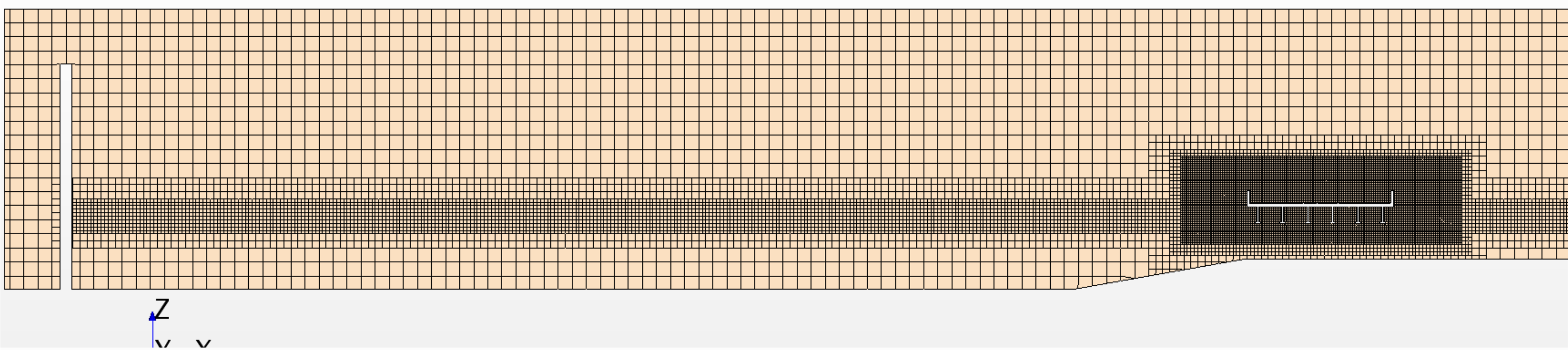
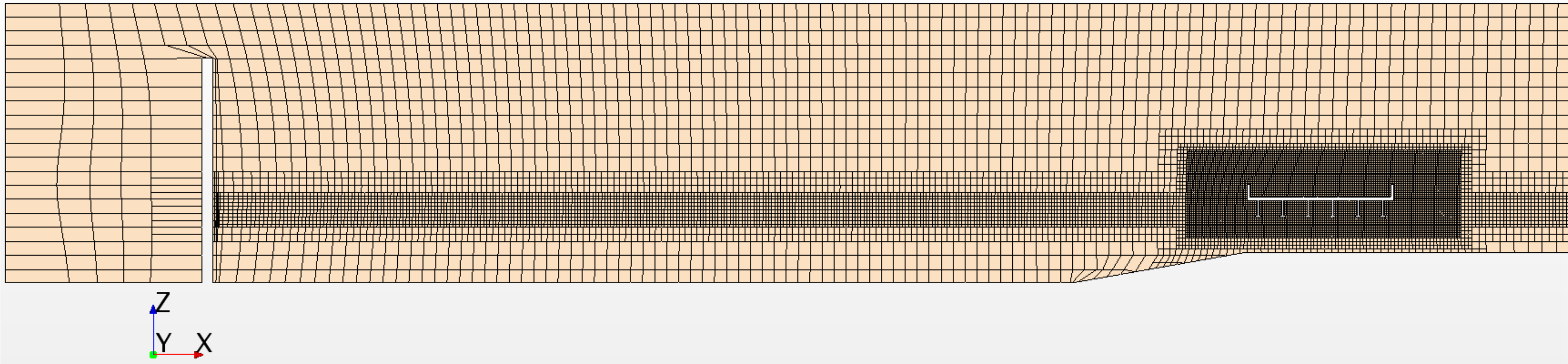
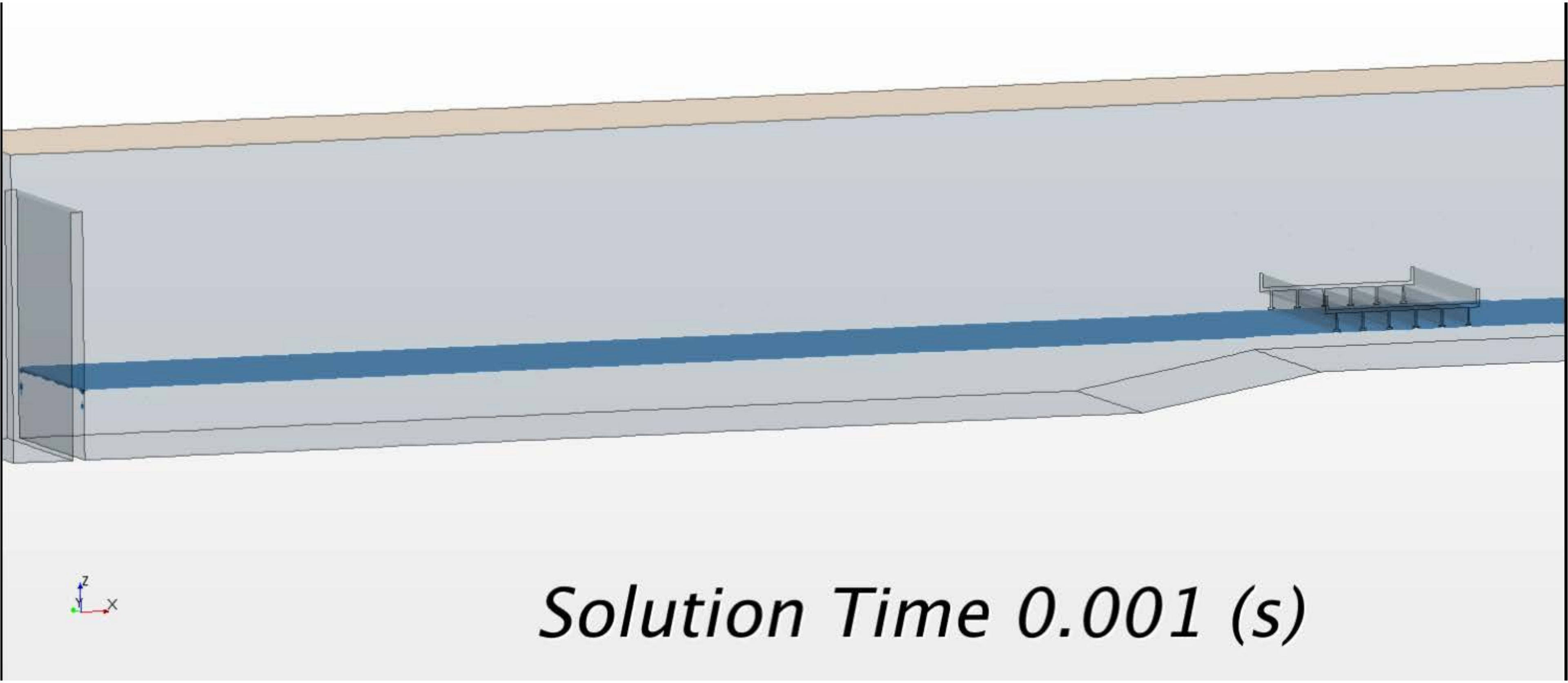


Plate Moves to Generate Wave
Mesh Morphing Adjusts Mesh for Motion of Plate
Cells Behind Plate Stretched, in Front Compressed

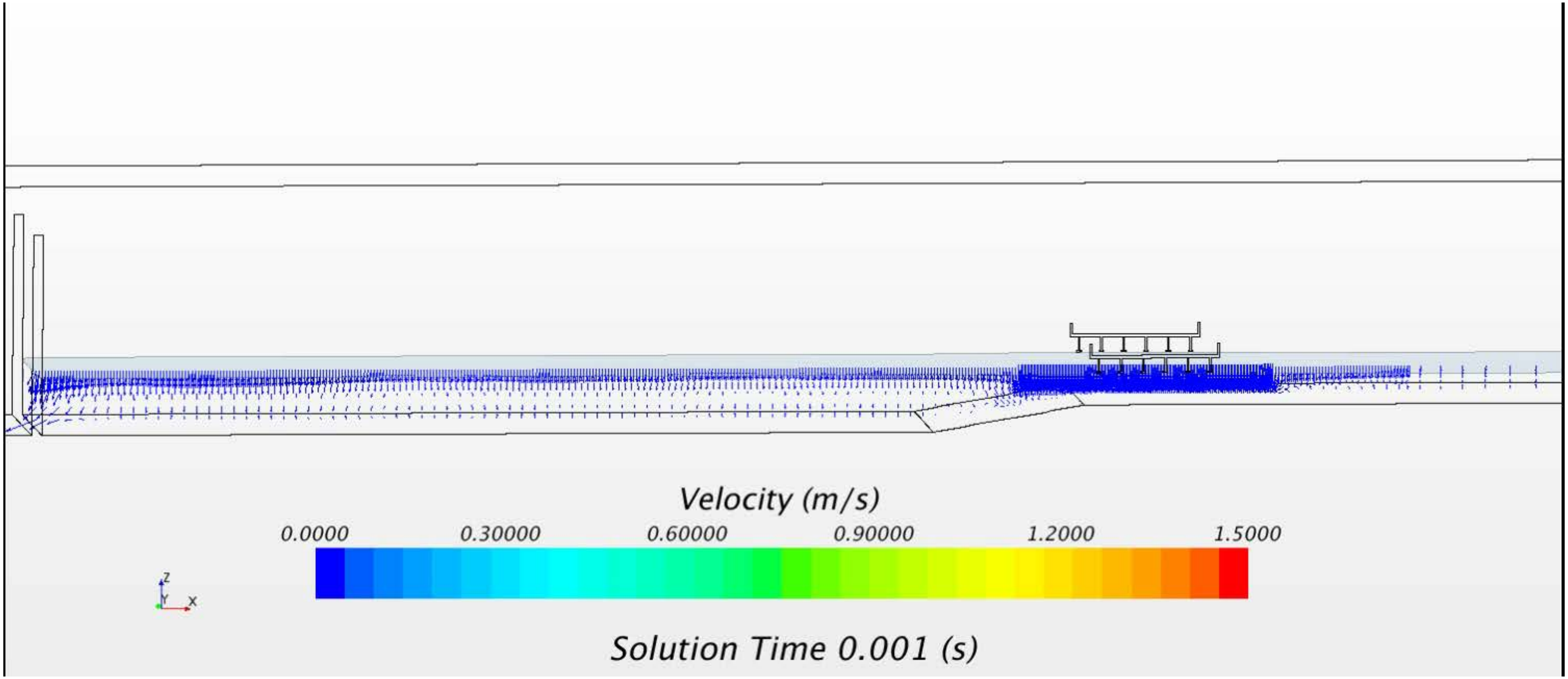




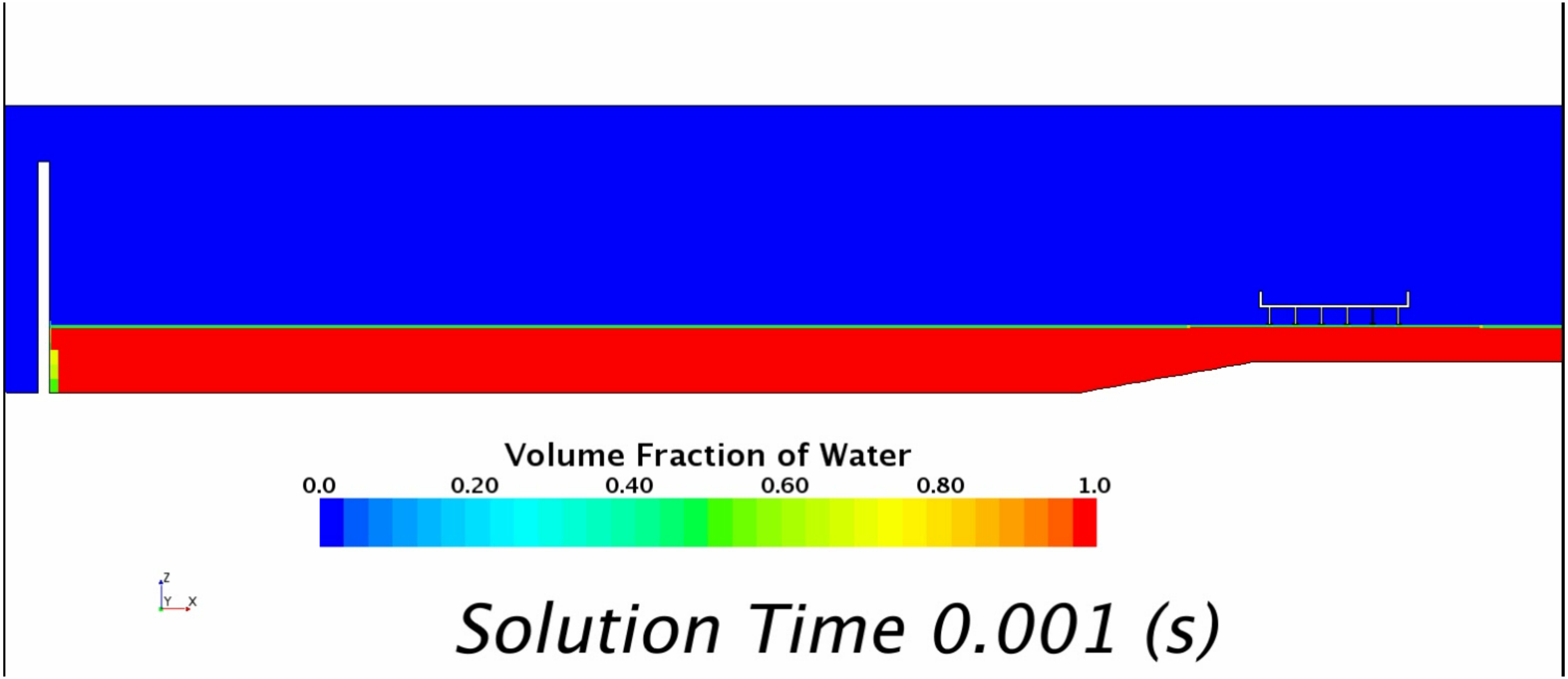
Tsunami Flume Water Surface Animation



Tsunami Flume Velocity Vector Animation

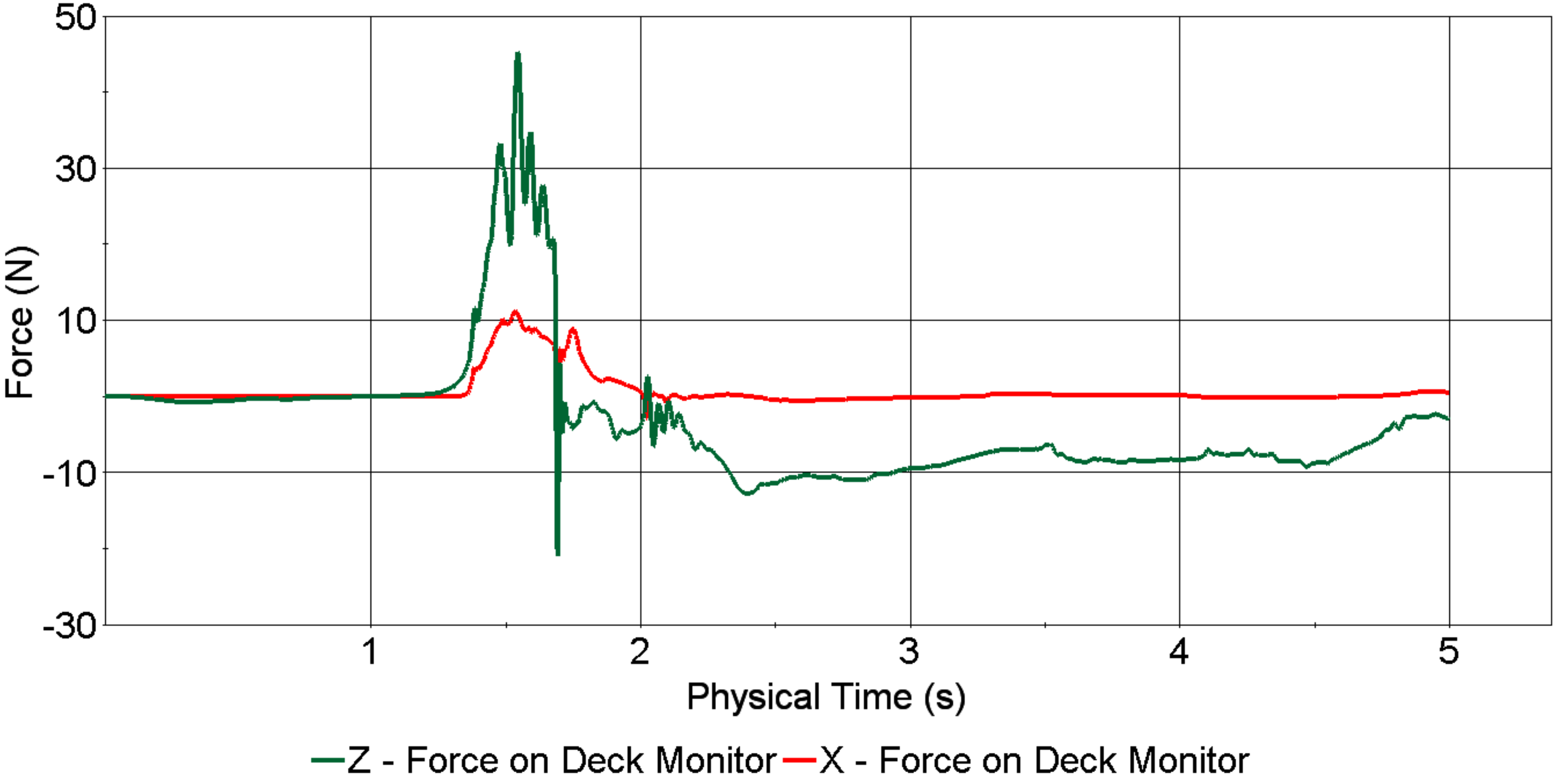


Tsunami Flume Water Volume Fraction Animation on Plane Cut through Bridge Deck

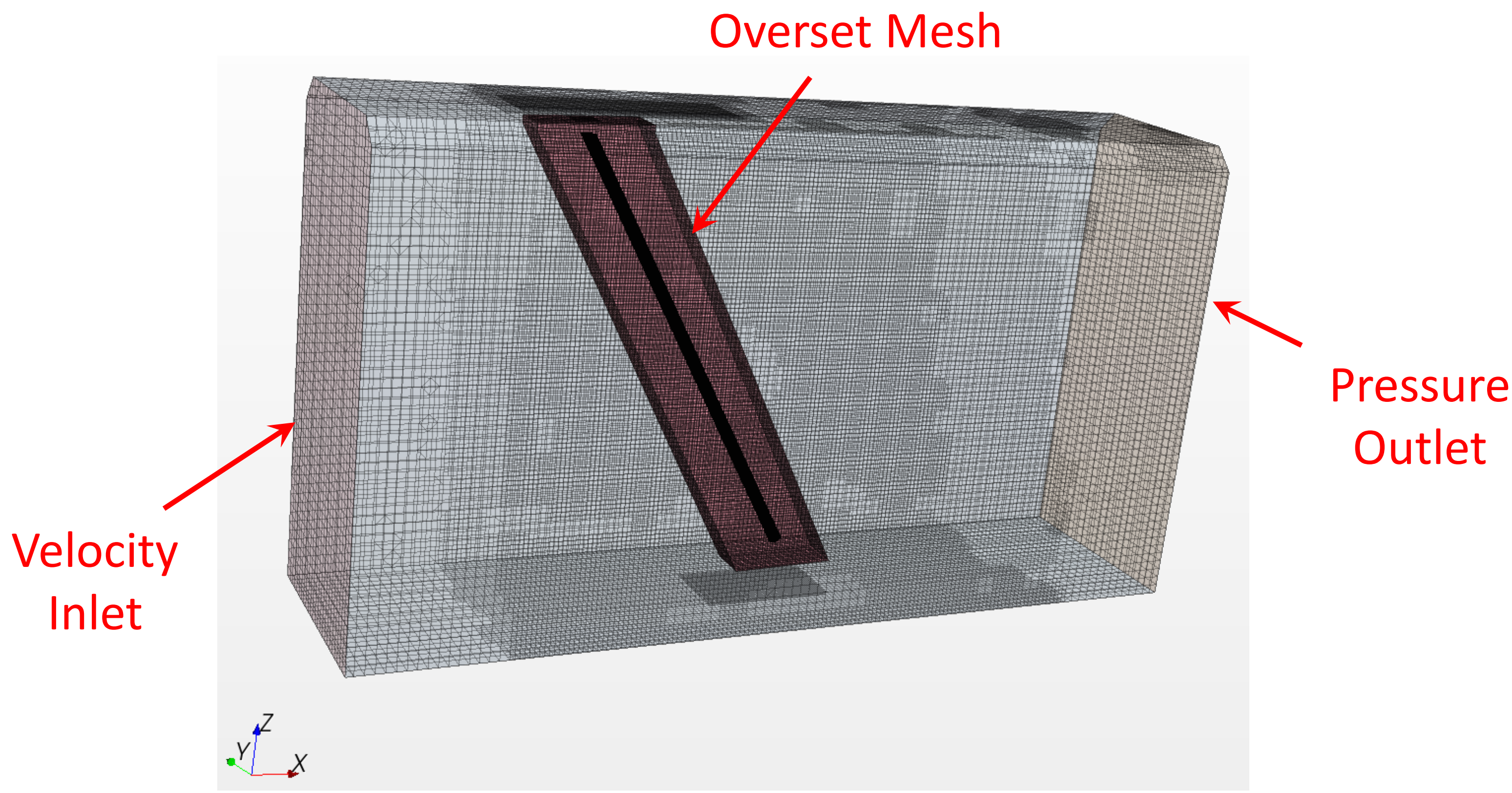


Force on Bridge Deck vs. Time

Deck Weight: Thermoplastic = 9 N (2 lbf.)
Concrete = 21 N (4.7 lbf.)

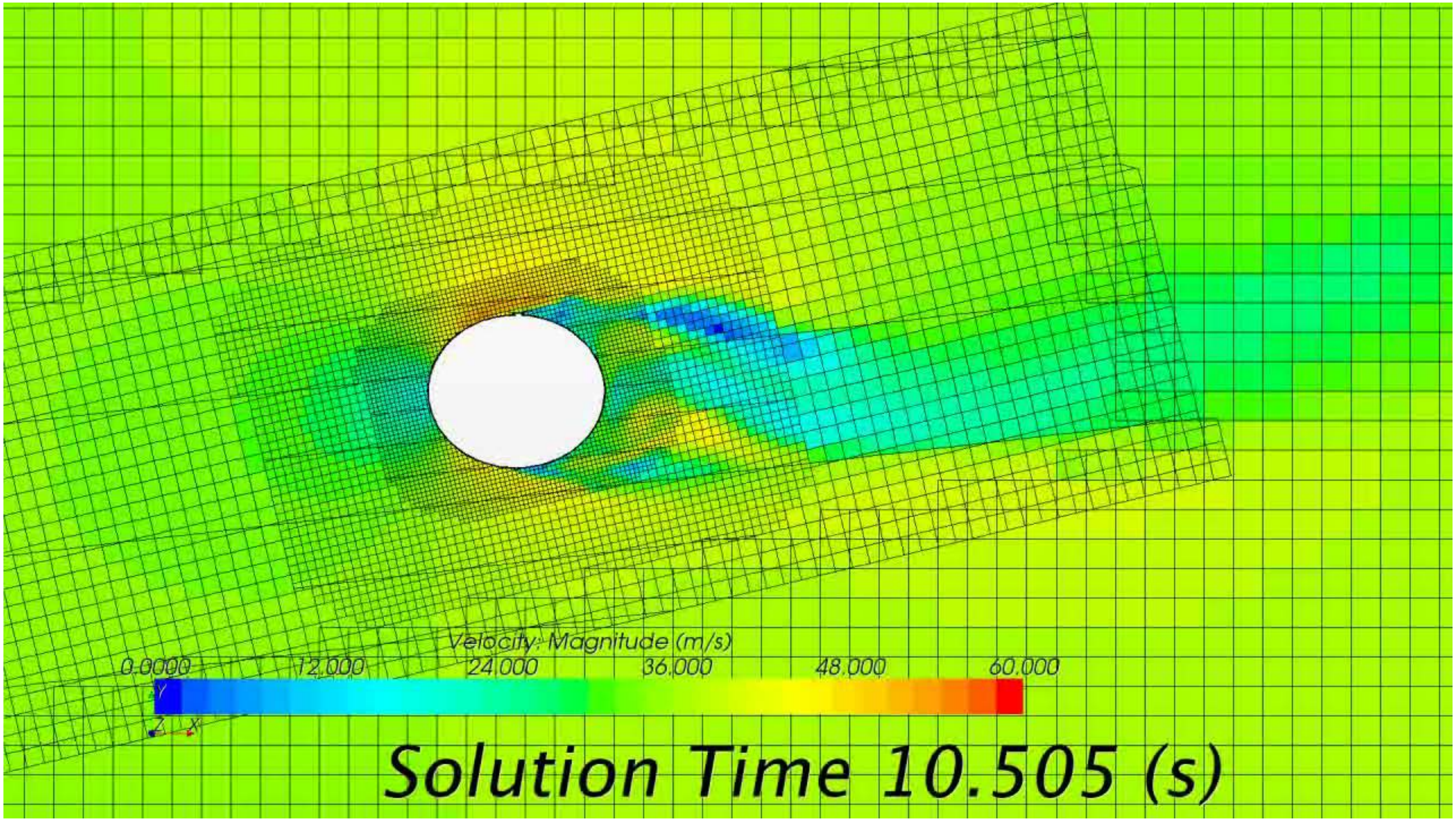


Cable Vibration Example: New Overset Mesh Capability Can Eliminate Mesh Morphing Problems for Some Problems Involving Object Motion



- 7.3 million cells, Time-step= 0.005 s
- Wind Velocity = 35 m/s
- Detached Eddie Simulation (SST K-Omega)

Scalar Horizontal Velocity W.R.T. Time



Physical Solution Time=13 seconds

Santa Ana River-Reach 9 -BNSF Rail Road bridge-3D Pier Extension Model Study

Bridge and Pier Views

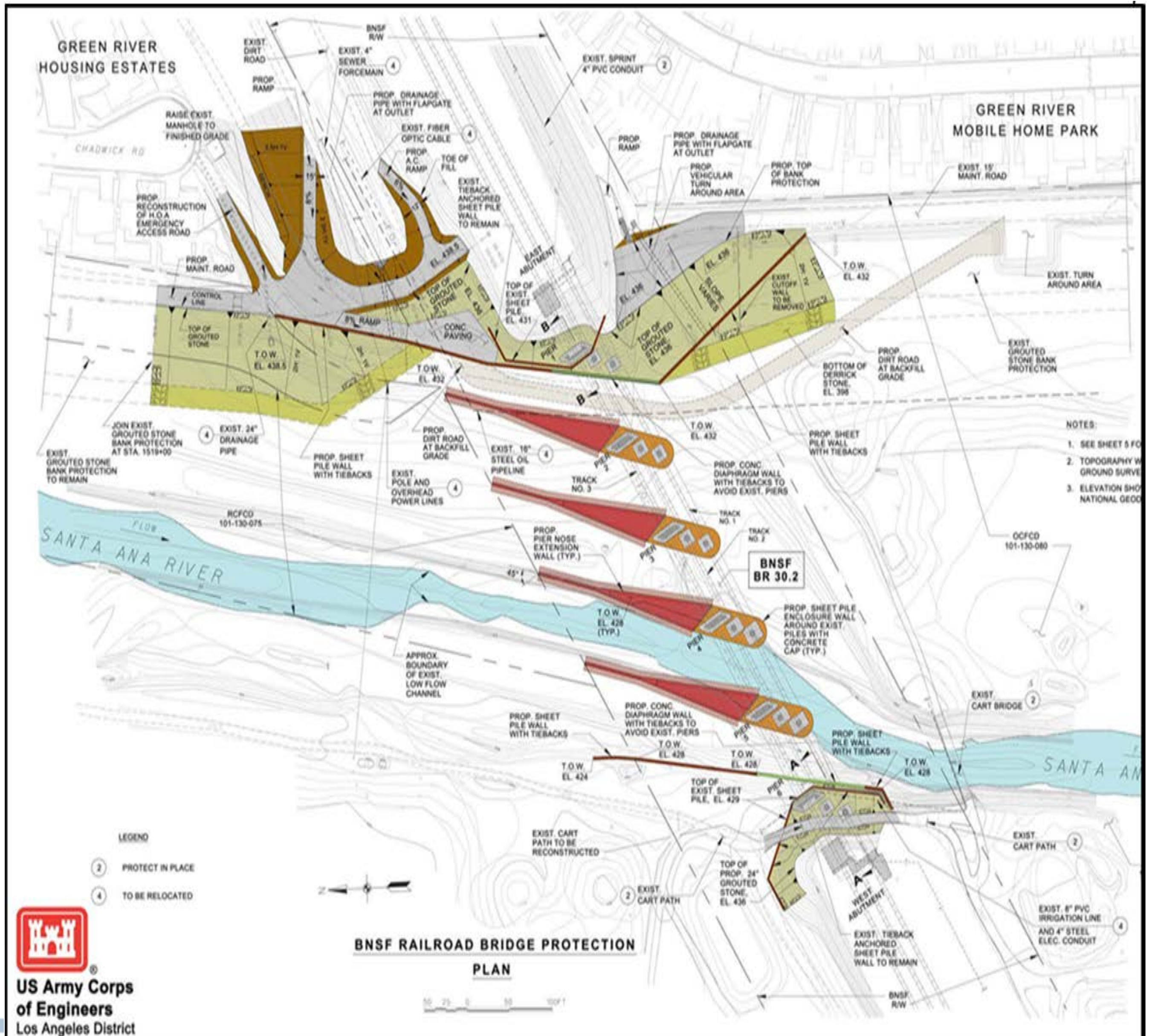
BNSF RR Bridge – view across left overbank

View downstream along pier columns

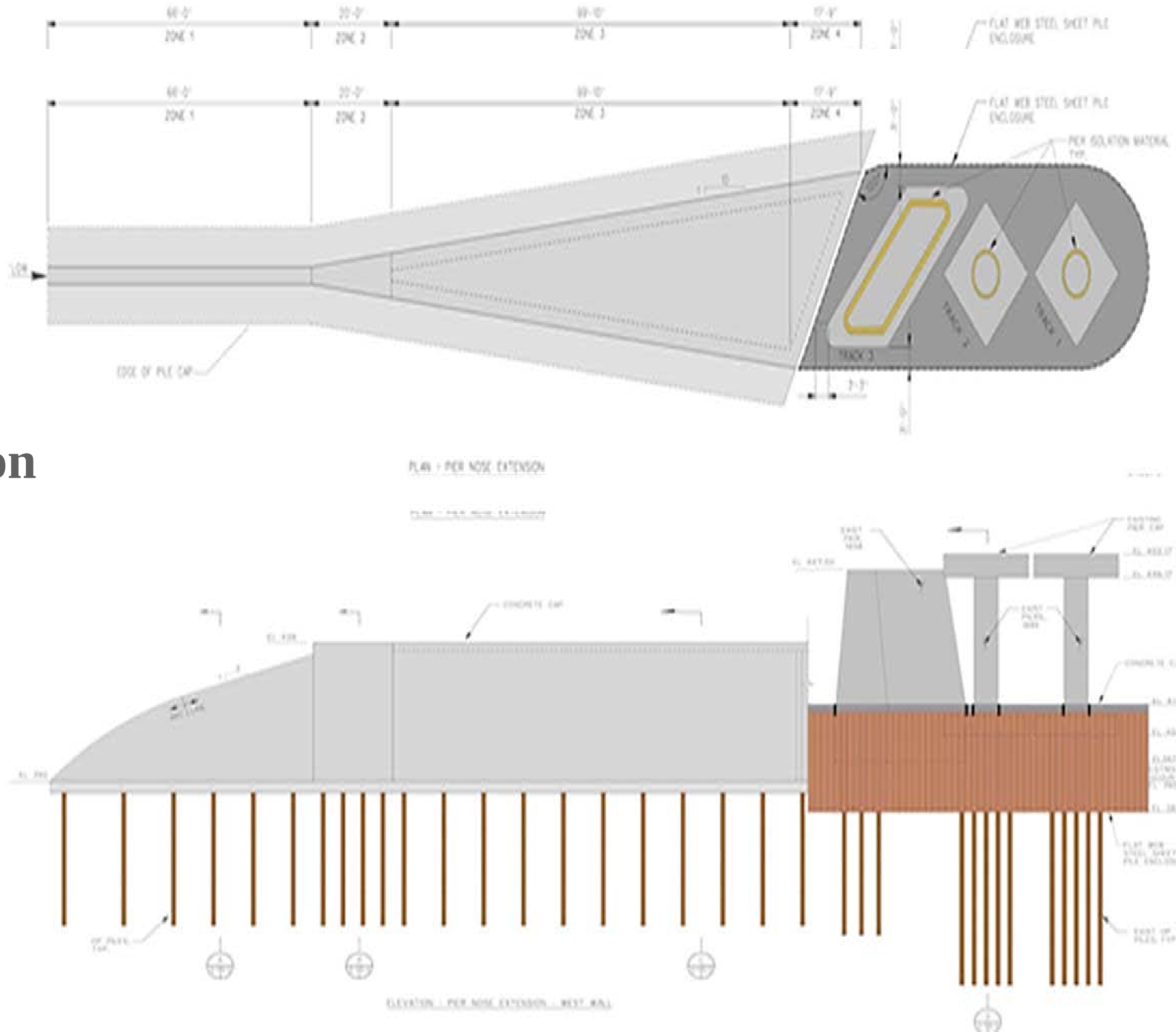
View across right overbank

2005 Flood: 10,000 cfs

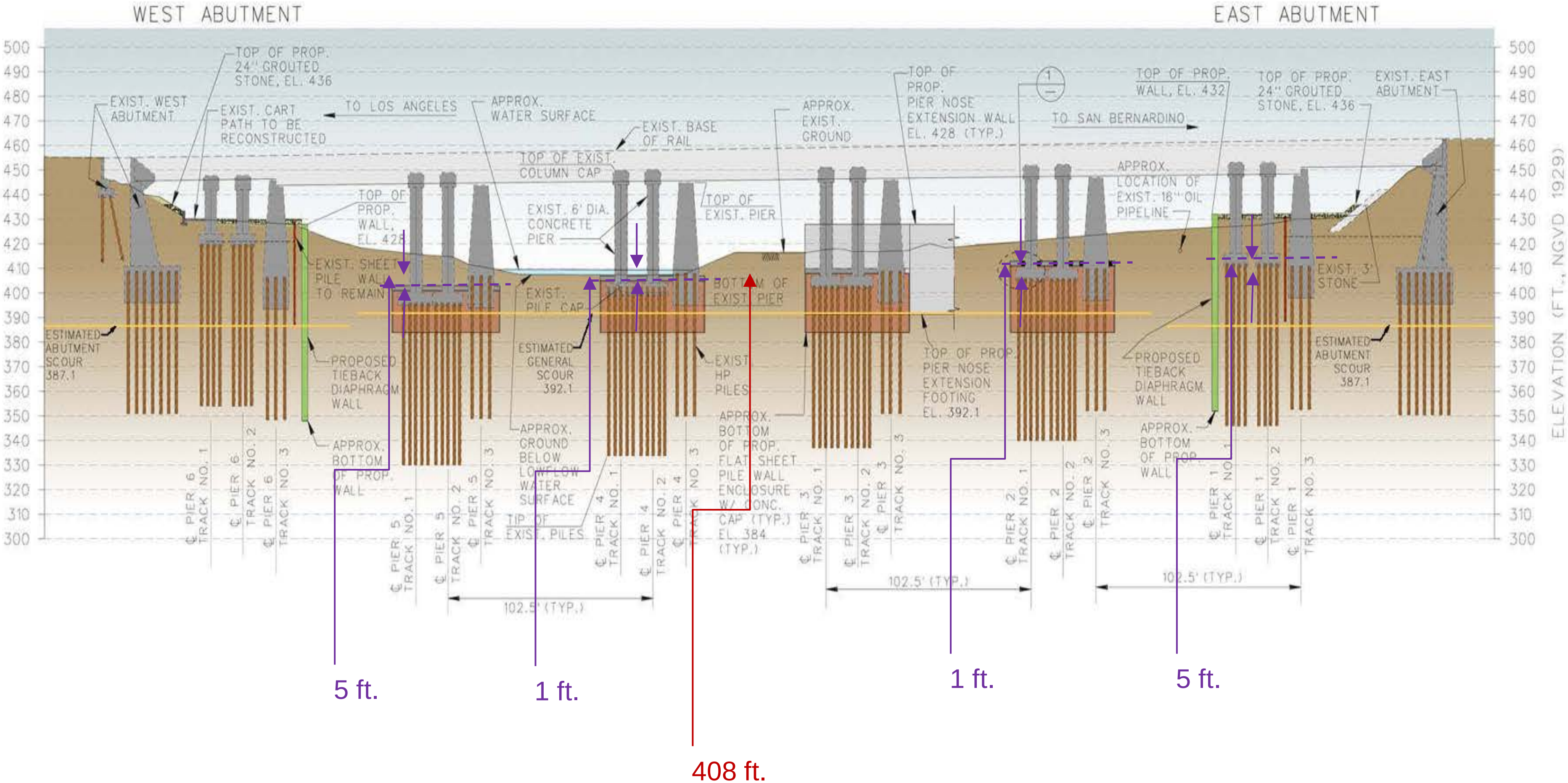
Current Proposed Project Plan



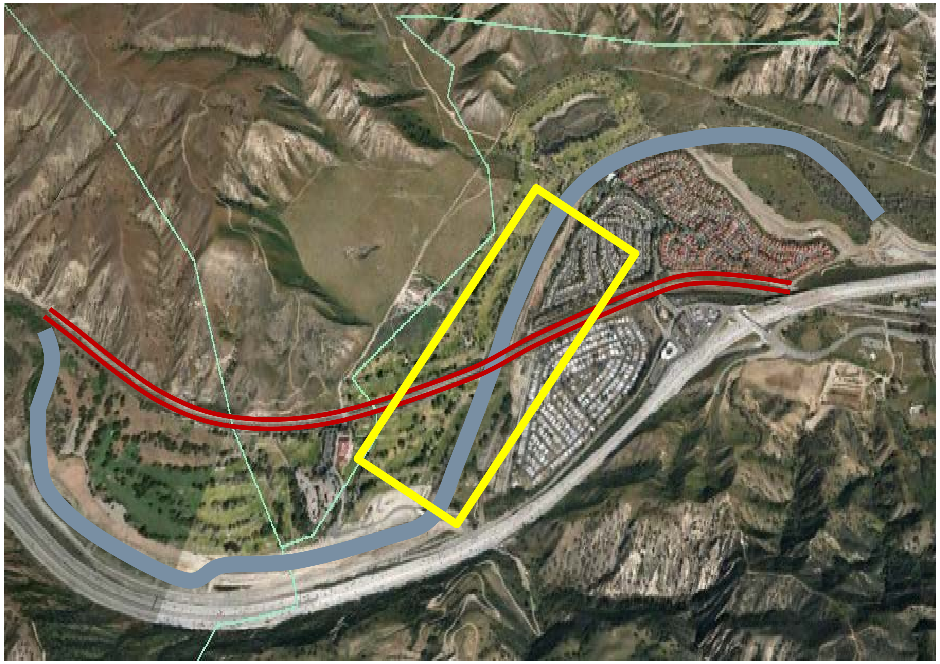
Proposed Bridge Pier Extension Configuration – Top and Side Views

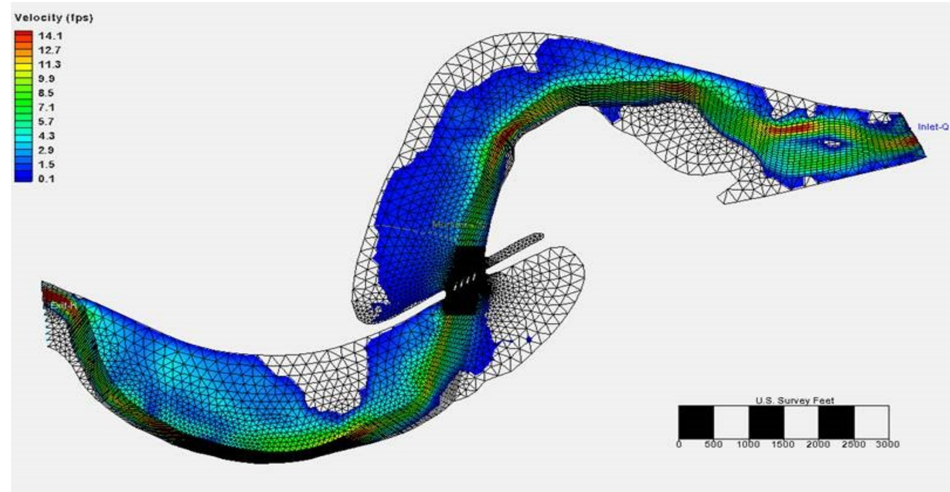


Cross Section Elevation View



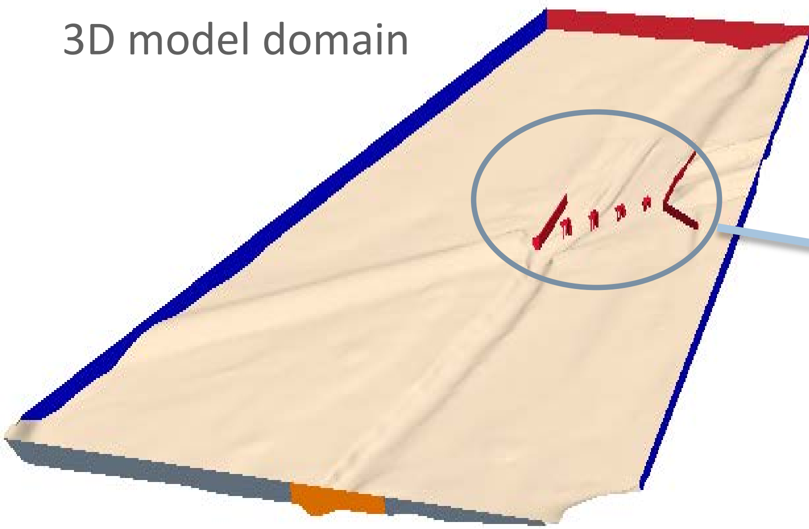
Computational domains

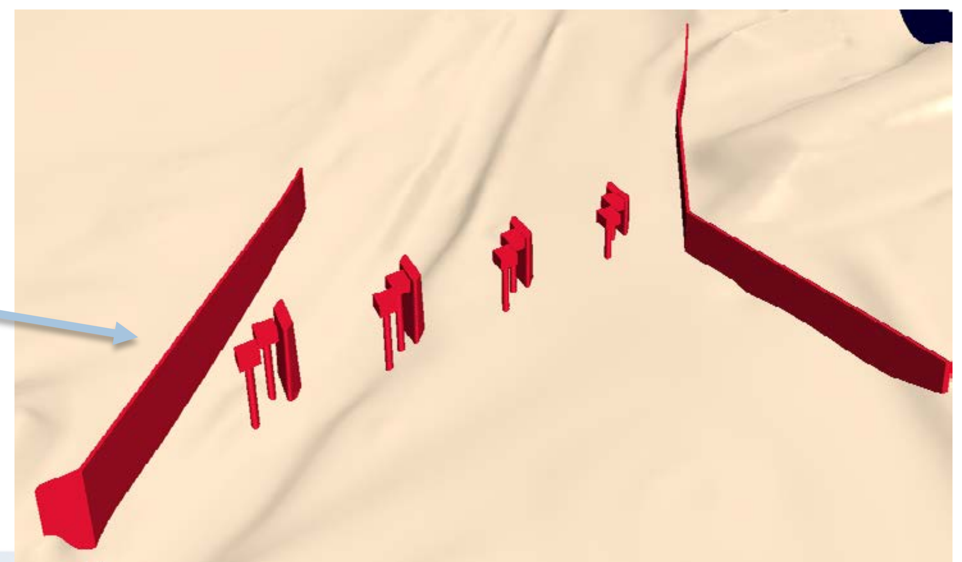




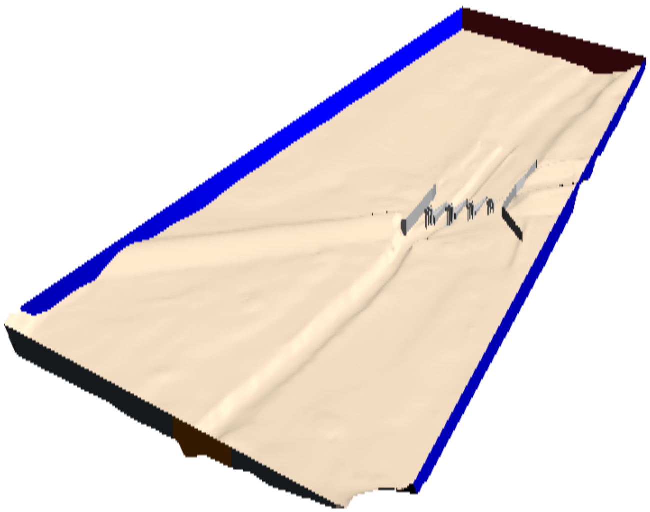
2D AdH model domain

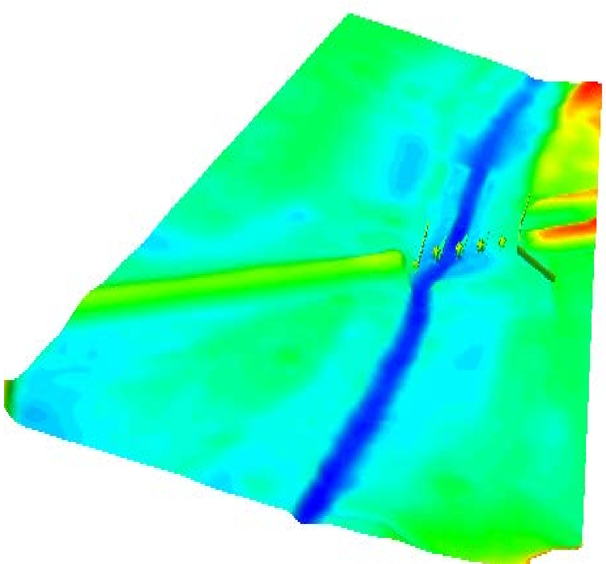
3D model domain

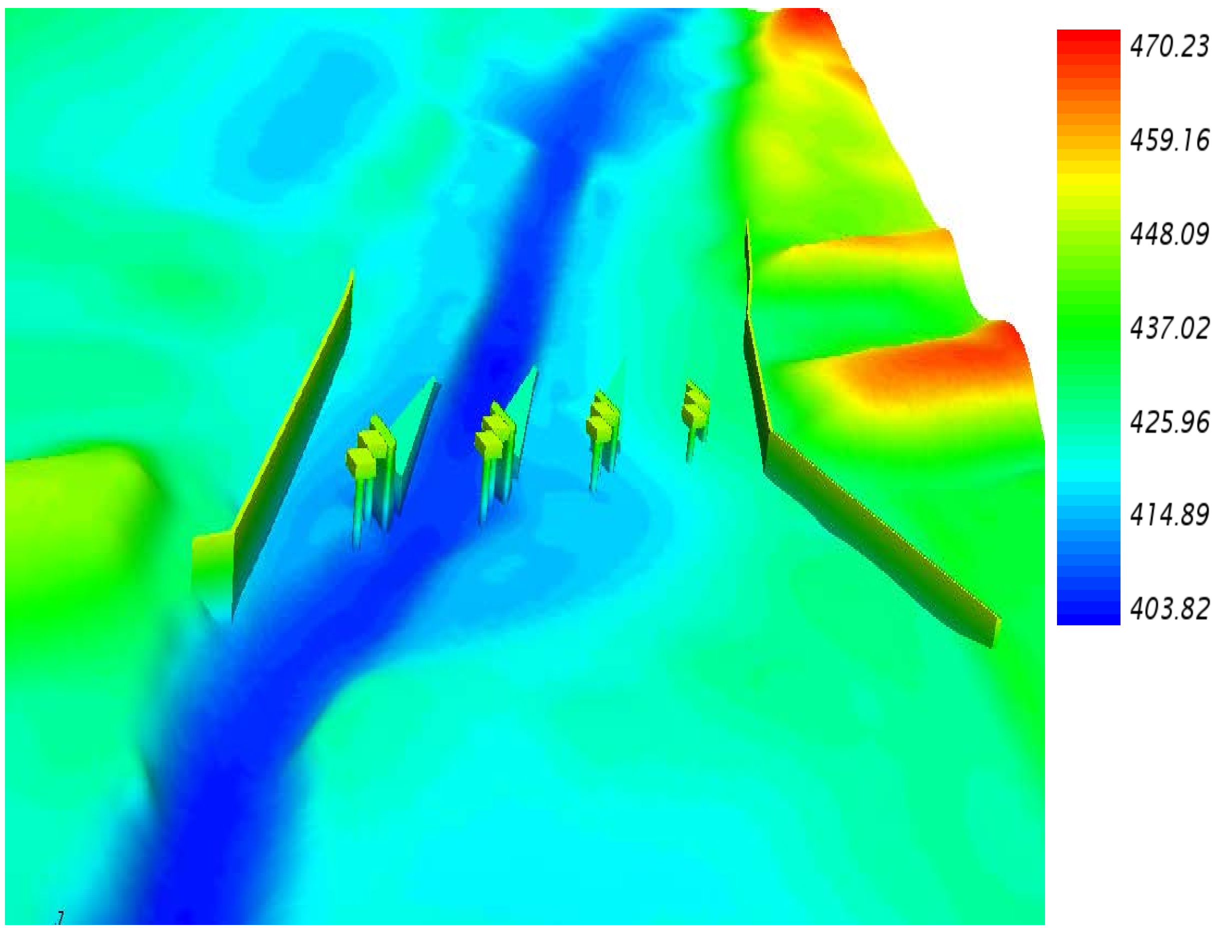




3D CFD Computational Domain
Current Bathymetry



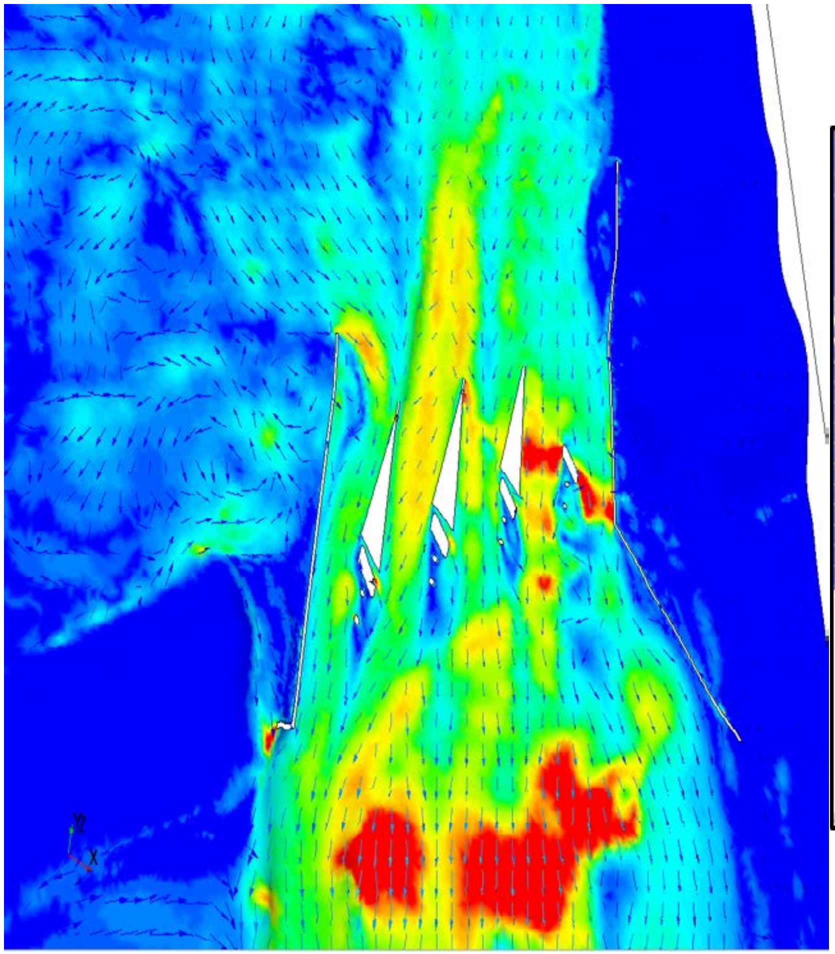




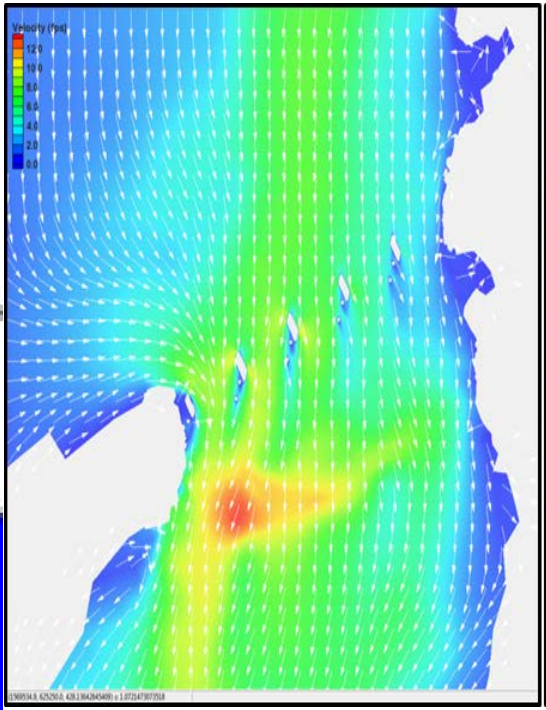
Current Bathymetry (Colors showing elevation in feet)

Velocity for 2D and 3D Models

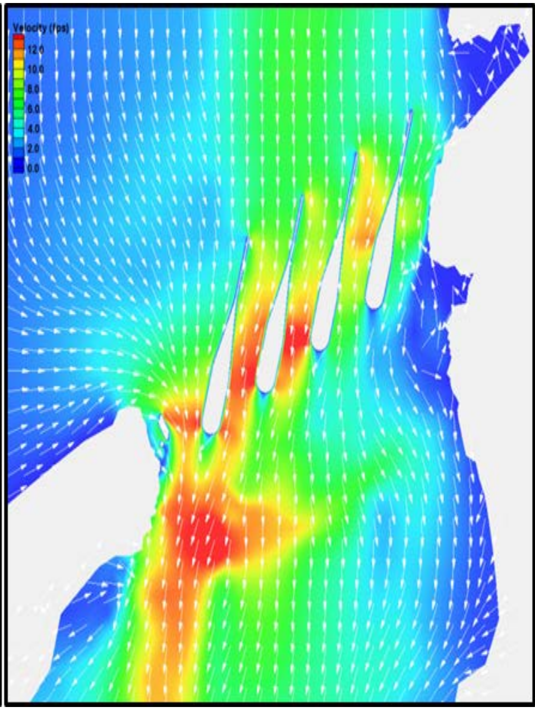
3D model velocity



Q190 no pier-Ext

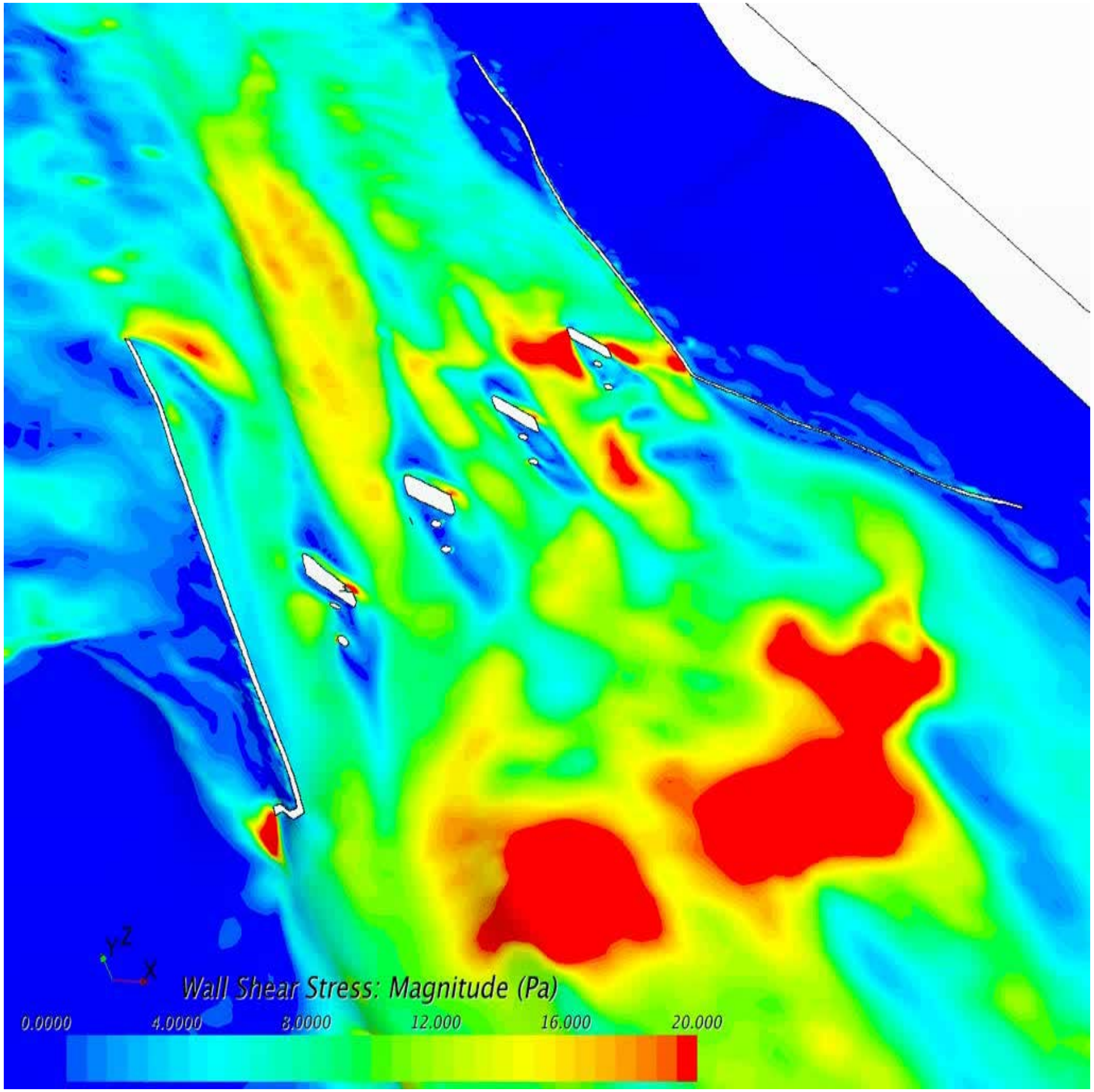


Q190 with pier-Ext

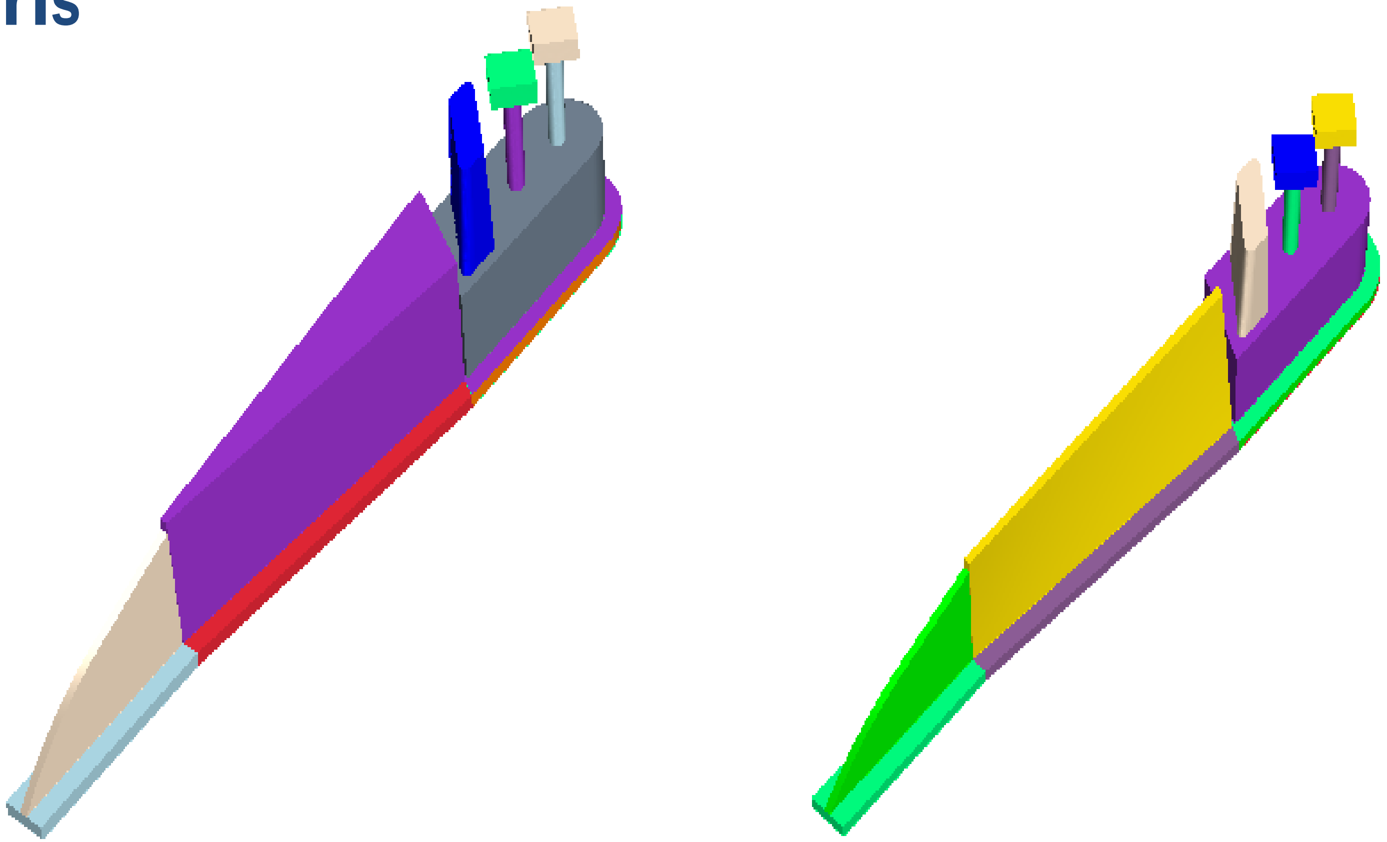


2D model runs performed with the AdH model velocity

Shear Stress – No Pier Extensions



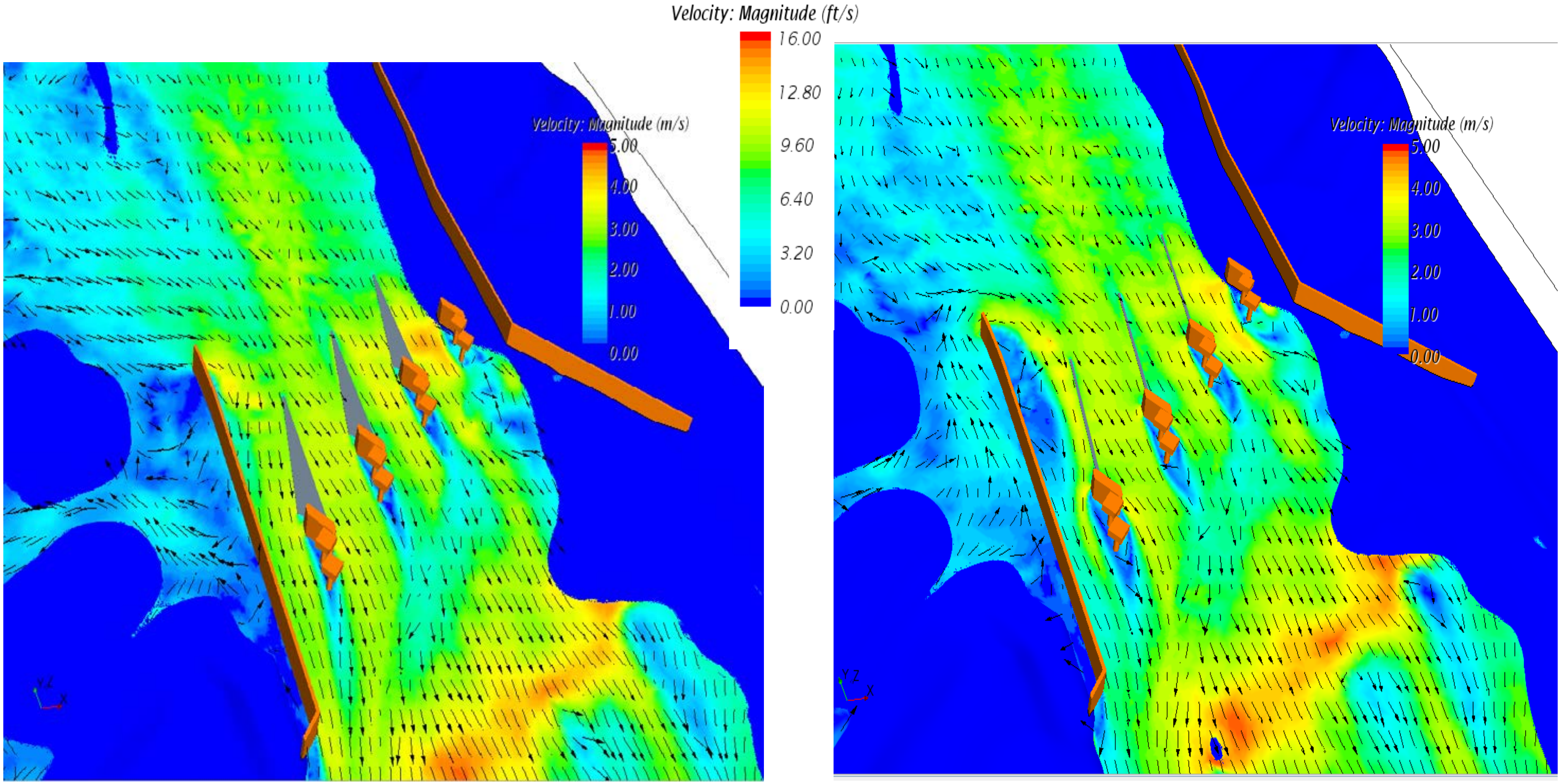
Effect of Tapering
Idea: More flow area & less potential to catch debris



Original Configuration

Tapered Configuration

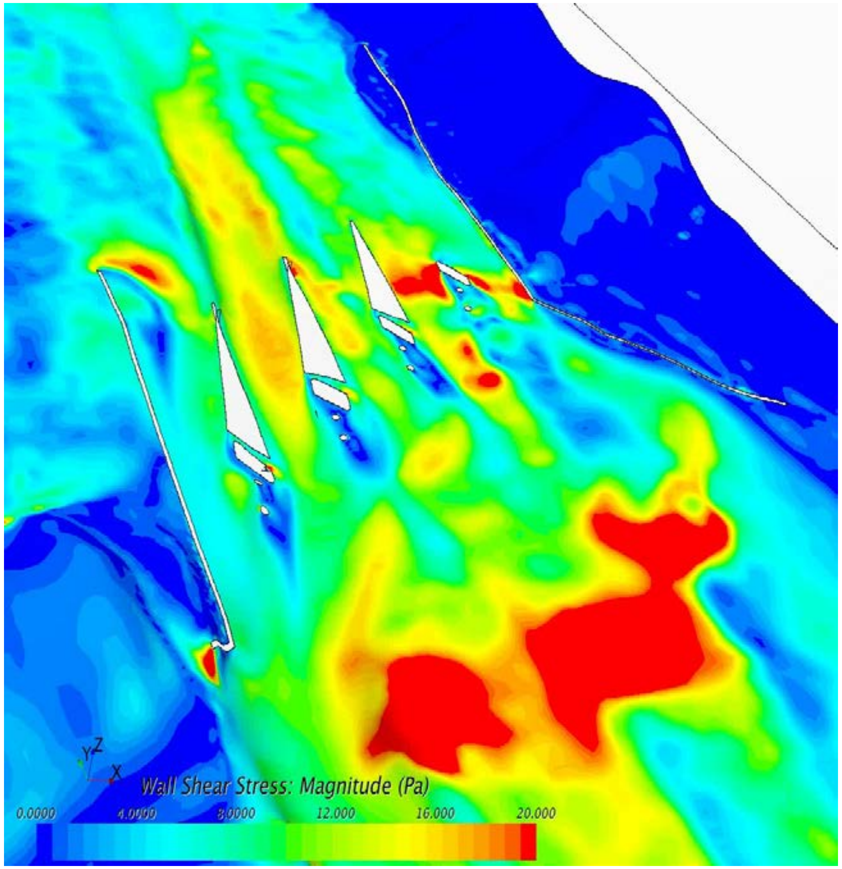
Velocity Magnitude (at elevation 425.5ft)



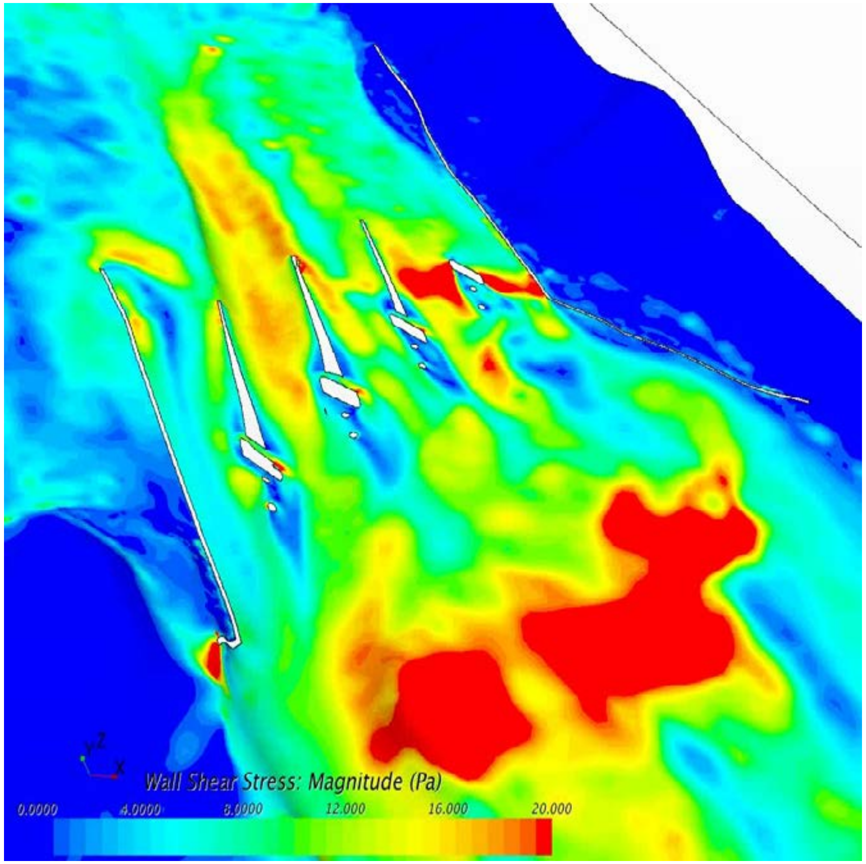
Non-Tapered Pier Extensions

Tapered Pier Extensions

Bed Shear Stress

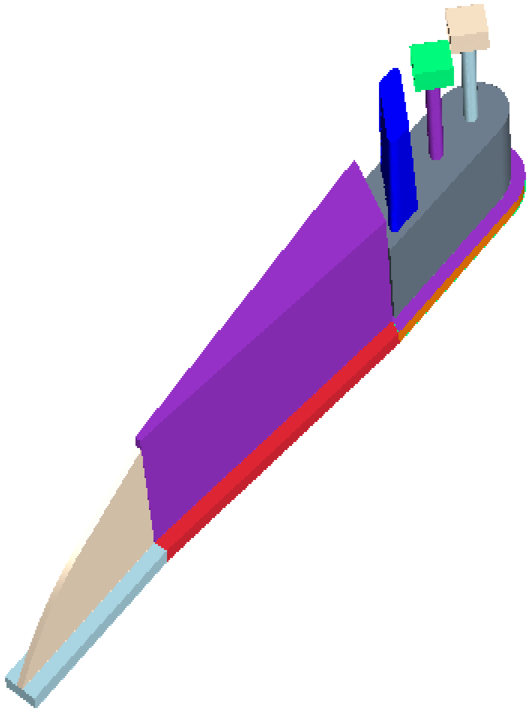


Non-Tapered Pier Extensions

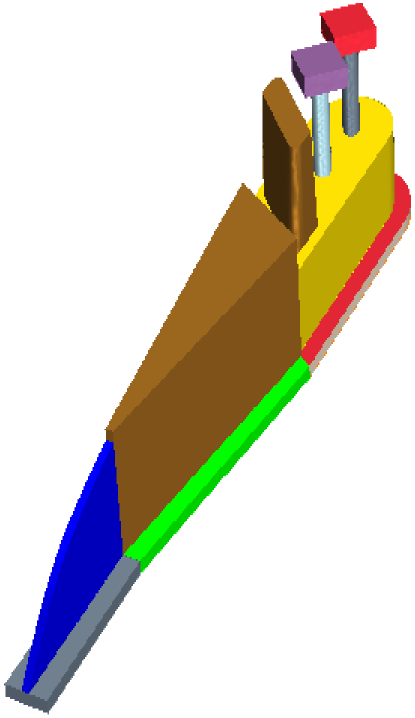


Tapered Pier Extensions

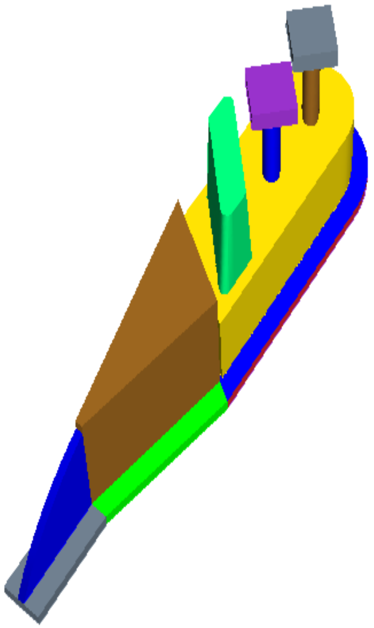
Effect of Reducing Pier Extension Length



Original Configuration



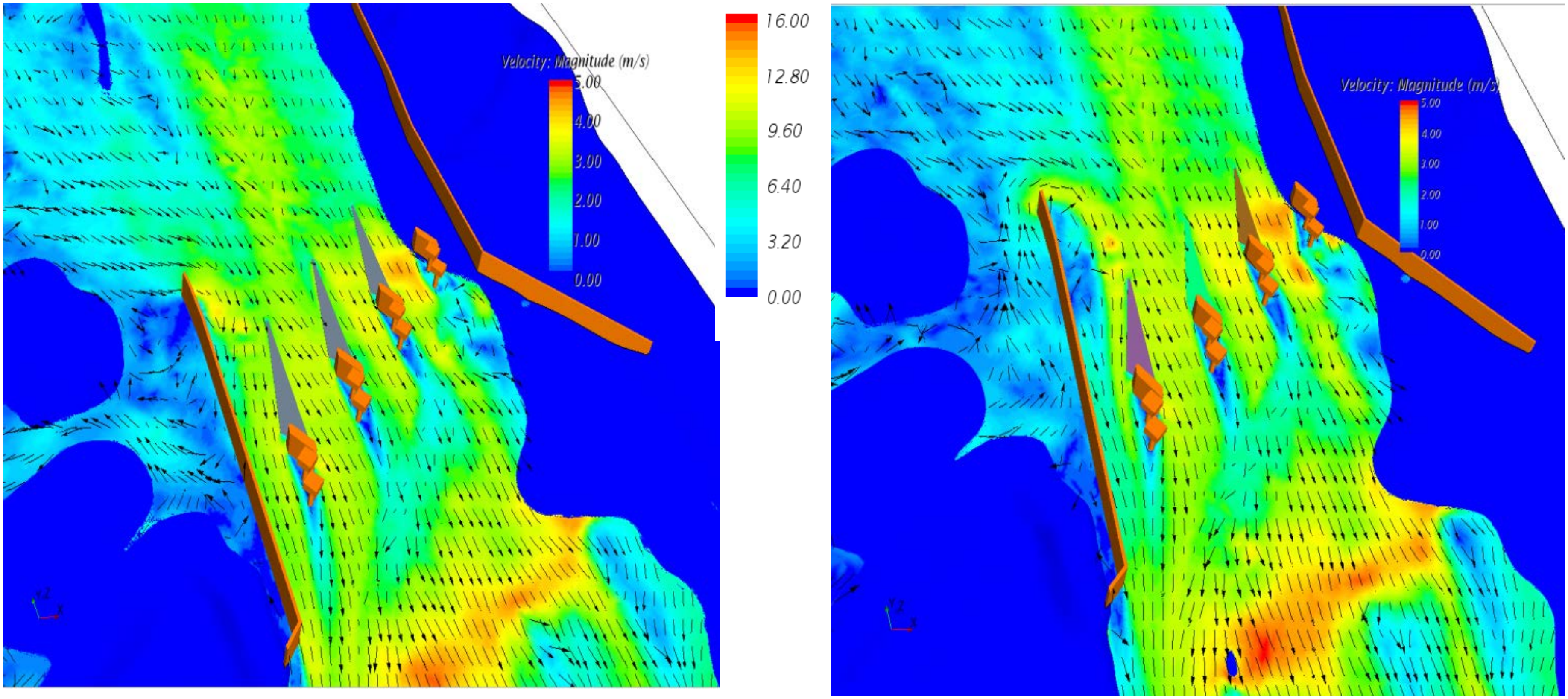
Extension Length 80%



Extension Length 50%

Velocity (below surface at 425.5 ft)

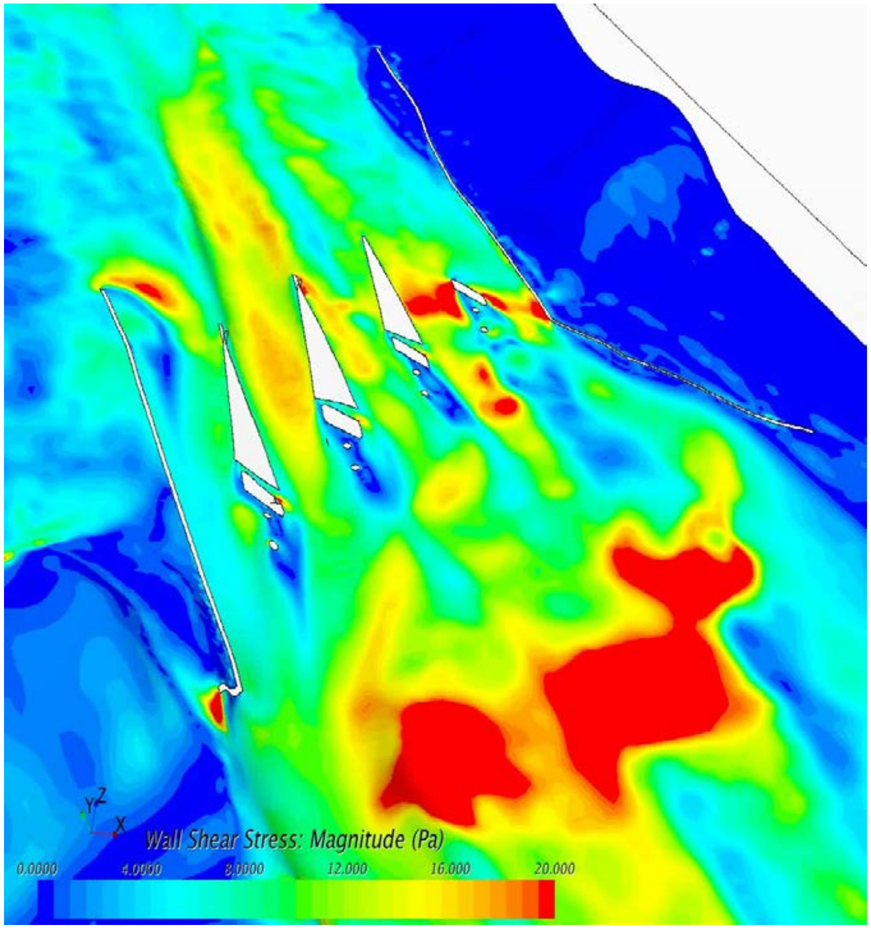
Velocity (ft/s)



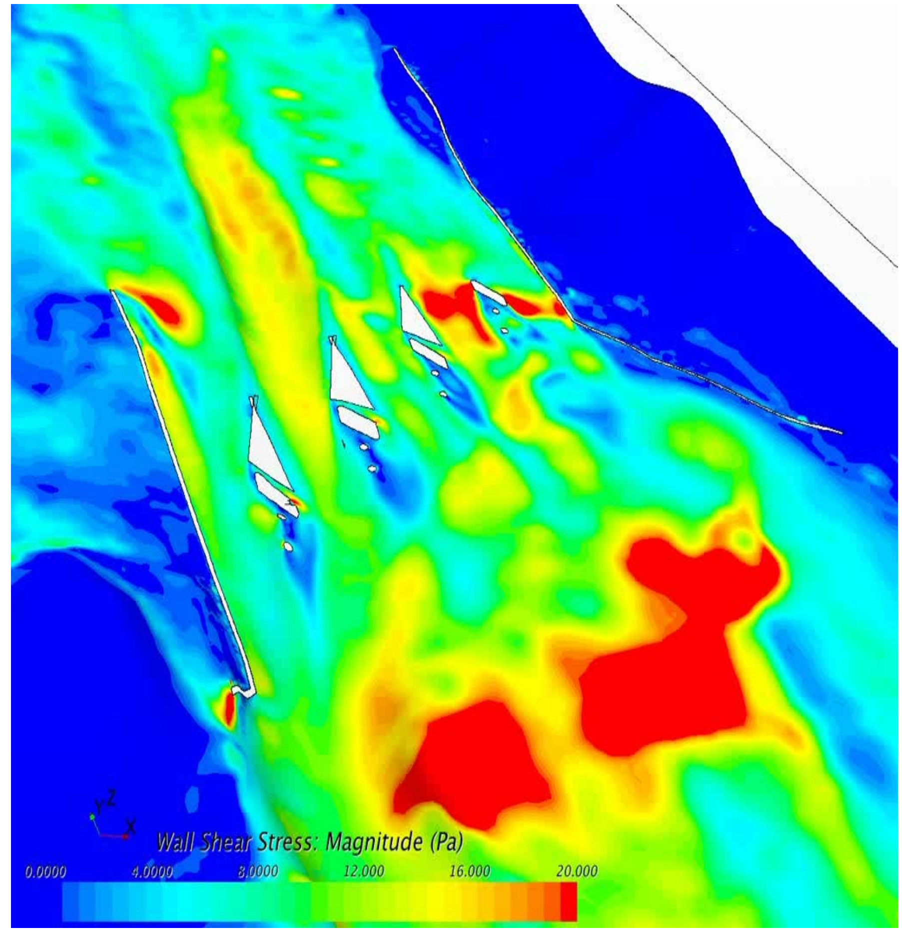
Original Configuration

Extension Length 50%

Bed Shear Stress with half the pier extension length

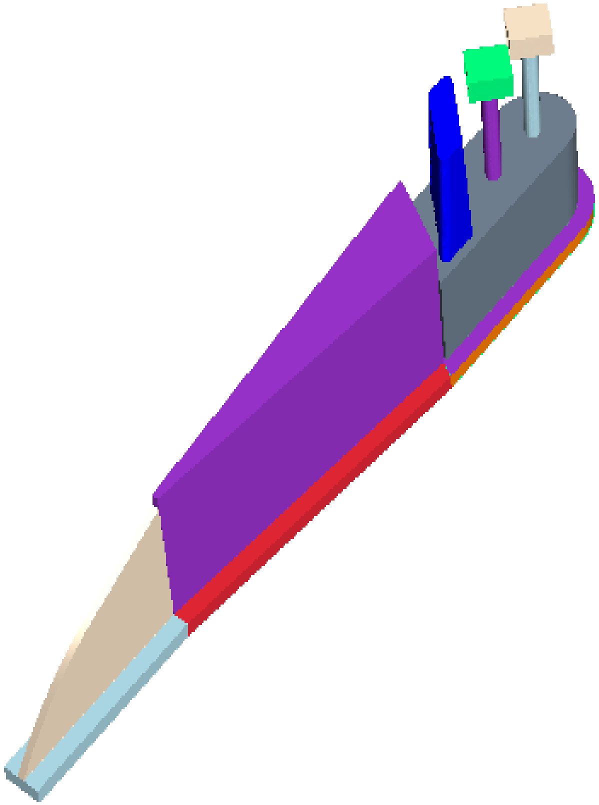


Original Configuration

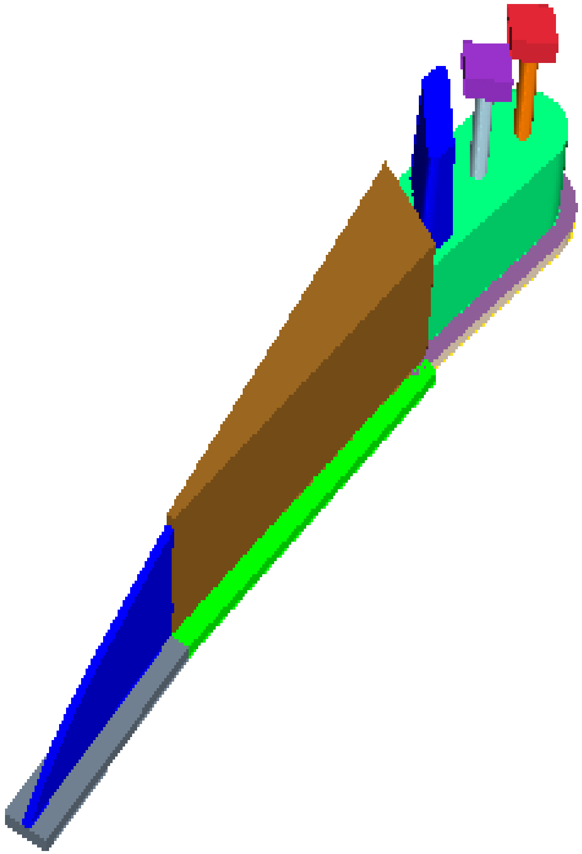


Extension Length 50%

Effect of Changing Angles

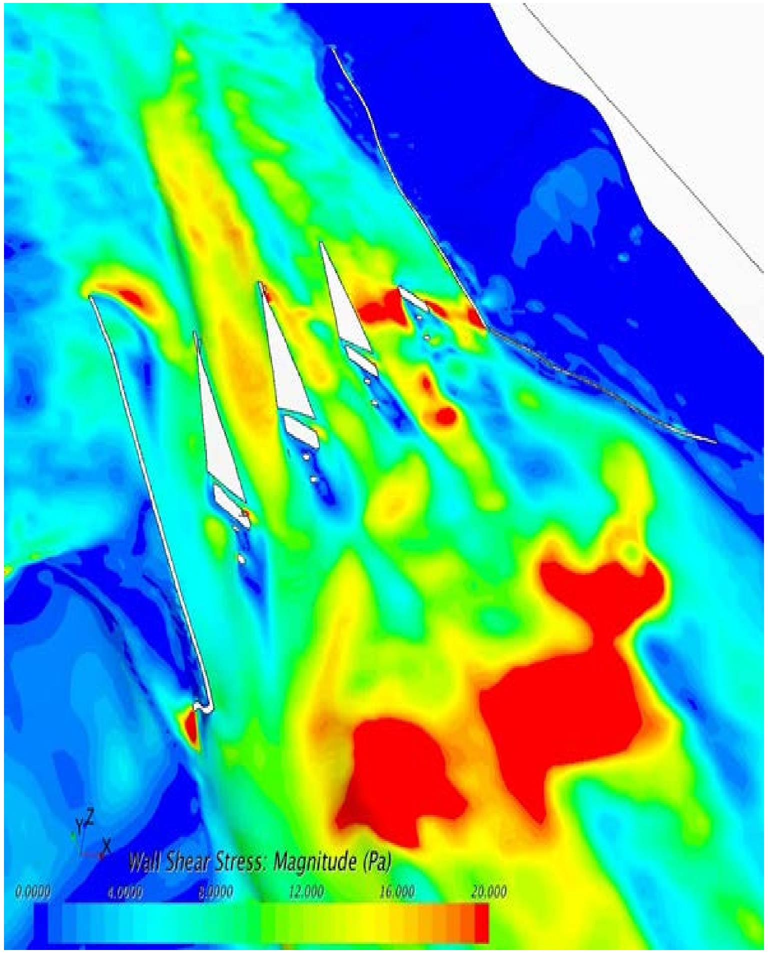


Original Configuration

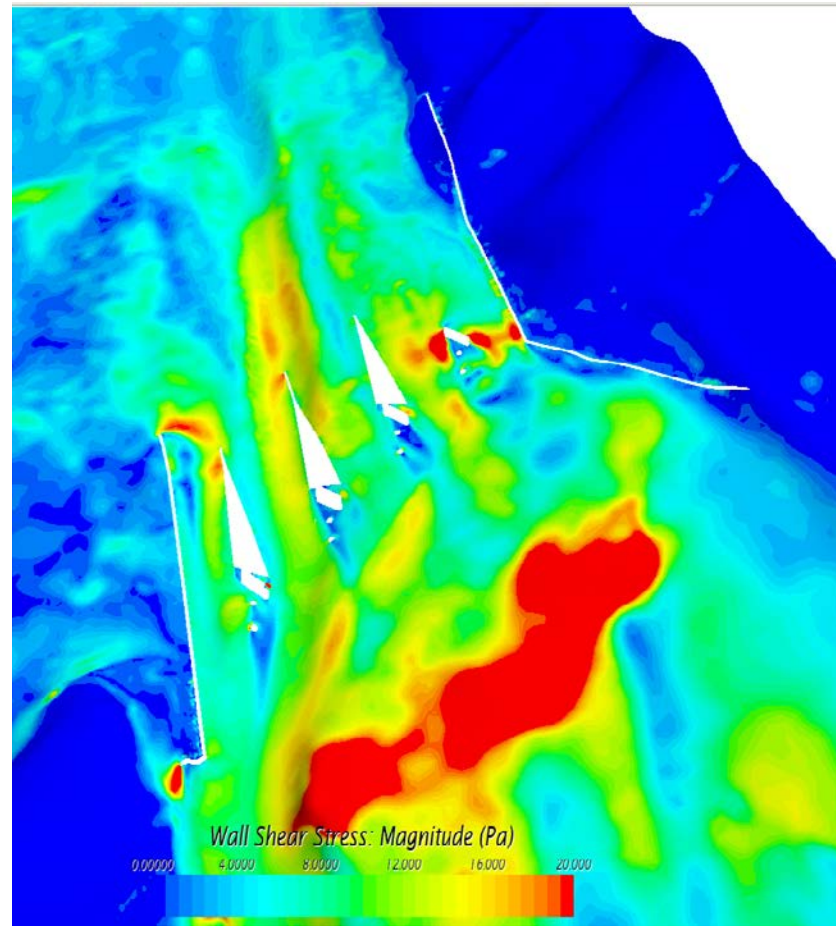


Angle 10^0

Bed Shear Stress

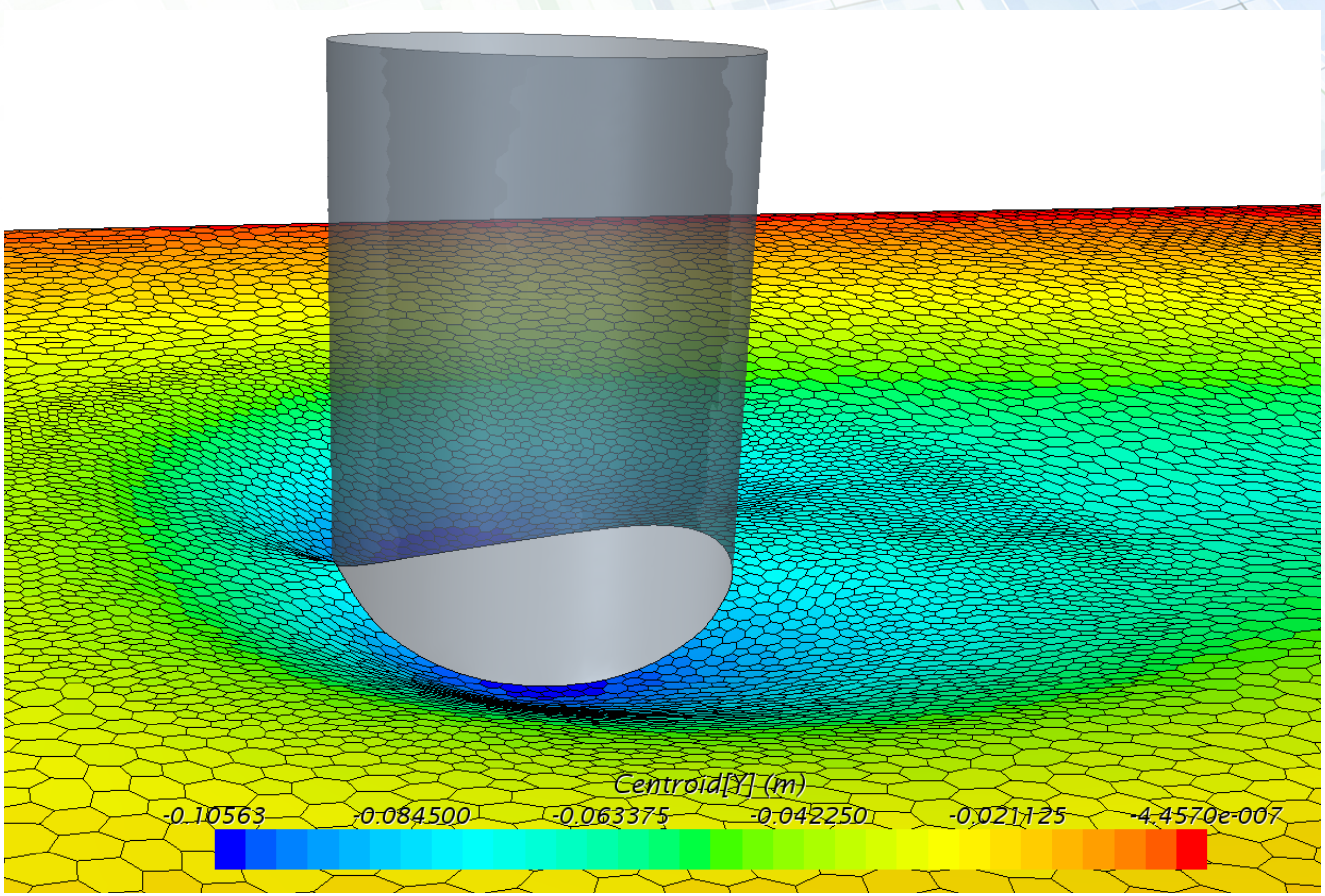


Original Configuration

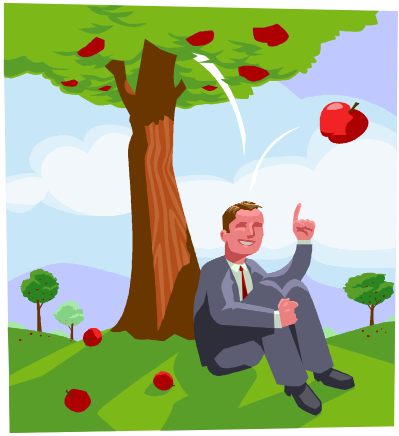


Extension Angle 10 deg

3D Scour Modeling Update



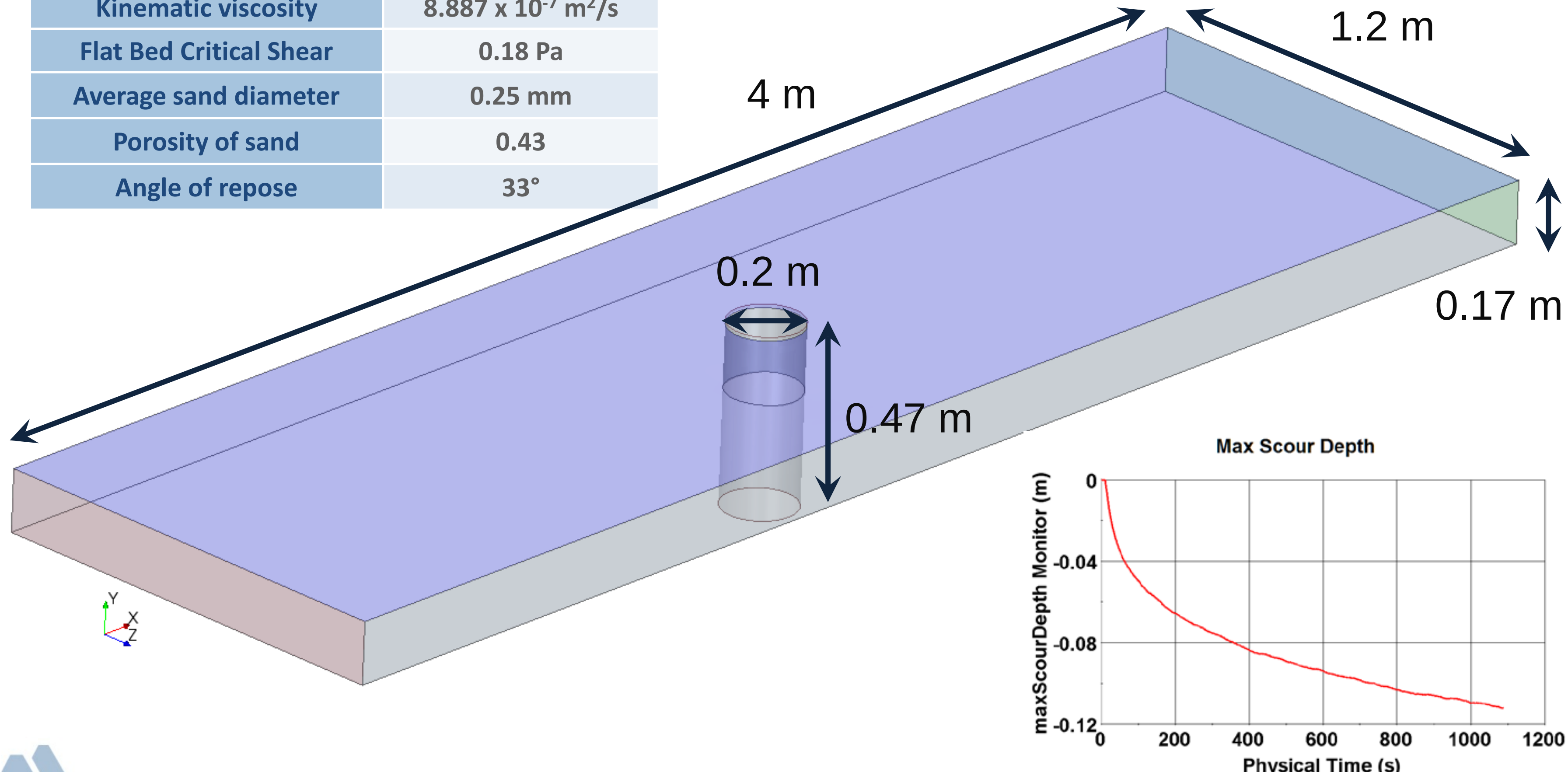
Three-dimensional scour analysis



- Erosion (scour) theory is a big area of research
  - Many papers published
- The theory must be implemented with procedures that run on digital computers
  - Requires much more than traditional differential equation solvers
- Computational machinery for scour analysis receives less attention than theory
  - Moving bed & deforming mesh
  - Particle models need mechanism for
    - Entry through a rough wall
    - Obtaining smooth settling rate distribution

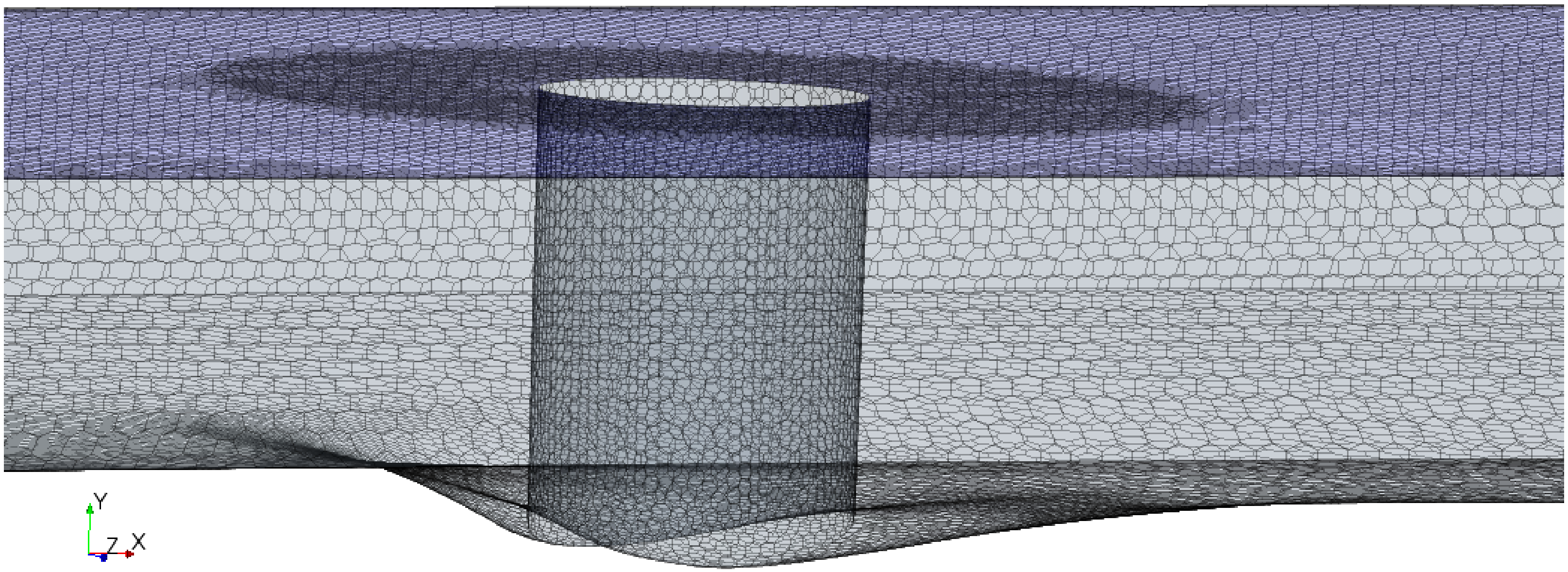
Model Scour Flume Geometry and Conditions

Flow Parameter	Value
Inlet velocity	0.5 m/s
Flow depth	0.17 m
Density of water	1000 kg/m^3
Density of sand	2650 kg/m^3
Kinematic viscosity	8.887 x 10^{-7} m^2/s
Flat Bed Critical Shear	0.18 Pa
Average sand diameter	0.25 mm
Porosity of sand	0.43
Angle of repose	33°

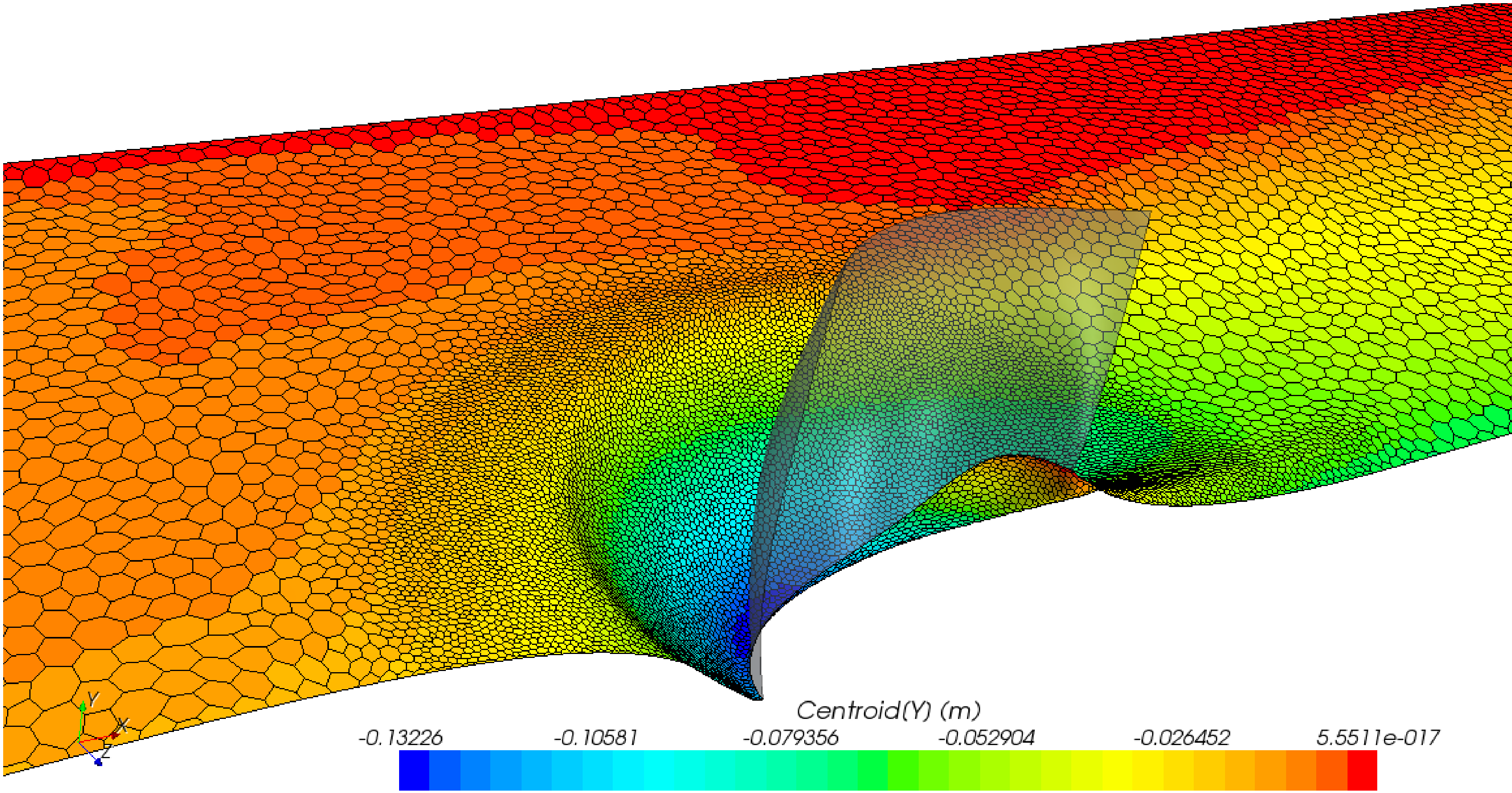


Model Components

- Van Rijn sediment erosion rate function
  - Easily replaced by other functions
  - Includes variable critical shear stress factor (lower for downhill, higher for uphill flow)
- Mesh morphing stretches/compresses mesh to maintain cell quality as scour displaces the bed (does not add or remove cell layers)
- Periodic remeshing to restore high cell quality to stretched meshed (adds cell layers where scour hole becomes deep and eliminates problem cells)
- Scour computation and remesh cycle done automatically with Java macro capability

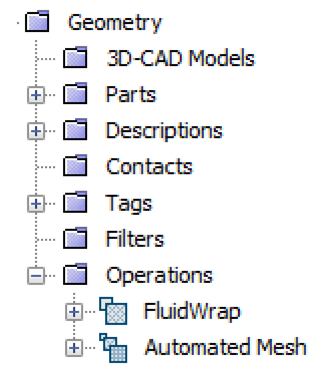


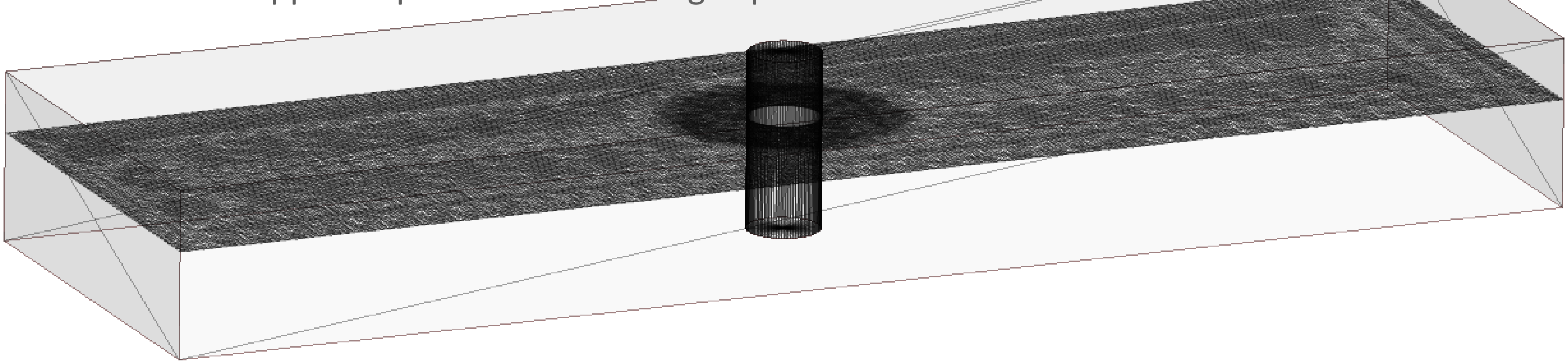
Scour after about 6 minutes with distorted pier after nearly 200 remeshings



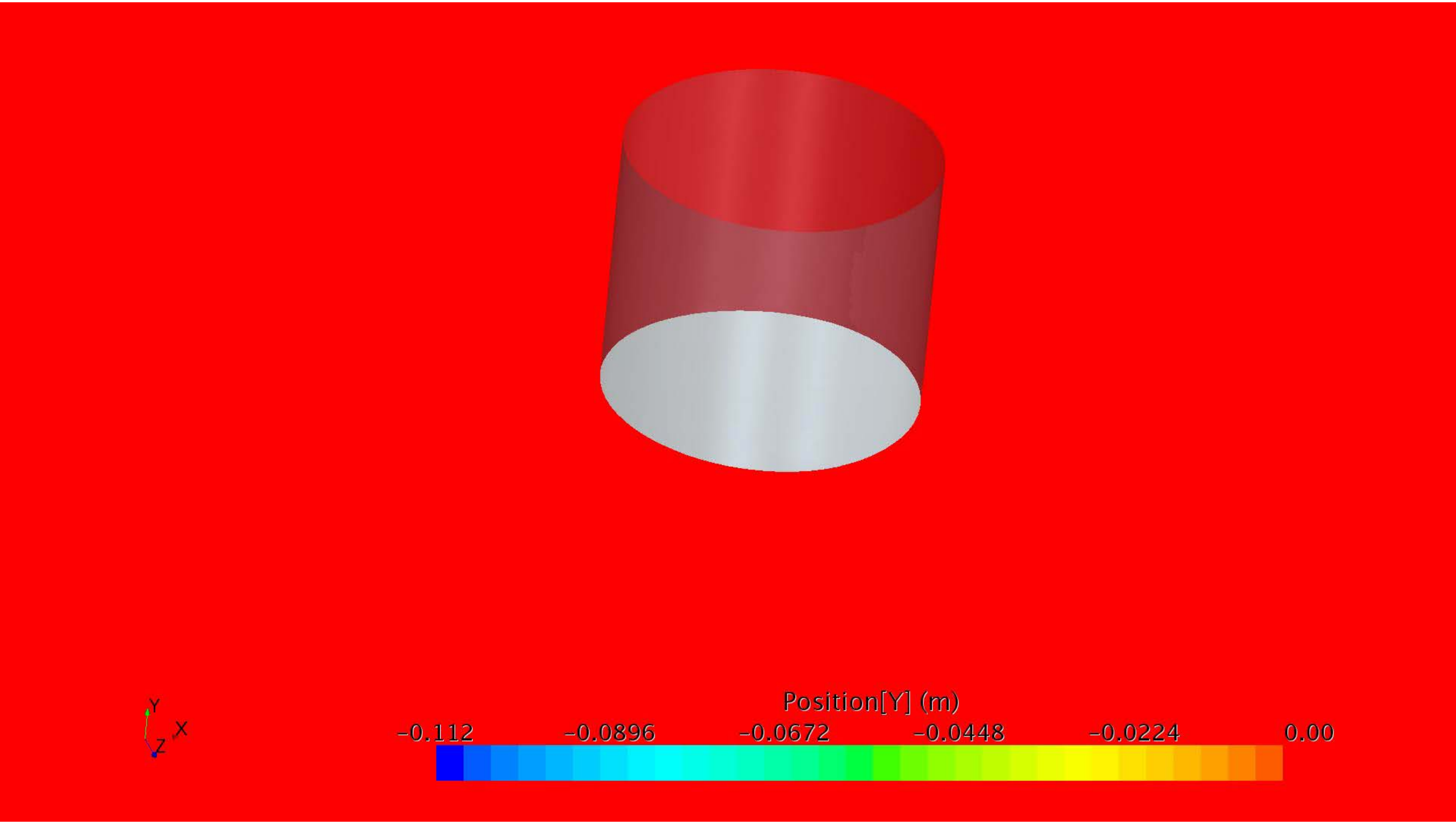
Repeated Remeshing Problem Nearly Solved

- Object surfaces in domain are distorted by floating morpher B.C. on pier
- New Slide along surface morpher B.C. solves the distortion problem
  - The new B.C. still has some bugs
  - Irregular and small cells at the pier-bed joint problem still present
- Parts base meshing best for remesh as needed
  - Define the bed surface as a separate part
  - Extract **only** bed surface to export in Nastran file at remesh time
  - Replace bed surface part
  - Use wrapper in large domain with bed surface to regenerate liquid region
  - Use mesh part operation to remesh liquid region
- The parts base remesh works in serial operation but not in parallel
  - Wrapper step fails when running in parallel mode

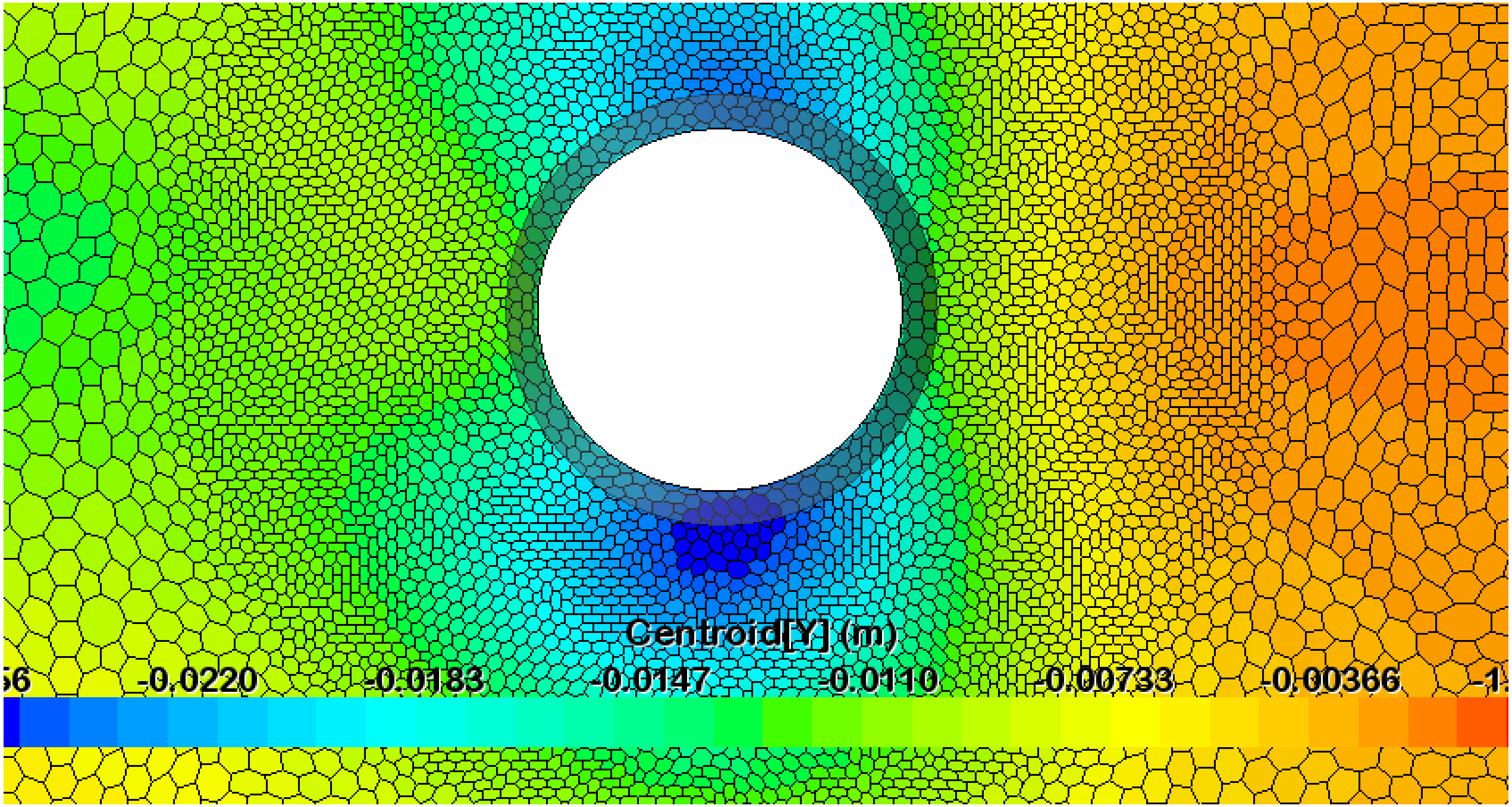




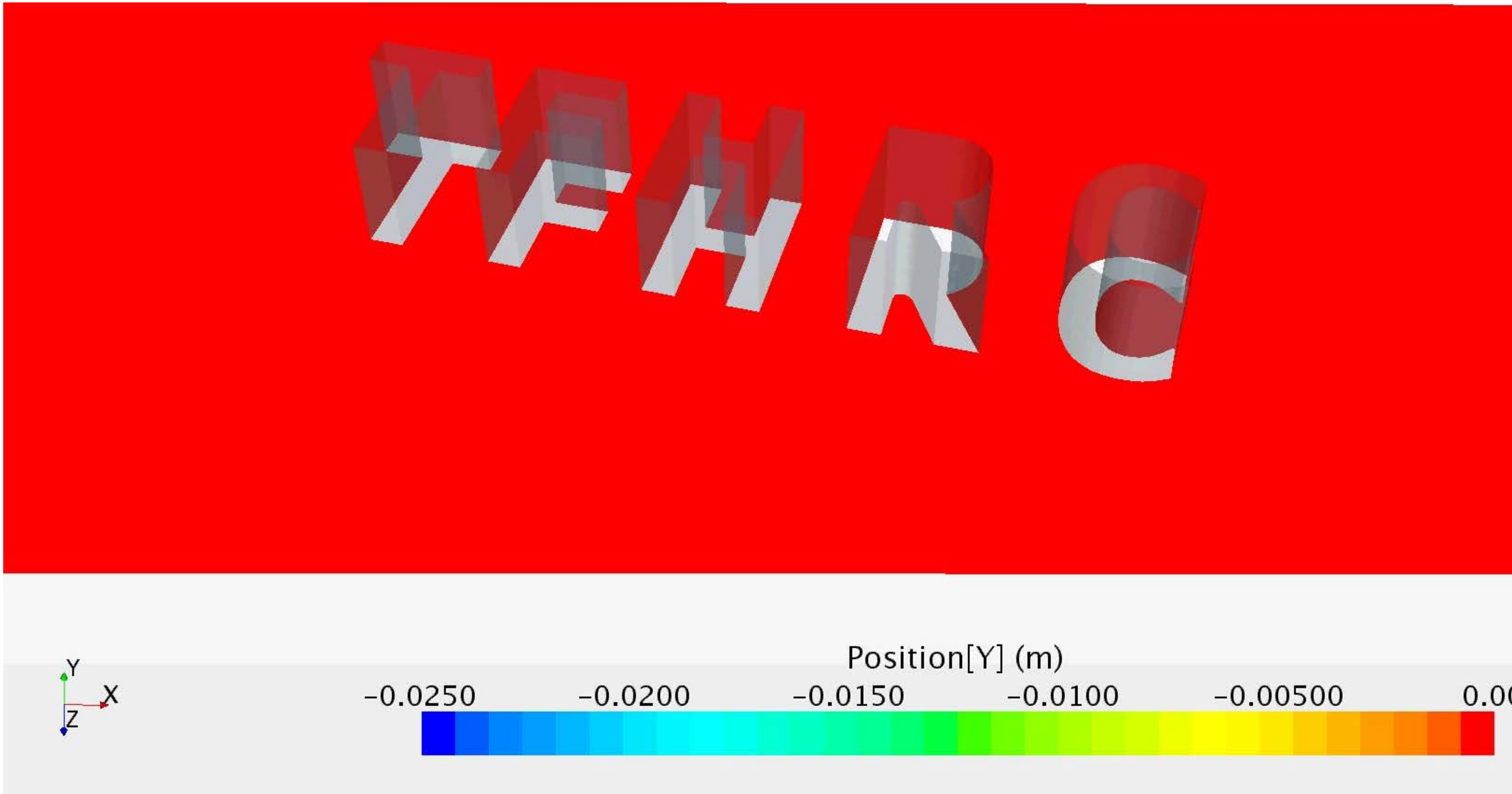
General and Pier Scour, First 20 Minutes



Pier is not out of round before a remesh



Scour Around Group of Complex Shaped Piers (Turner-Fairbank Highway Research Center)



Thank you for your attention

For more information,
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Questions
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