Development of FDOT SERF and RETA Design Equations for Coastal Scour when a Single Vertical Pile is Subjected to Wave Attack

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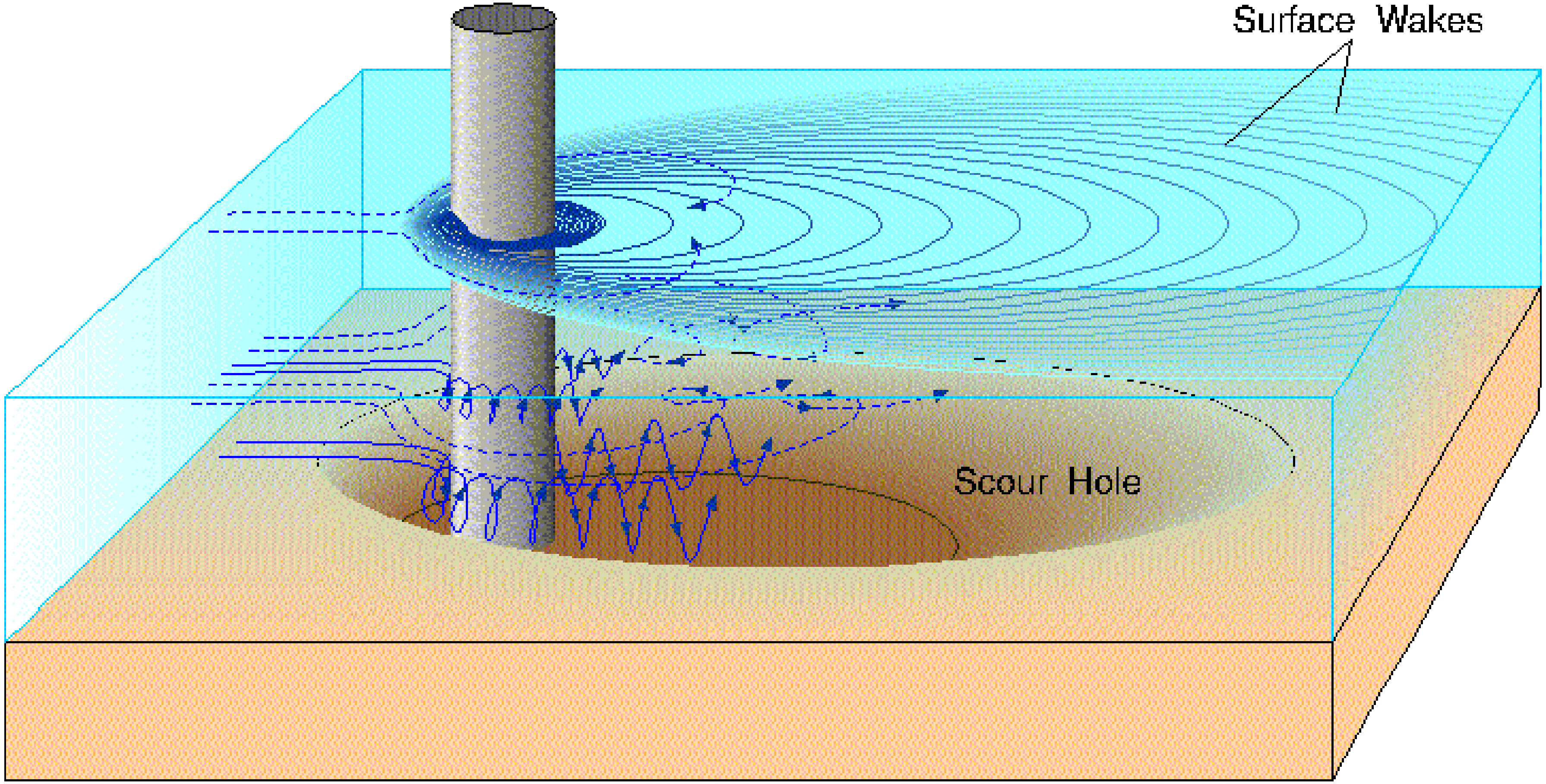
Local Scour



Local Scour Illustration

Motivation

- Florida is doing much better in scour! Of 12,000+ bridges, only 102 are now “scour critical”

- HEC-18/FDOT bridge scour manual may lead to significant overdesign cost/over-conservatism because soil conditions were not taken into account when designing for scour

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SERF/RETA – Motivation

Alternative scour design method:

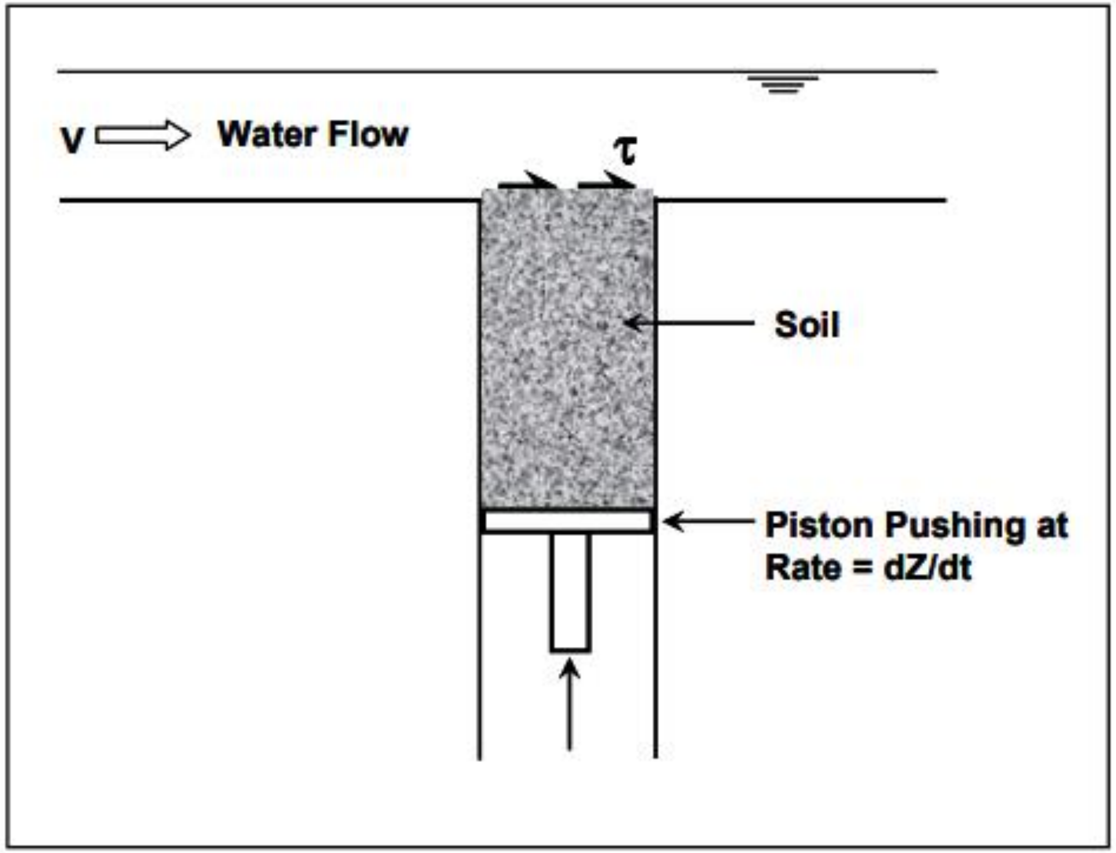
1. Develop conservative hydrograph to get flow as a function of time

2. Use hydrograph to estimate bed stresses in the field as a function of time

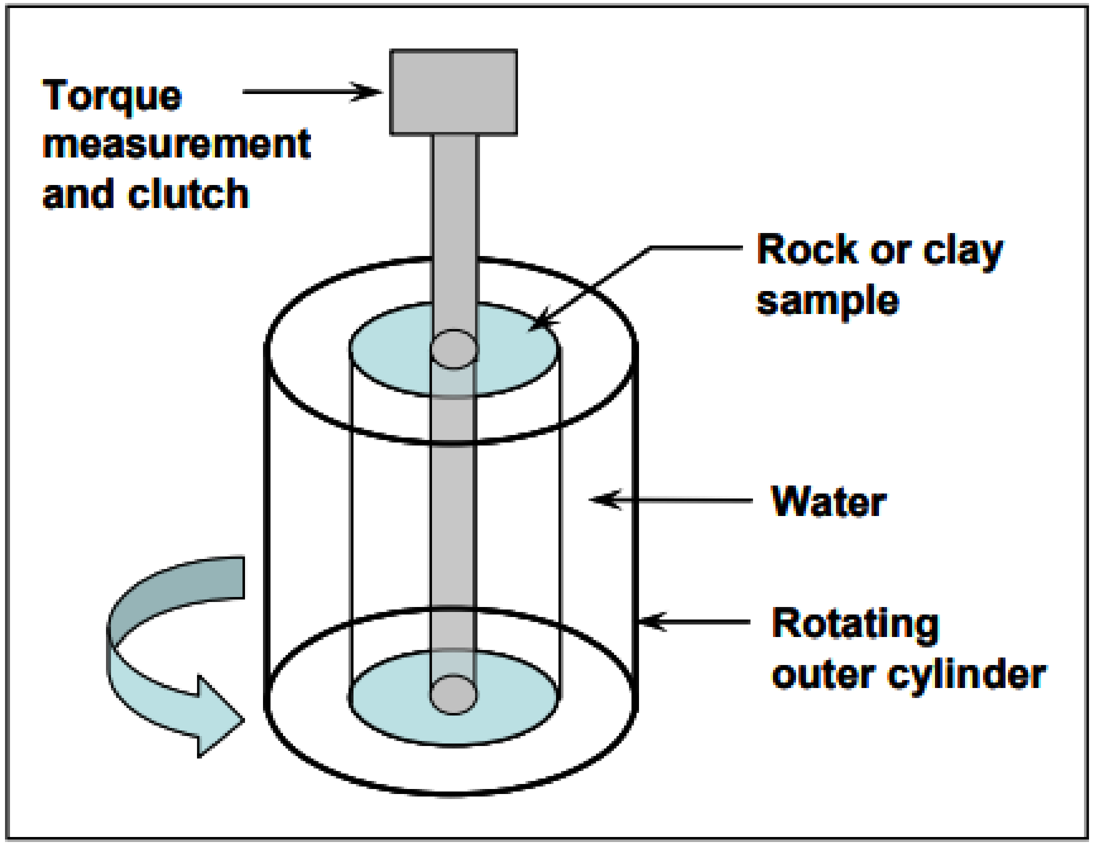
3. Collect soil sample and subject it to erosion testing; this gives relationship between stress and erosion

4. Each stress from (2) corresponds to an erosion rate from (3). Add the erosion rates together to get total scour depth over bridge's lifetime.

SERF – Scour Testing



Piston-style erosion test (SERF)



Rotational-Style Erosion Test (RETA)

SERF/RETA Steady Flow Equation

$$\tau_{max} = k_w k_{sp} k_{sh} k_\alpha \left[0.094\rho u^2 \left(\frac{1}{\log_{10} Re} - \frac{1}{10}\right)\right]$$

- τ_{max} = maximum bed stress
- $k_w, k_{sp}, k_{sh}, k_\alpha$ = correction factors for pier width, pile group spacing, pile length, attack angle
- u = mean velocity
- Re = Pile Reynolds Number = $\frac{uD}{\nu}$
  - D = pile diameter
  - ν = kinematic viscosity of water
- <u>Similar equation for wave action does not exist for field-scale structures!</u>

Toward Development of Wave-Specific Design Equations

- Briaud et al. (Texas A&M) showed that steady-flow max stress is a function of $\rho u^2 (1/\log_{10} Re \ - 1/10)$

- Sumer, Fredsoe et al. (Delft) showed that equilibrium wave scour is a function of KC and L/D
  - KC = Keuligan-Carpenter Number = $\frac{U_m T}{D}$
    - U_m = mean max upstream wave velocity from linear wave theory
    - T = wave period
  - L = wavelength

Toward Development of Wave-Specific Design Equations

- FDOT/Sheppard showed that equilibrium scour depth is a function of D/D_{50}

- Approach – model several piles under wave attack at small-scale; match data; and then upscale and fit parametric equations to data using *KC, L/D, Re, and* D/D_{50} as nondimensional governing variables

Model Parameters

- Proposed – RANS/$k\epsilon$ modeling – this blows up due to turbulent production/diffusion balancing assumption

- Solution – Detached Eddy Simulation (DES) – combined best aspects of Large-Eddy Simulation (LES) with wall effects associated with RANS model

- Turbulence model coupled to volume of fluid (VOF) model to account for air-water free-surface

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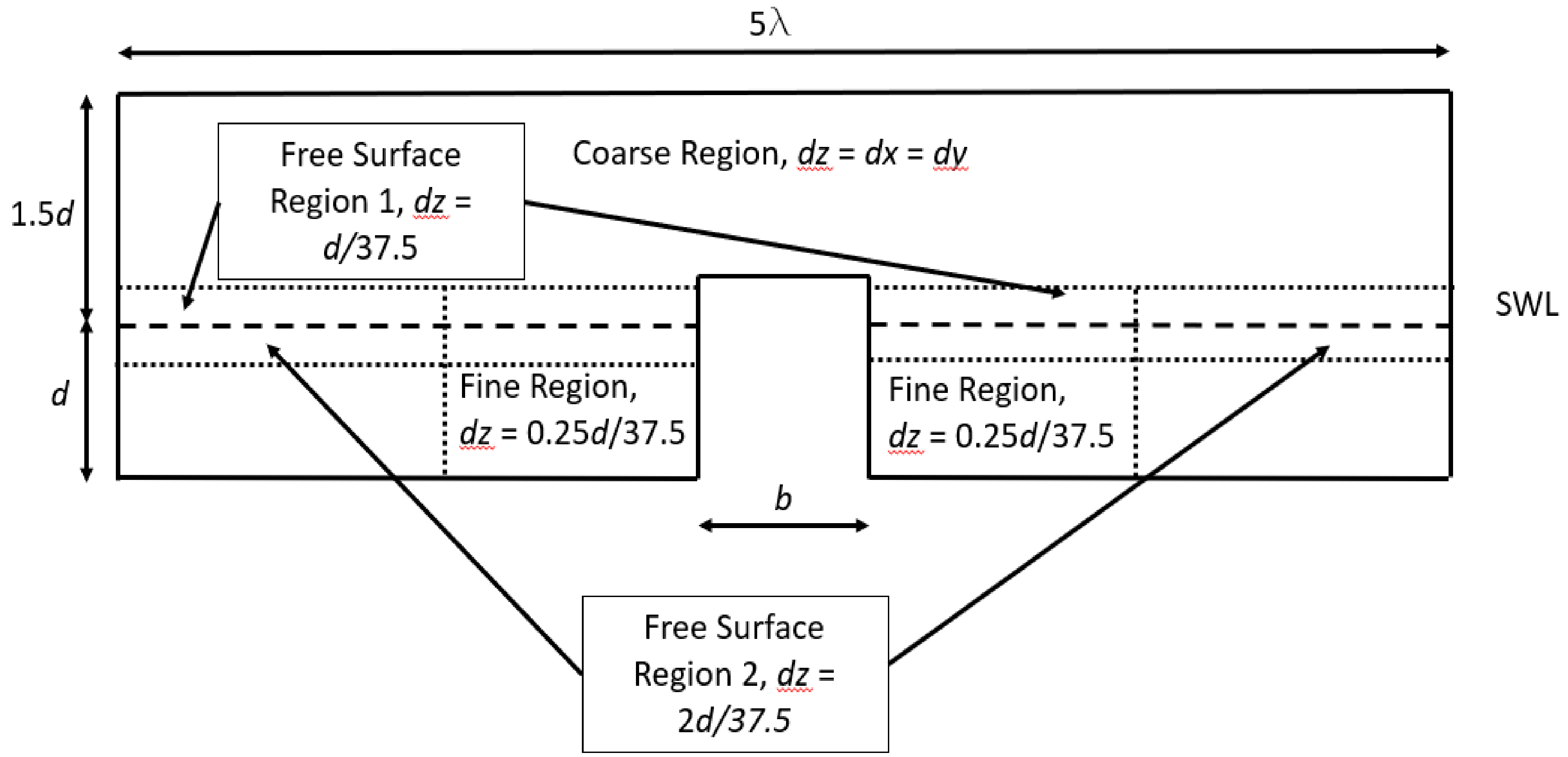
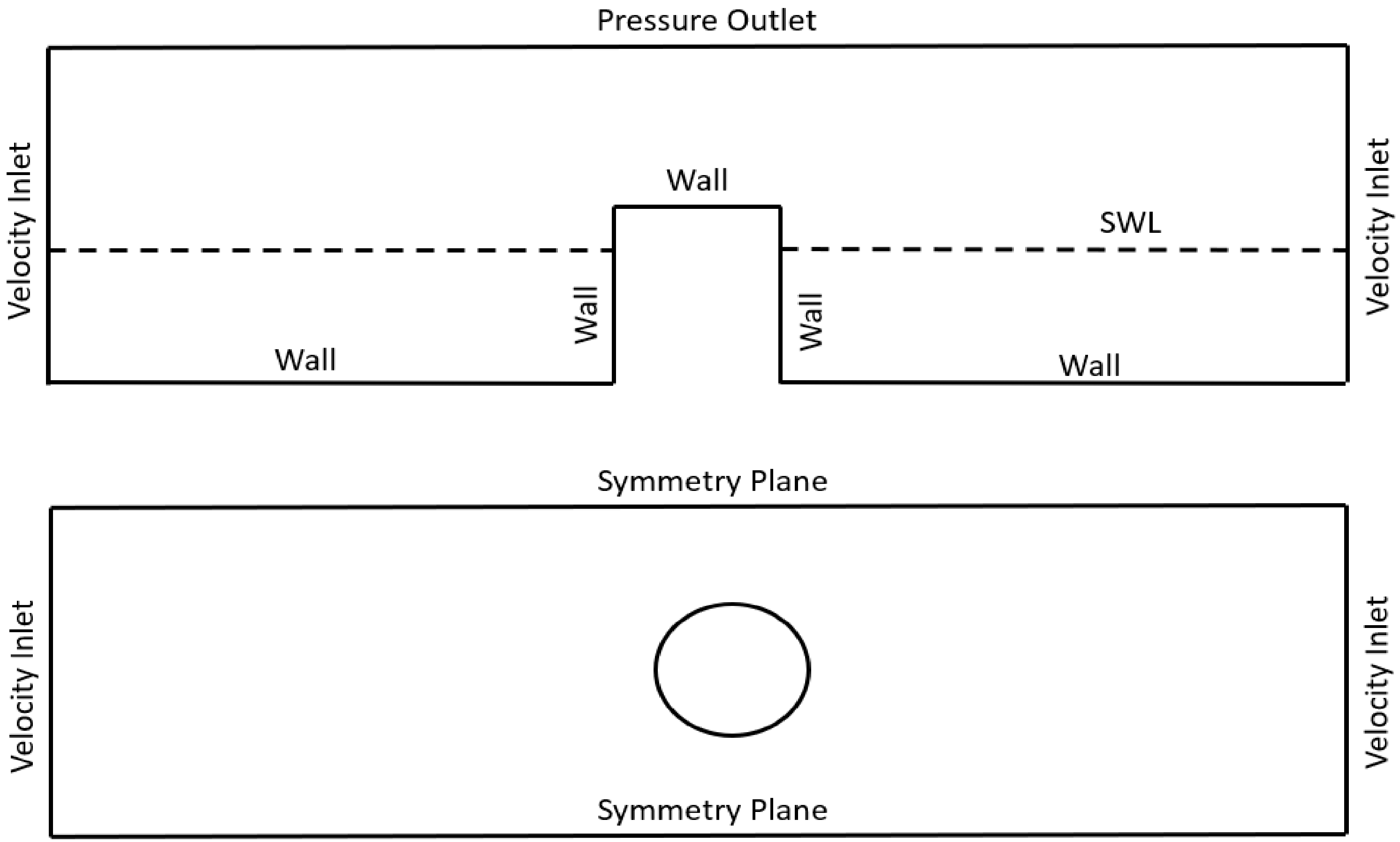
Mesh Parameters



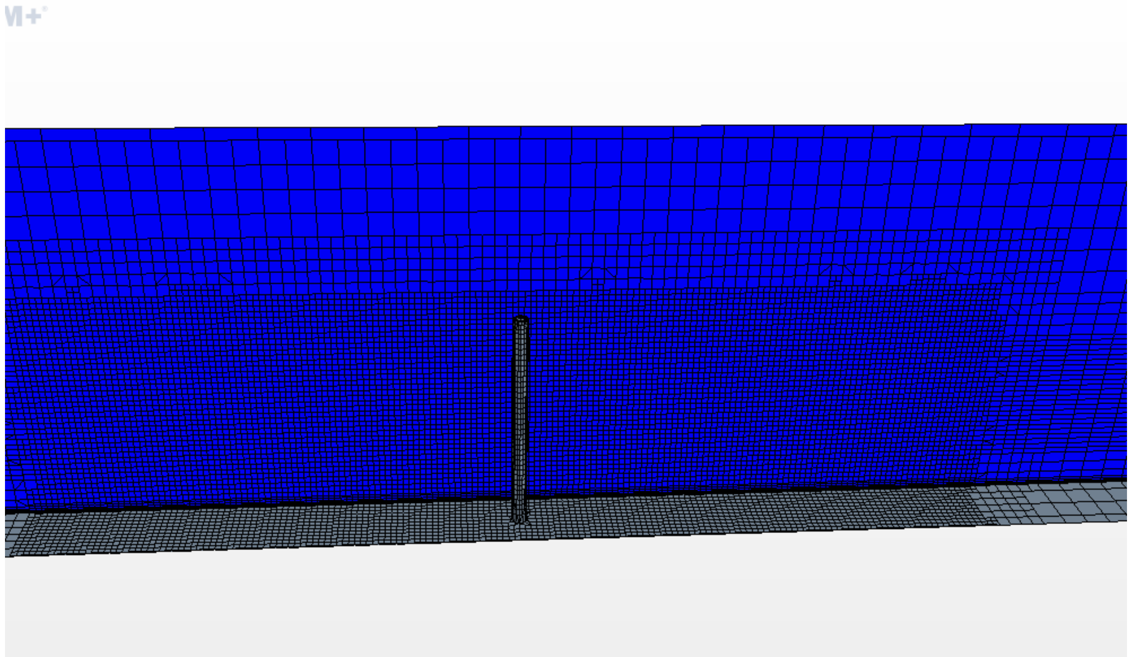
Model Meshing Parameters

Boundary Conditions

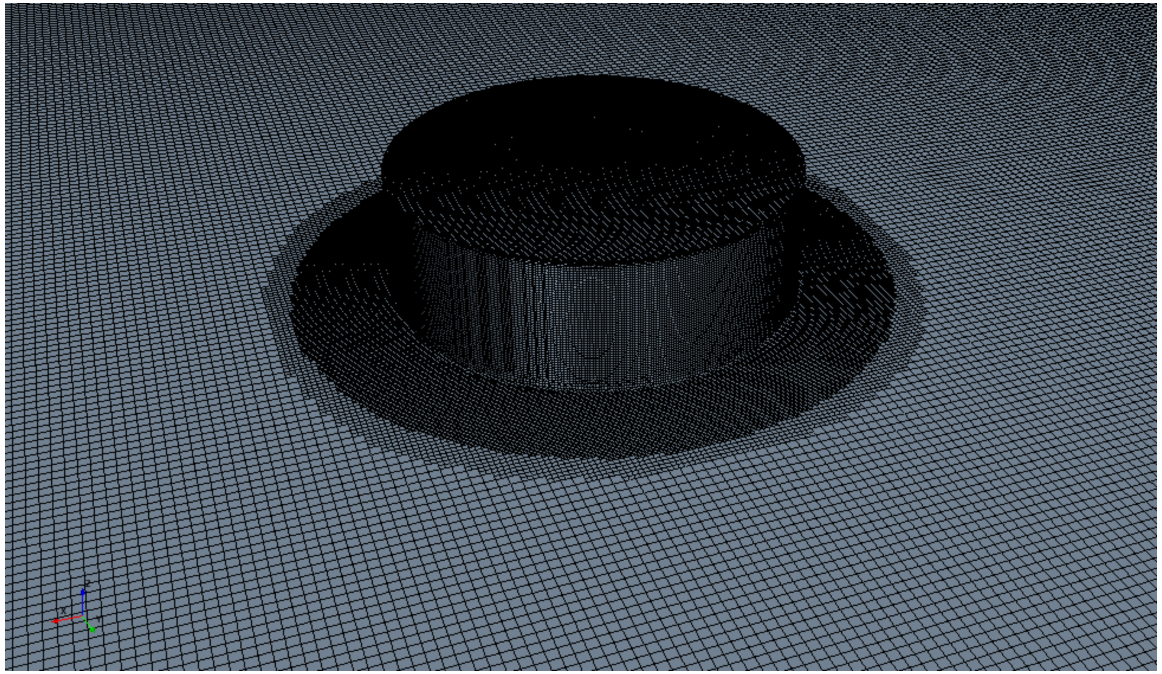


Model boundary conditions showing front-view (top) and top-view (bottom)

Meshed Models



Meshed large-scale pile



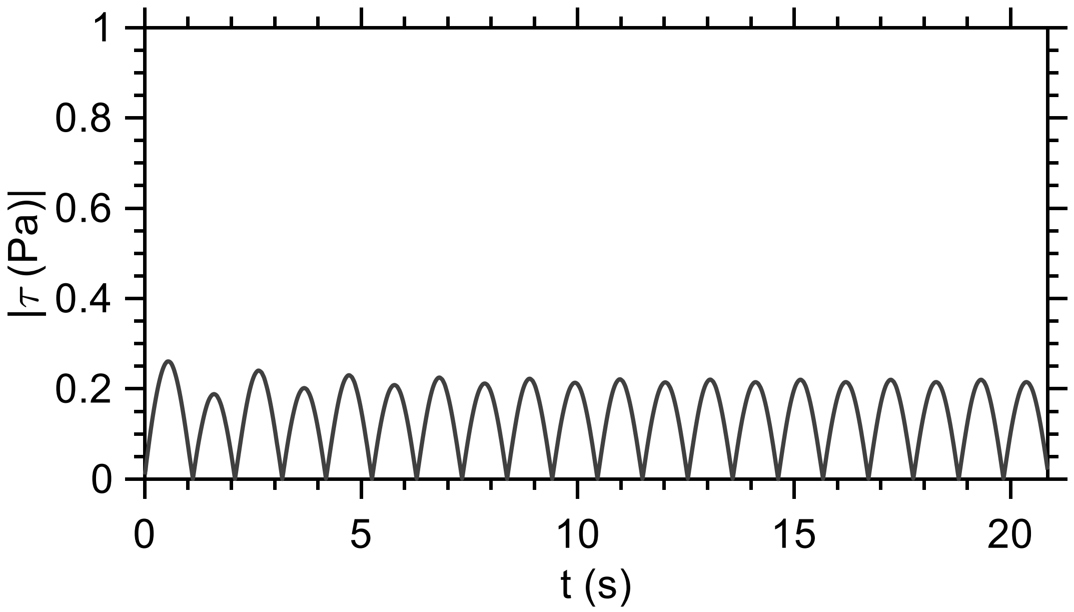
Meshed small-scale pile

Test Matrix – Medium-Scale Data

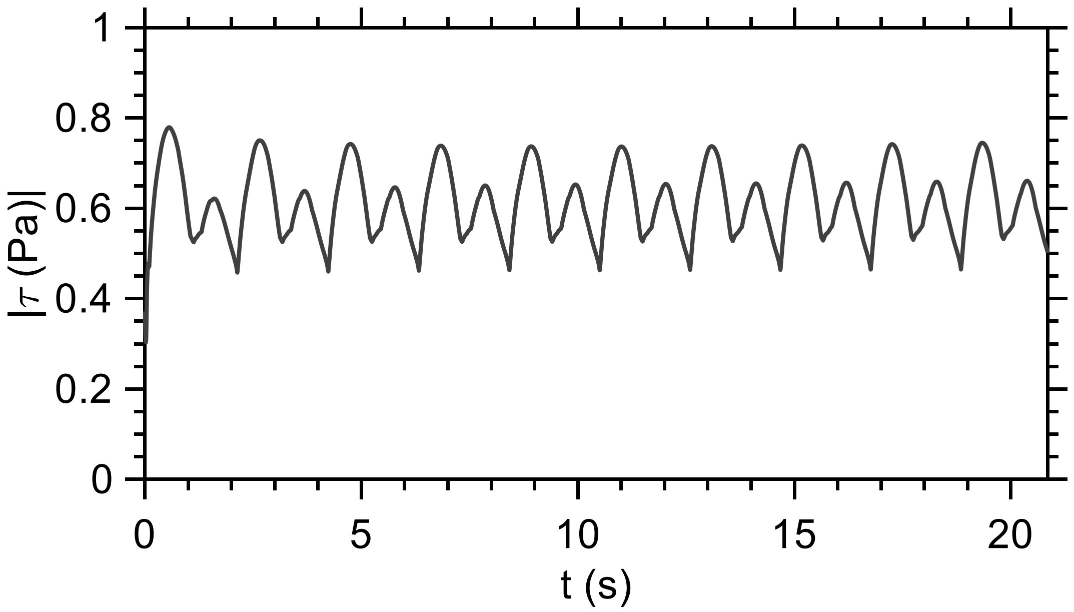
Initial Proposed Testing Matrix

Run Number	T (s)	H (cm)	λ (m)	b (m)	d (m)
1	3.5	12.0	6.79	1.0	0.40
2	3.5	8.6	6.79	1.0	0.40
3	3.5	4.9	6.79	1.0	0.40
4	2.0	8.2	3.70	1.0	0.40
5	3.5	2.5	6.79	1.0	0.40
6	3.5	5.7	6.79	1.0	0.40
7	3.5	6.4	6.79	0.54	0.40
8	3.5	6.9	6.79	0.54	0.40
9	3.5	6.9	6.79	0.54	0.40
10	3.5	6.9	6.79	0.54	0.40
11	3.5	6.4	6.79	0.54	0.40
12	3.5	5.6	6.79	0.54	0.40
13	3.5	12.0	6.79	1.53	0.40
14	3.5	8.7	6.79	1.53	0.40
15	3.5	6.9	6.79	1.53	0.40
16	3.5	6.4	6.79	1.53	0.40

Sample Results



Sample Results – Data Matching

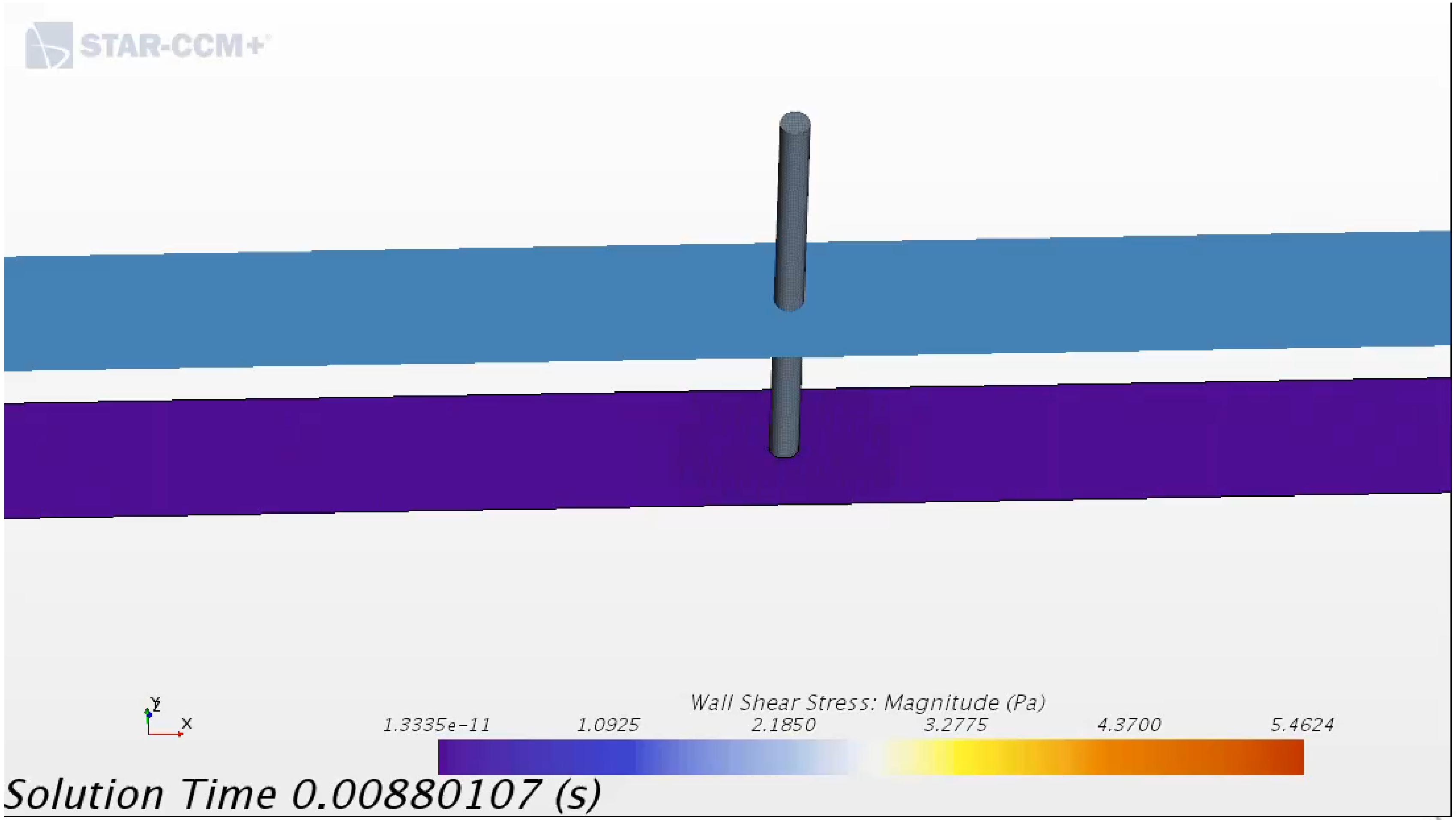


Sample Results – Maximum Stress

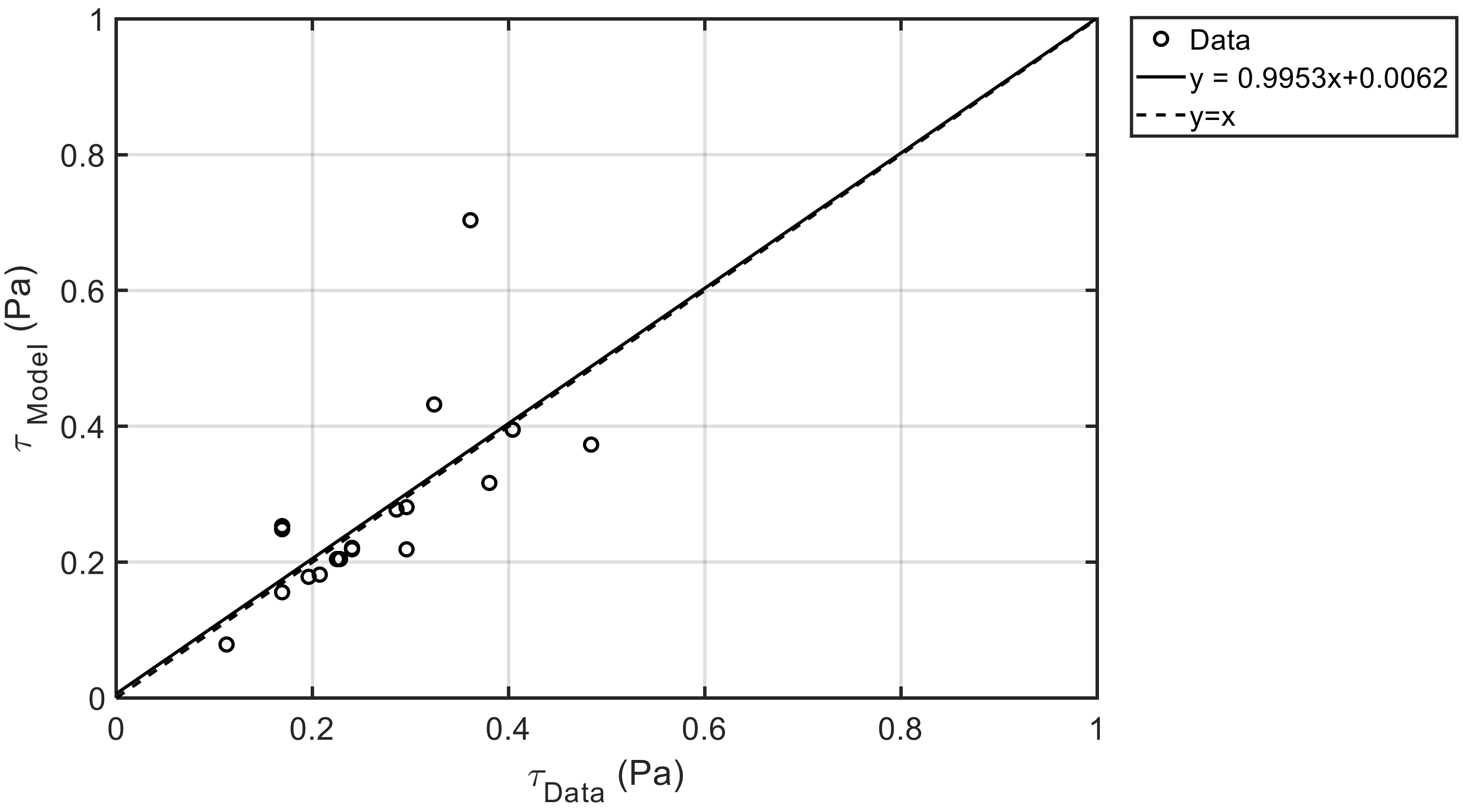
Supplement Original Test Matrix

- Original test matrix was only for small L/D; need to also examine large L/D; therefore five additional runs added to test matrix to account for large L/D

Sample Results



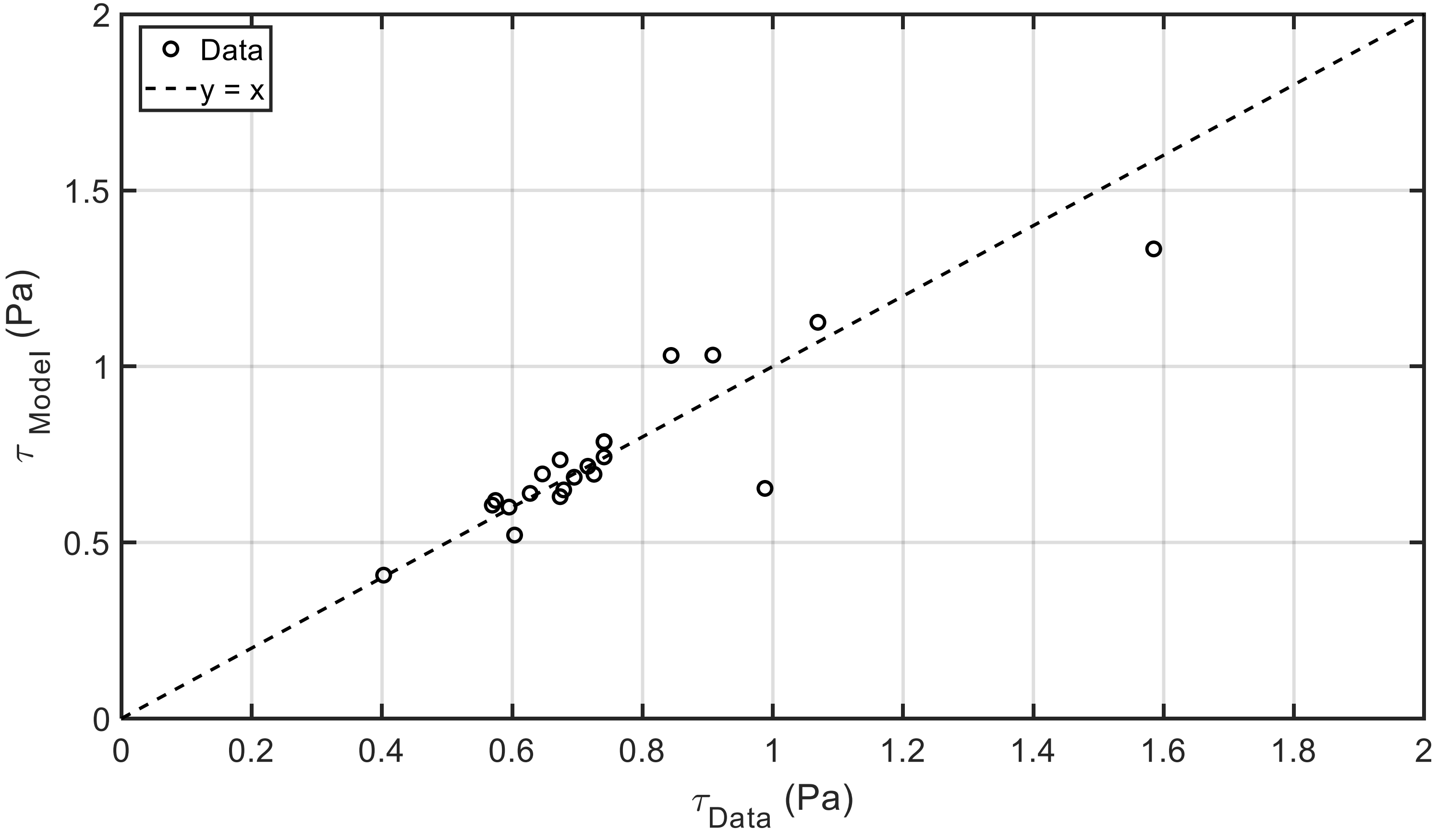
Matched Data Results



Results showing matched data

Initial Parametric Model

$$\frac{\tau}{\rho U_m^2} = a_0 + a_1 Re^{0.58} + a_2 \left(\frac{L}{D}\right)^{-0.7} + a_3 KC^{-4.25} + a_4 \left(\frac{D}{D_{50}}\right)^{0.07} + a_5 [\ln(Re)]^3$$



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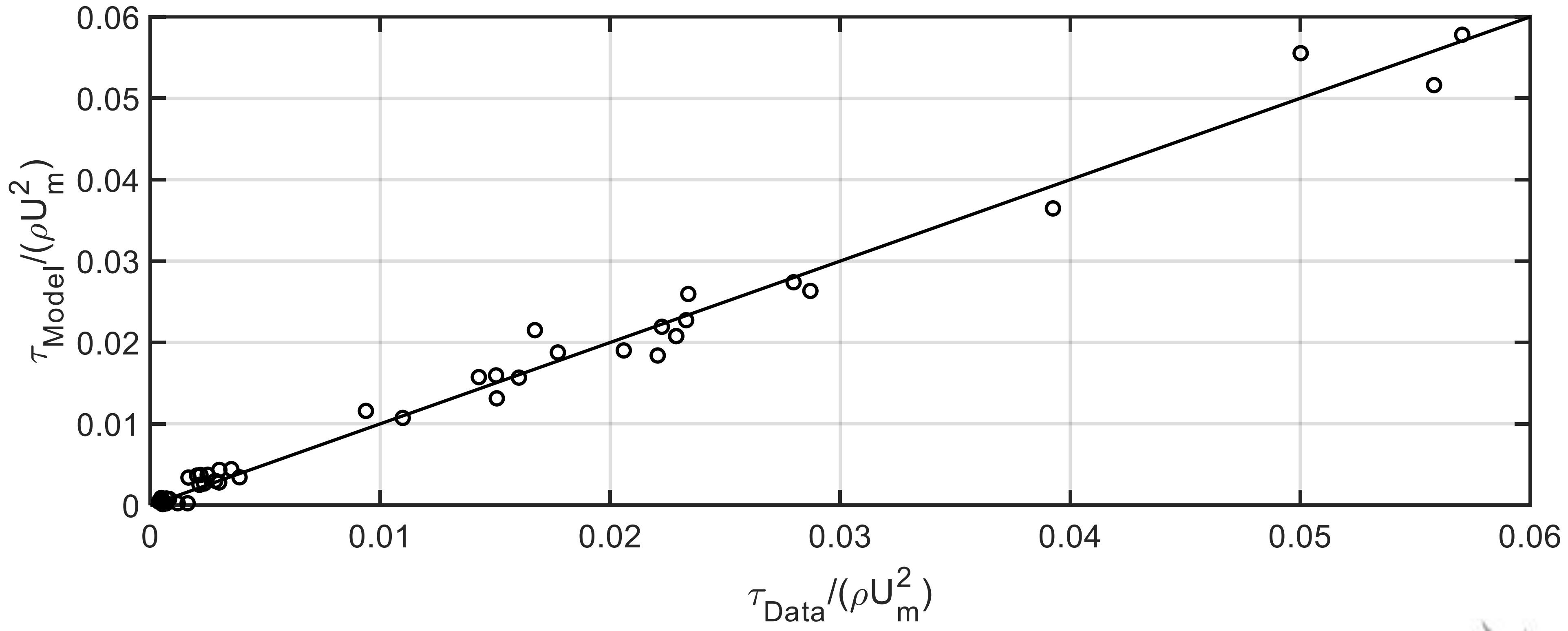
Ongoing Work – Large-Scale Models

Run No	T (s)	H (m)	h (m)	b (m)	L (m)
1	8.00	4.50	7.50	1.53	63.16
2	12.00	4.50	7.50	1.53	99.46
3	16.00	4.50	7.50	1.53	134.57
4	8.00	4.50	7.50	1.00	63.16
5	12.00	4.50	7.50	1.00	99.46
6	16.00	4.50	7.50	1.00	134.57
7	8.00	4.50	7.50	0.54	63.16
8	12.00	4.50	7.50	0.54	99.46
9	16.00	4.50	7.50	0.54	134.57
10	8.00	2.25	7.50	1.53	63.16
11	12.00	2.25	7.50	1.53	99.46
12	16.00	2.25	7.50	1.53	134.57
13	8.00	2.25	7.50	1.00	63.16
14	12.00	2.25	7.50	1.00	99.46
15	16.00	2.25	7.50	1.00	134.57
16	8.00	2.25	7.50	0.54	63.16
17	12.00	2.25	7.50	0.54	99.46
18	16.00	2.25	7.50	0.54	134.57
19	8.00	9.00	15.00	1.53	81.70
20	12.00	9.00	15.00	1.53	135.45
21	16.00	9.00	15.00	1.53	186.32
22	8.00	9.00	15.00	1.00	81.70
23	12.00	9.00	15.00	1.00	135.45
24	16.00	9.00	15.00	1.00	186.32
25	8.00	9.00	15.00	0.54	81.70
26	12.00	9.00	15.00	0.54	135.45
27	16.00	9.00	15.00	0.54	186.32
28	8.00	4.50	15.00	1.53	81.70
29	12.00	4.50	15.00	1.53	135.45
30	16.00	4.50	15.00	1.53	186.32
31	8.00	4.50	15.00	1.00	81.70
32	12.00	4.50	15.00	1.00	135.45
33	16.00	4.50	15.00	1.00	186.32
34	8.00	4.50	15.00	0.54	81.70
35	12.00	4.50	15.00	0.54	135.45
36	16.00	4.50	15.00	0.54	186.32

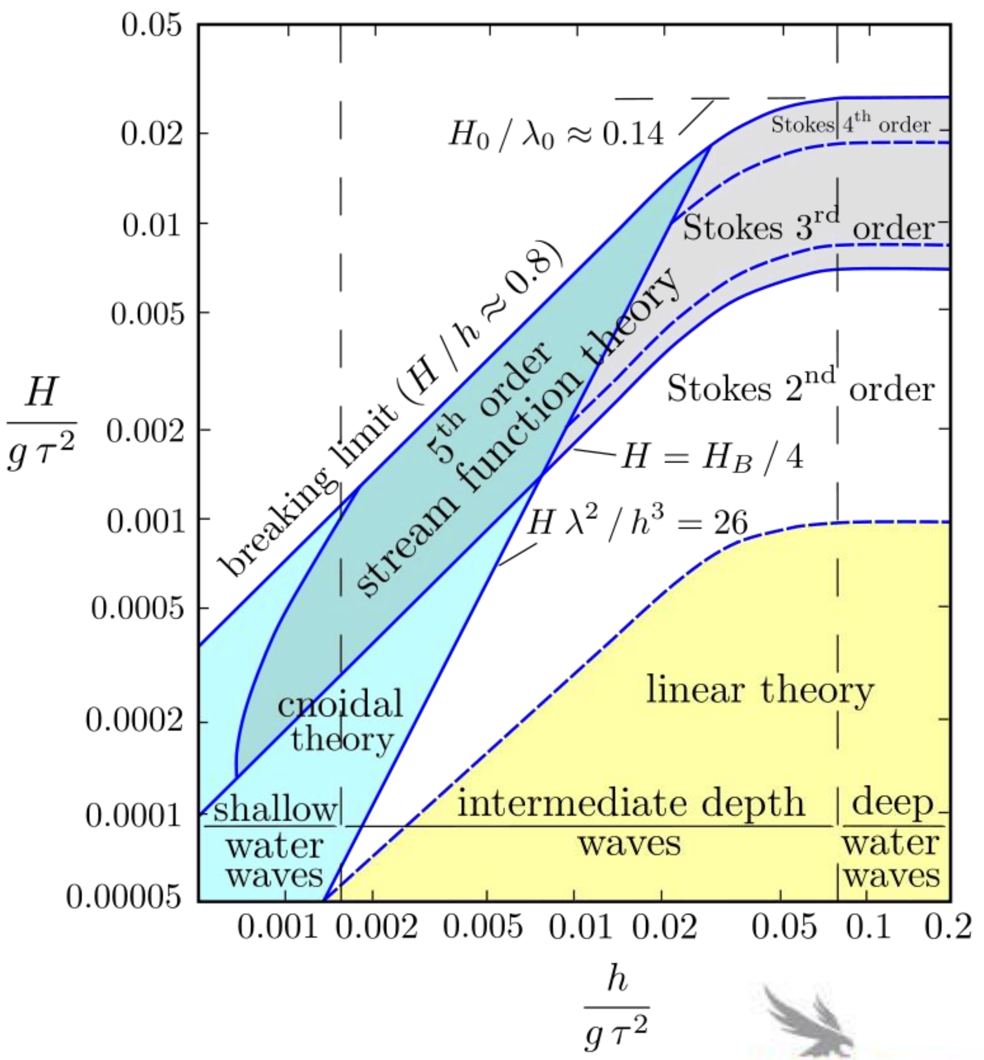
Ongoing Work – Current Large Parametric Model

$$\frac{\tau}{\rho U_m^2} = a_0 + a_1 KC^{-5.25} + a_2\left(\frac{D}{L}\right)^{0.78} + a_3 Re^{-0.25} + a_4 \ln(Fr)^6$$



Ongoing Work – Sorting out Wave Steepness

- All large-scale models were run using a cnoidal wave input approach
- This assumption may lead to instability because it is only for steep waves
- Currently, higher-order stokes and linear models are being investigated for other wave runs



Upcoming Work

REFINE DATA FROM LARGE-SCALE MODELS

CONTINUE RUNNING LARGE-SCALE MODELS AND EXAMINE WAVE STEEPNESS

SUPPLEMENT LARGE-SCALE RESULTS

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Thank you!