A METHODOLOGY FOR OBTAINING DESIGN PIER SCOUR DEPTHS

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OUTLINE

- Problem statement
- Local scour at single circular piles
- Methodology for scour at complex piers <u>without</u> physical model tests
- Methodology for scour at complex piers <u>with</u> physical model tests
- Summary

PROBLEM STATEMENT

- Determine the equilibrium local scour depth at a complex structure under design flow conditions

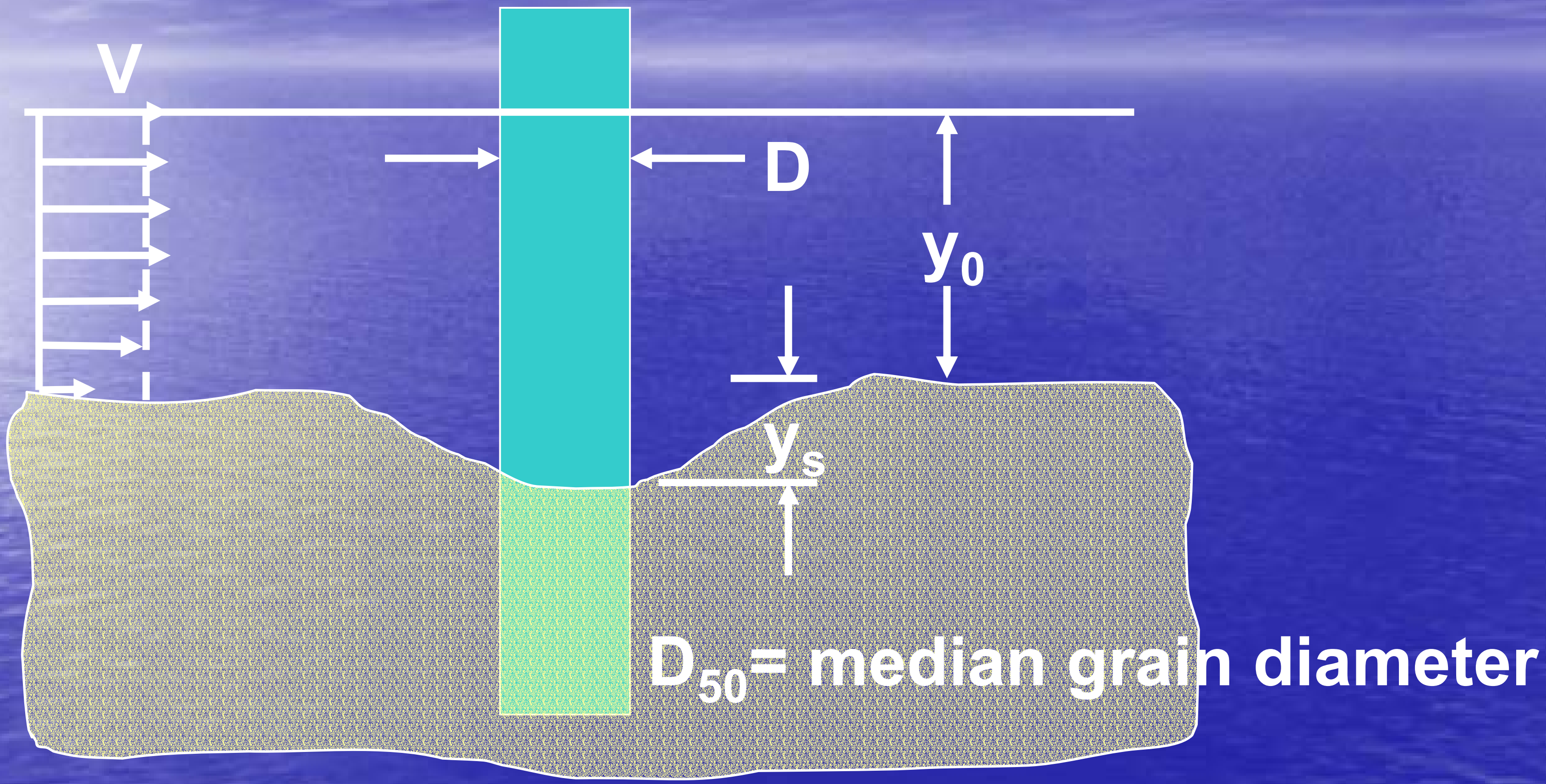
GENERAL APPROACH

- Most local scour information and knowledge is for single circular piles
- Use single pile scour knowledge to predict scour at complex structures

SINGLE PILE PREDICTIVE EQUATIONS

- Many equations in the literature
- Equations developed at University of Florida

Local Scour Definition Sketch



Background

- Research at University of Florida
  - Flume tests
  - Model studies
  - Formulation of predictive equations
- Large scale Clearwater Scour tests
  - USGS Flume in Turners Falls, Mass.
- High Velocity Live Bed Scour tests
  - University of Auckland in Auckland, NZ

Predictive Equations

- Clearwater scour

$$\frac{y_s}{D} = K_s \; 2.5 \; f_1\left(\frac{y_0}{D}\right) f_2\left(\frac{V}{V_c}\right) f_3\left(\frac{D}{D_{50}}\right)$$

- Live Bed scour

$$\frac{y_s}{D} = f\left(\frac{y_0}{D}, \frac{V}{V_c}, \frac{D}{D_{50}}, \frac{V_{lp}}{V_c}\right)$$

Predictive equations

- Clearwater scour $0.45 \le \frac{V}{V_c} \le 1$

$$f_1\left(\frac{y_0}{D}\right) = tanh\left[\left(\frac{y_0}{D}\right)^{0.4}\right],$$

$$f_2\left(\frac{V}{V_c}\right) = 1 + \frac{0.25\ ln\left(V/V_c\right)}{\left(V/V_c\right)^2},$$

$$f_3\left(\frac{D}{D_{50}}\right) =$$

$$\frac{2.95}{2.5\,exp\left[0.45\left(log\left(\frac{D}{D_{50}}\right) - 1.64\right)\right] + 0.45\,exp\left[-2.5\left(log\left(\frac{D}{D_{50}}\right) - 1.64\right)\right]}.$$

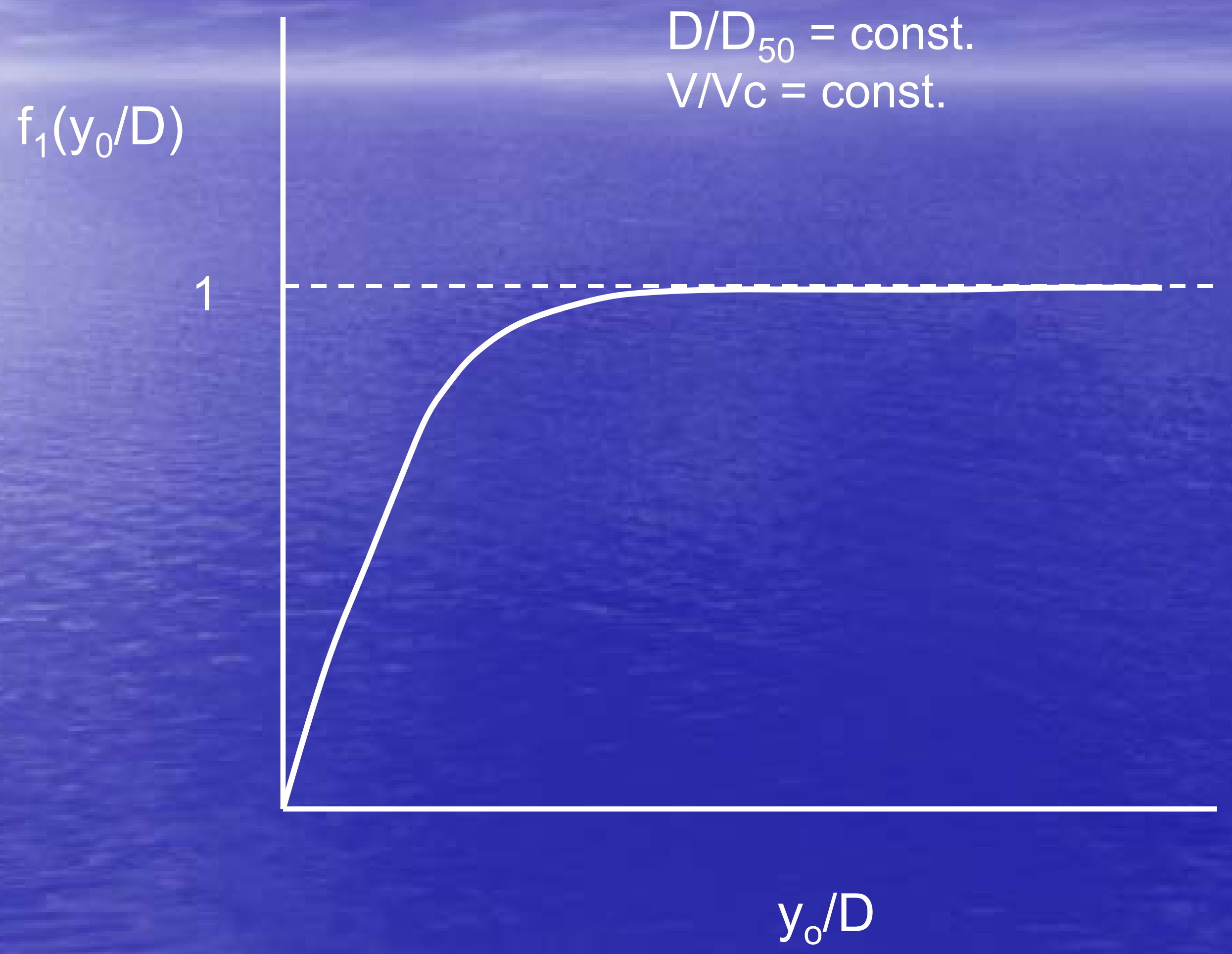
Predictive equations

$$1.0 \leq \frac{V}{V_c} \leq \frac{V_{lp}}{V_c}$$

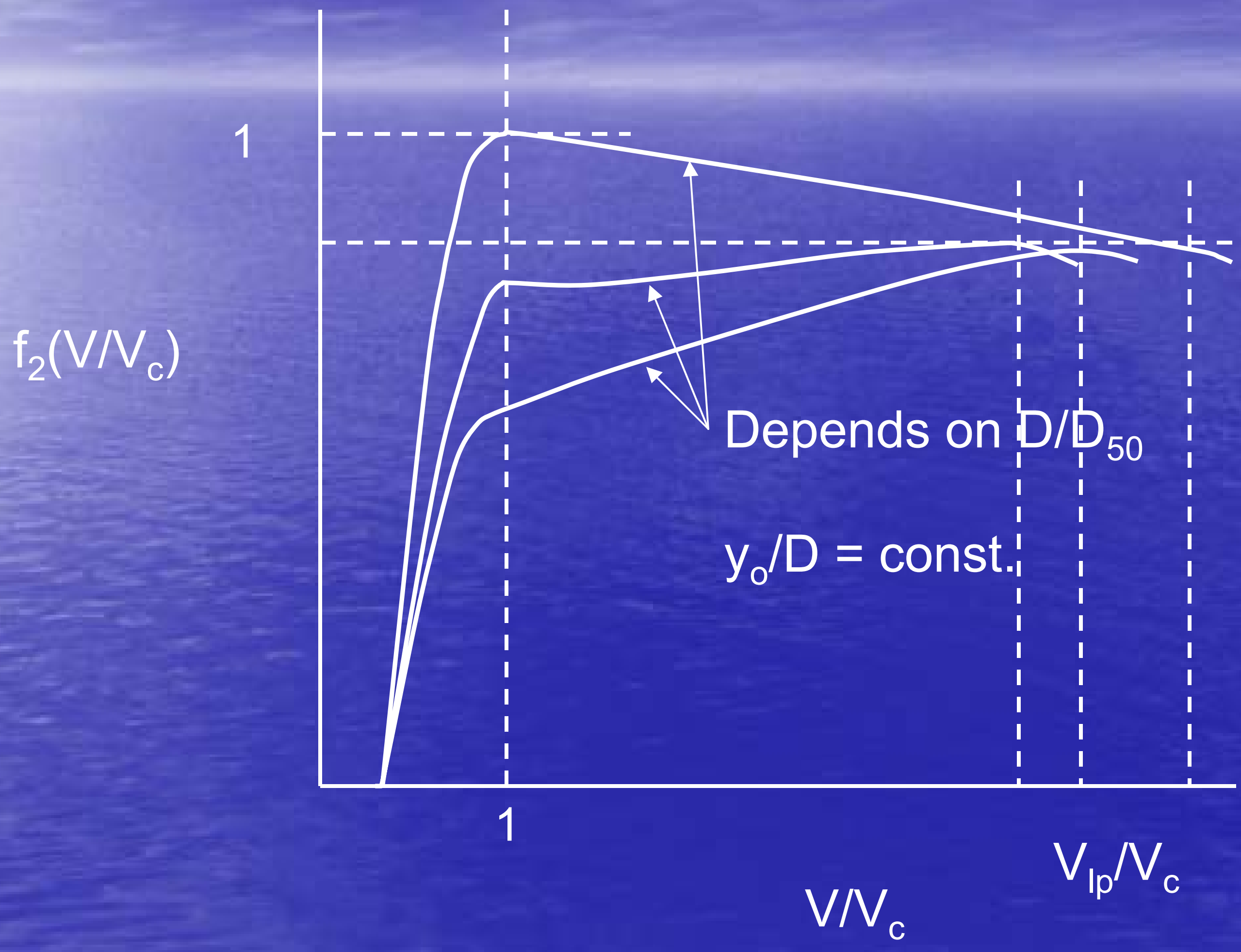
$$\frac{d_{se}}{D} = K_s \; f_1\left(\frac{y_0}{D}\right)\left[2.2\left(\frac{V - V_c}{V_{lp} - V_c}\right) + 2.5 \; f_3\left(\frac{D}{D_{50}}\right)\left(\frac{V_{lp} - V}{V_{lp} - V_c}\right)\right]$$

$$\frac{V}{V_c} > \frac{V_{lp}}{V_c}$$

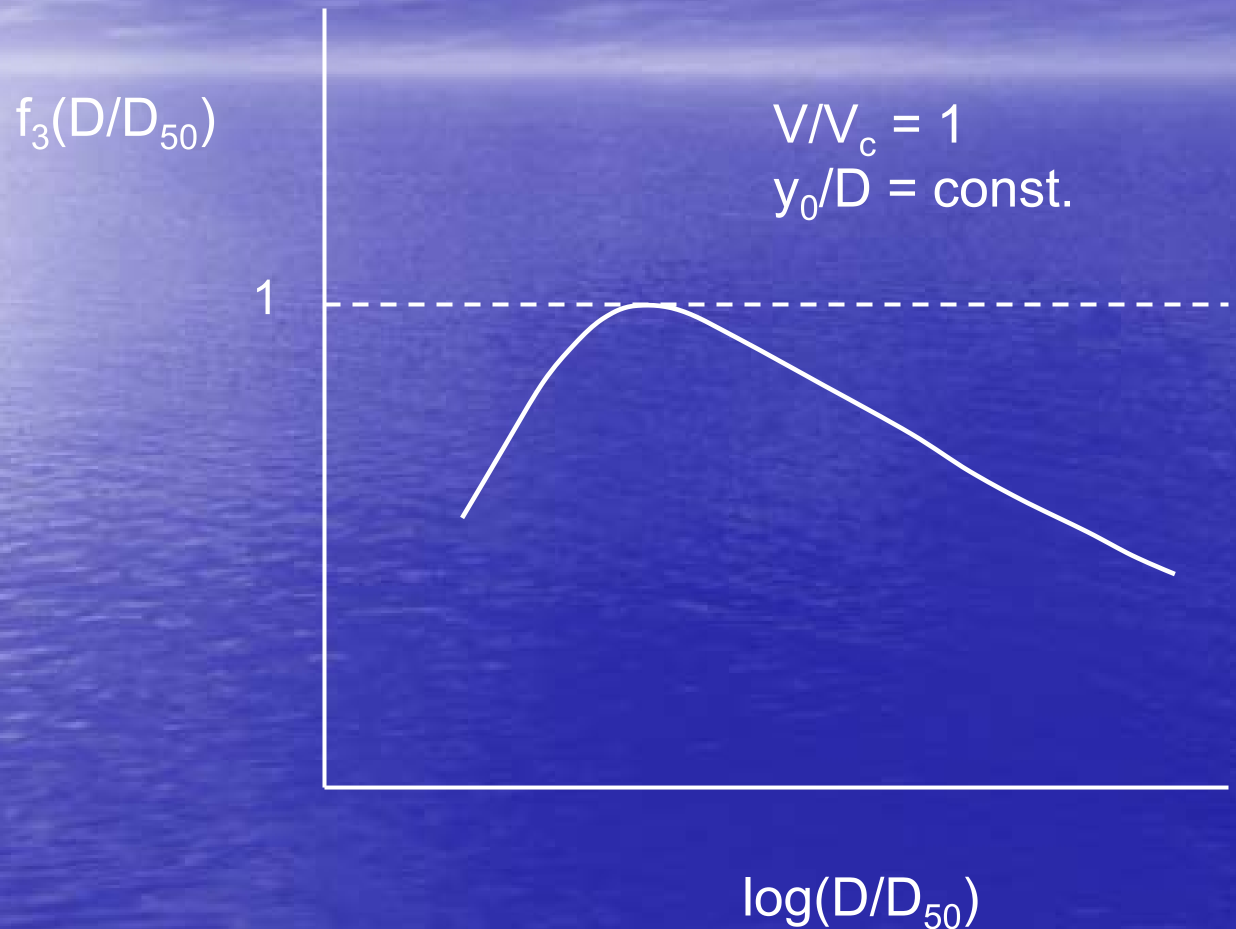
$$\frac{d_{se}}{D} = K_s \; 2.2 \; tanh\left[\left(\frac{y_0}{D}\right)^{0.4}\right]$$


D/D50 = const.
V/Vc = const.
f1(y0/D)
1
yo/D

Scour Dependence on V/V_c



Scour Dependence on D/D_{50}

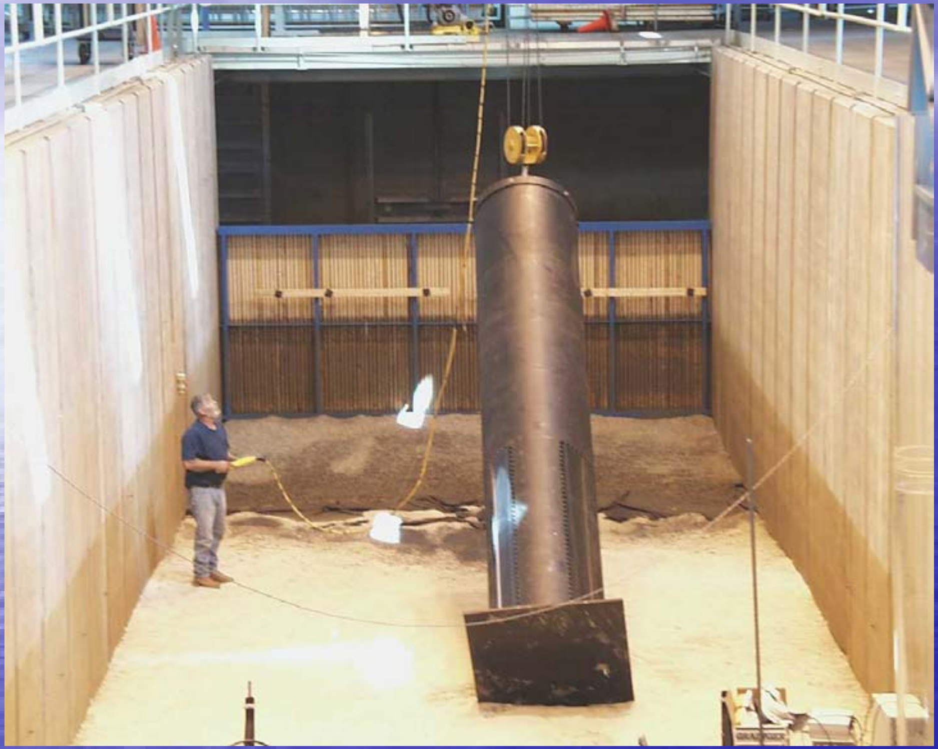


Large Structure Experiments

- Needed data for large D/D_{50}
- Located large flume at USGS Lab in Turners Falls, Massachusetts
- Performed clearwater tests with
  - 3 pile diameters (0.114 m, 0.305 m, 0.914 m)
  - 3 sediment sizes (0.22 mm, 0.8 mm, 2.9 mm)
- D/D_{50} values up to 4,156

USGS-BRD Laboratory

Clearwater Tests in USGS Flume



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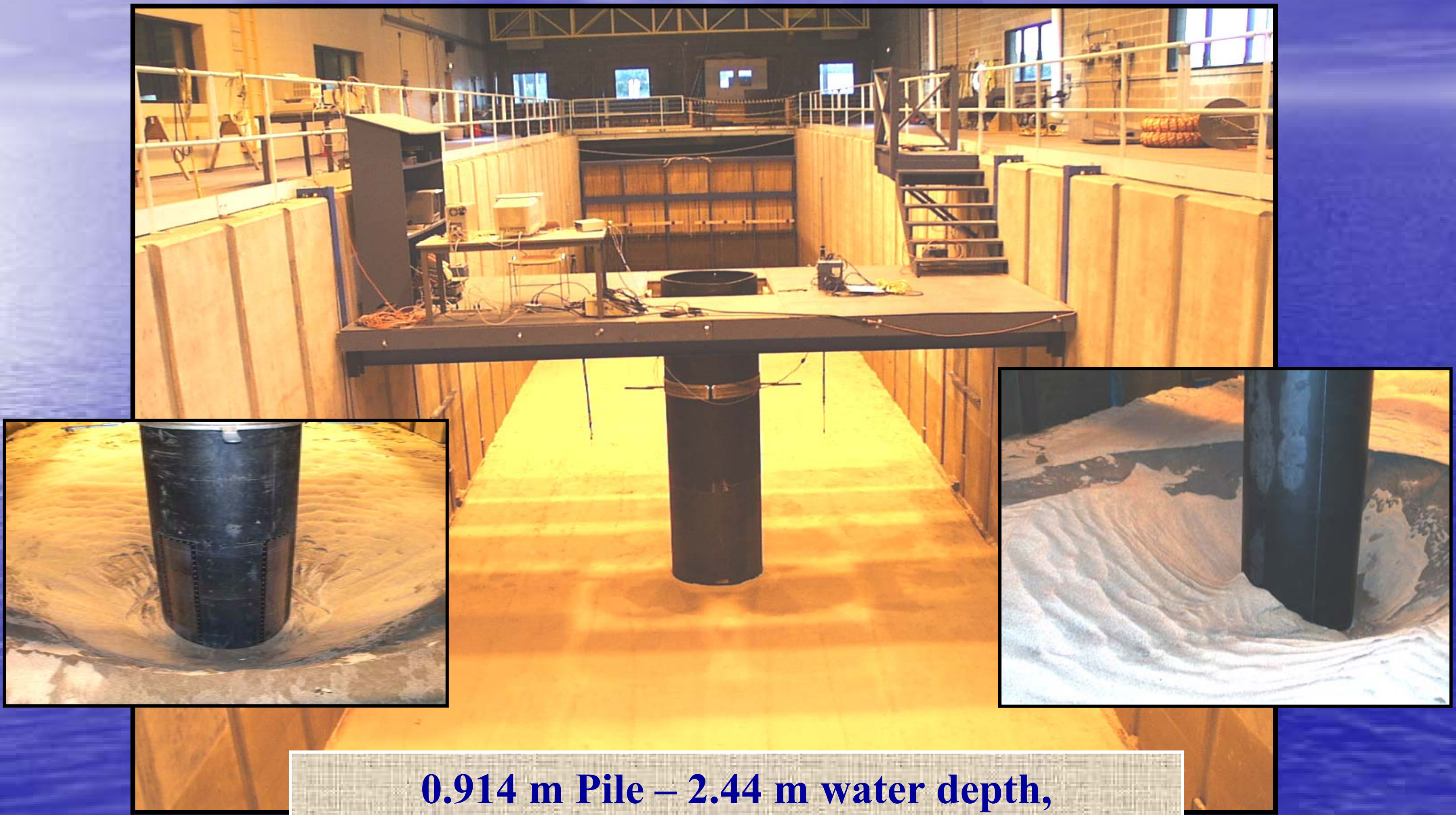
Clearwater Tests in USGS Flume

Clearwater Tests in USGS Flume



0.914 m Pile – 2.44 m water depth,

Clear Water Scour

Results of Clearwater Tests

- Verified predictive equations in clearwater scour range
- Provided new information regarding scour dependence on:
  - y_0/D
  - Suspended fine sediment

Objectives of Live Bed Scour Study

- Obtain data in the live bed scour range
- Determine if live bed peak exists
- If live bed peak exists, under what conditions

Facilities Needed for Live Bed Scour Tests

- Flume with
  - sediment recirculation capabilities
  - flow capacity to achieve required velocities
- Instrumentation for measuring flow, bedforms and scour depth
- Decided on University of Auckland

Auckland, New Zealand

Auckland, New Zealand


Auckland

University of Auckland
College of Engineering

Flume at the University of Auckland

5 ft wide by 4 ft deep by 148 ft long

- Tilting (1%)
- Maximum discharge:
  - Water: 42 cfs (1200 l/s) (60 hp, 30 hp)
  - Sediment: 2.1 cfs (60 l/s)
- Moveable instrument carriage (Non-Powered)

Auckland Flume

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Flume at the University of Auckland

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Test Structure

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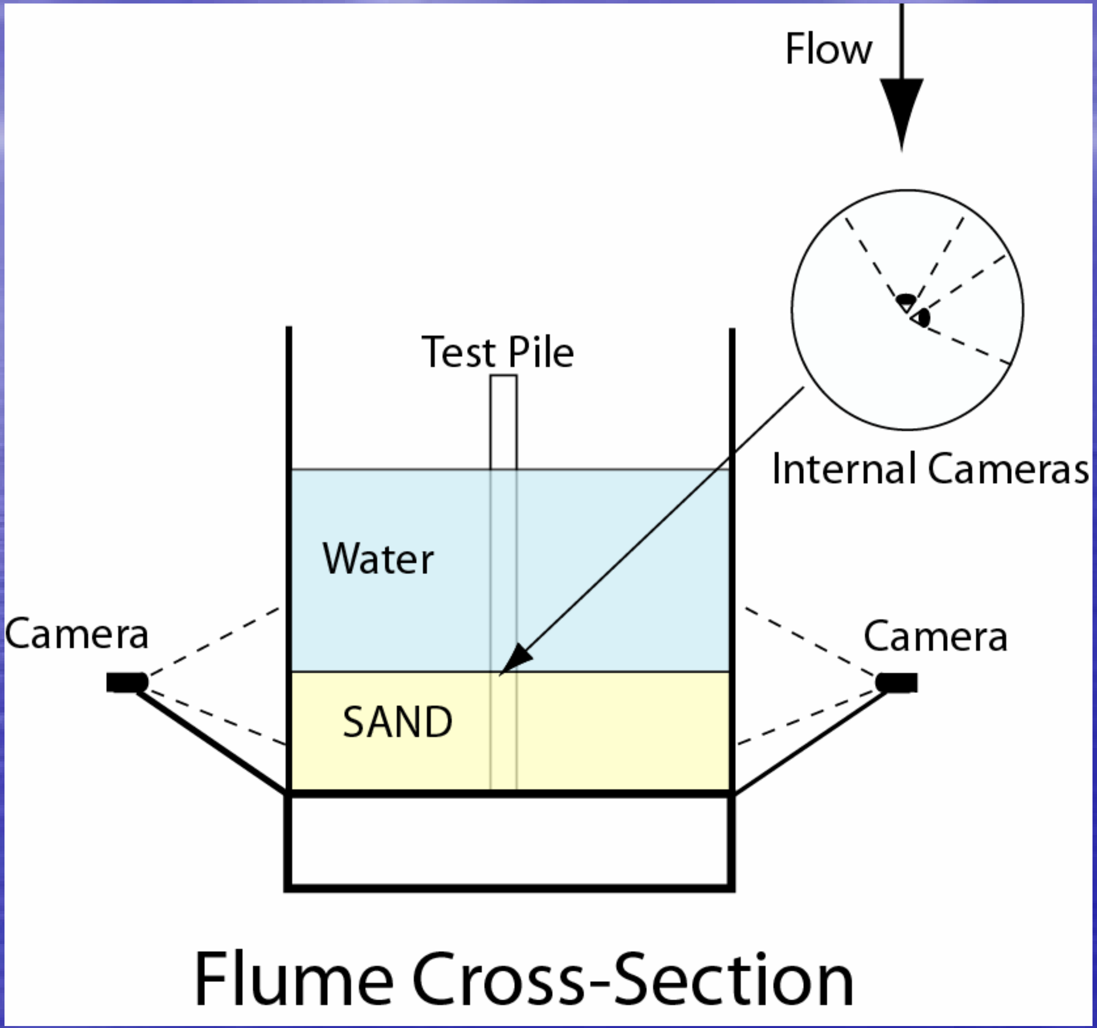
Instrumentation



Experiments

- Two Sand Sizes
  - D_{50} = 0.27 mm,
  - D_{50} = 0.84 mm,
- Circular Pile, D = 6 in (152 mm)
- 22 Tests

Live Bed Test

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Live Bed Test

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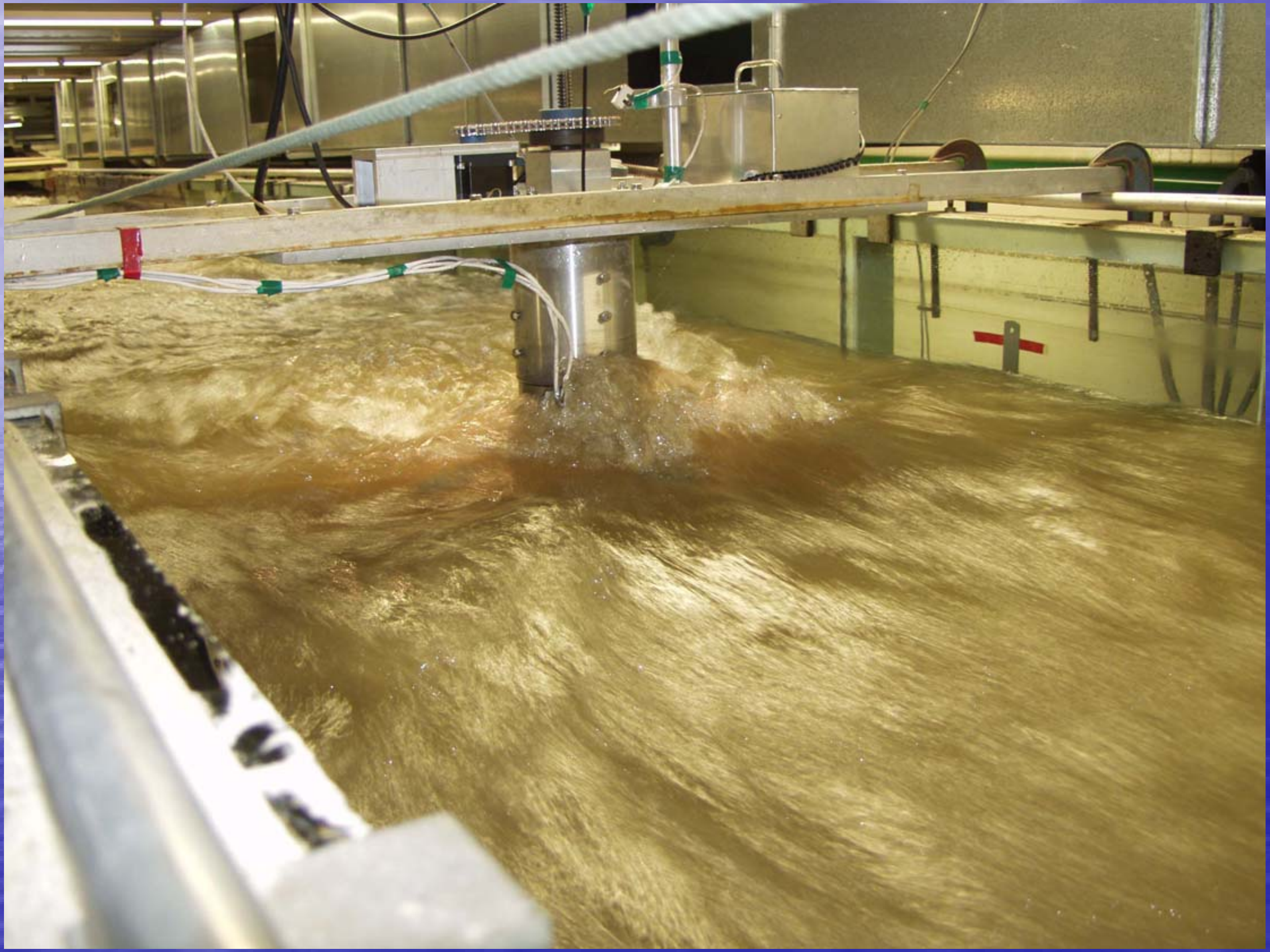
Live Bed Test



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Live Bed Test

University of Auckland Flume
Test 14

$D = 0.152$ m	$V_c = 0.41$ m/s
$D_{50} = 0.84$ mm	$V_{lp} = 2.1$ m/s
$Y_0 = 0.38$ m	$V/V_c = 2.95$
$V = 1.21$ m/s	$V_{lp}/V_c = 5.1$

Bed Forms

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Live Bed Scour Hole

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Live Bed Scour Hole

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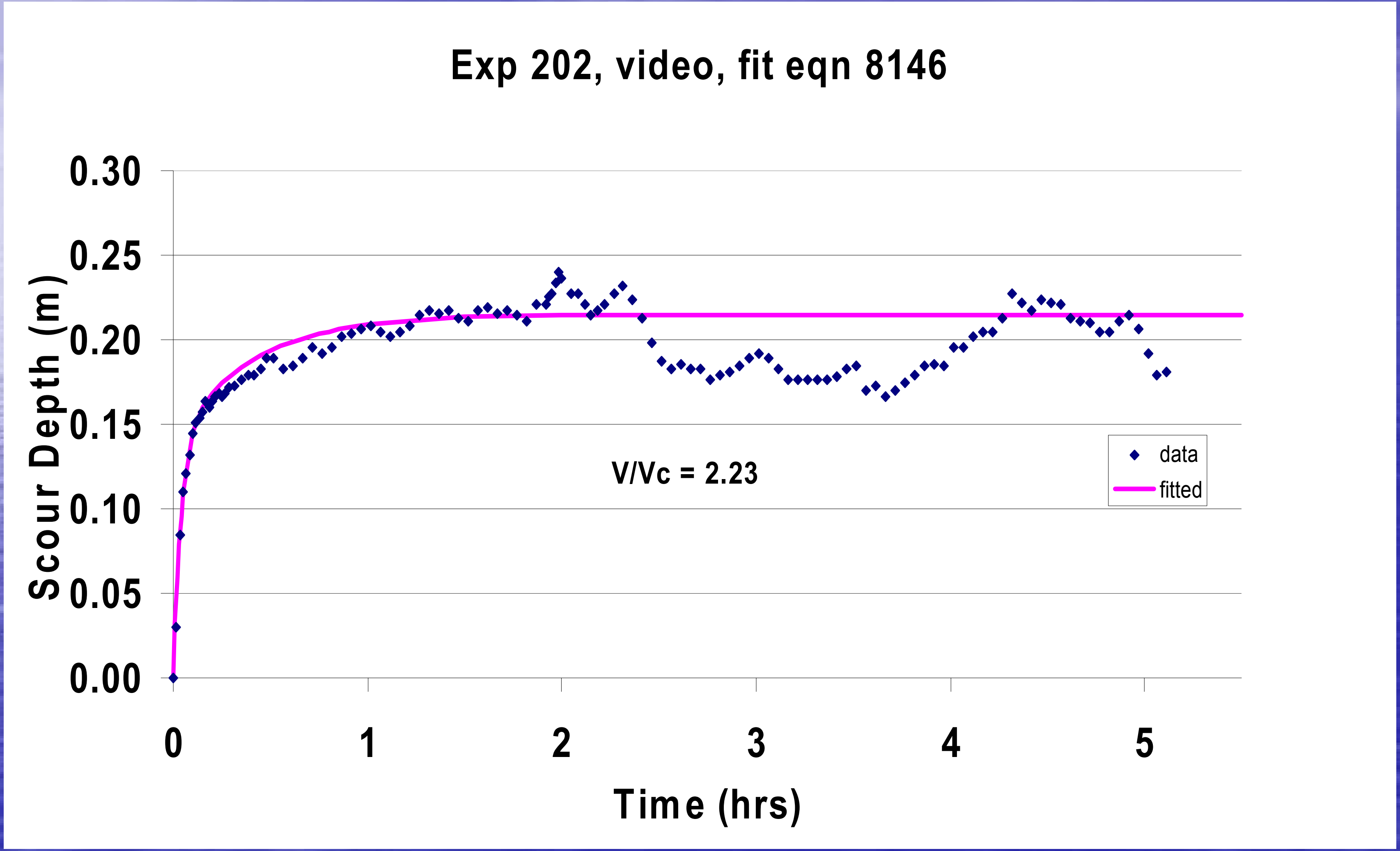
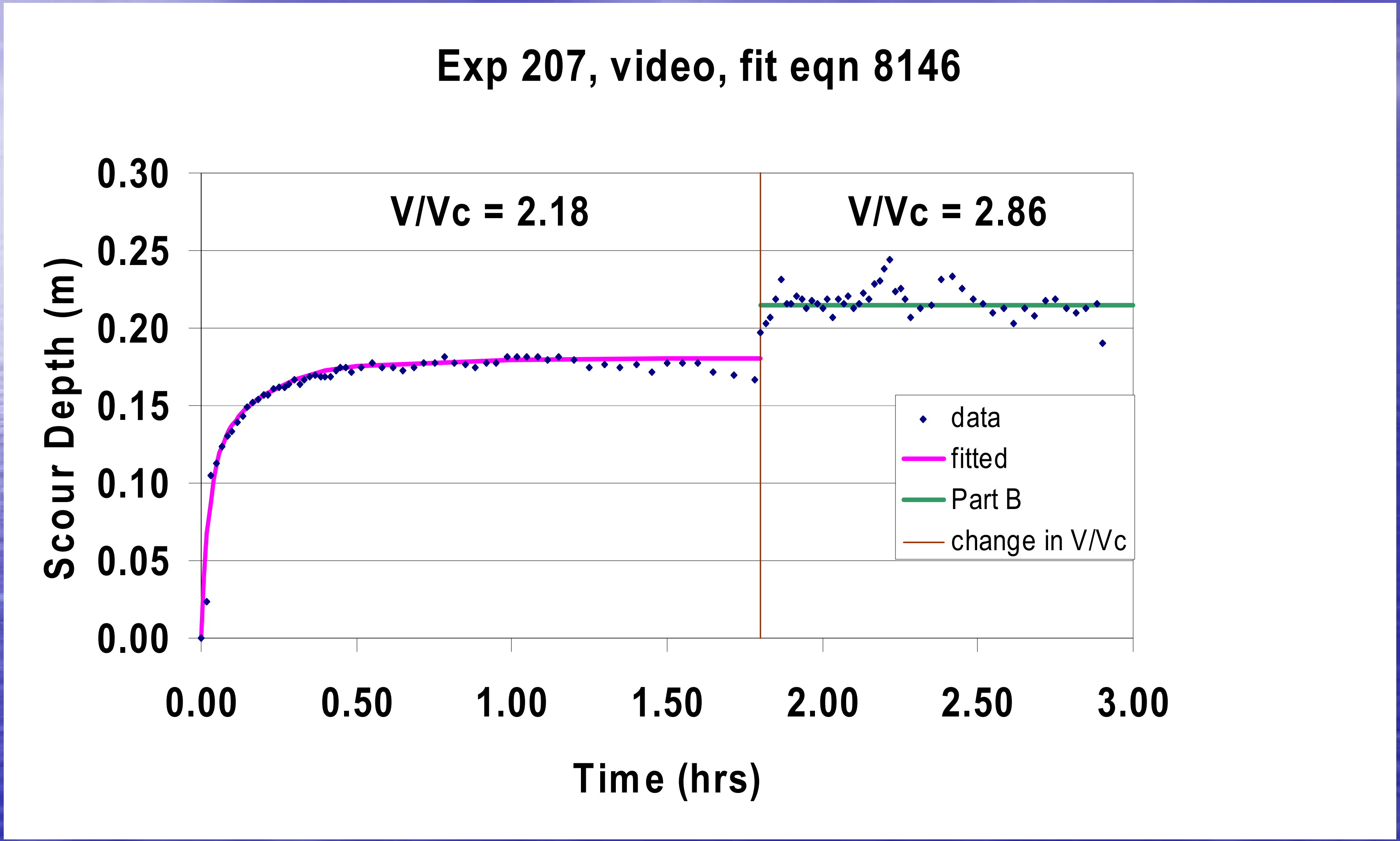
Live Bed Scour Data



Live Bed Scour Data



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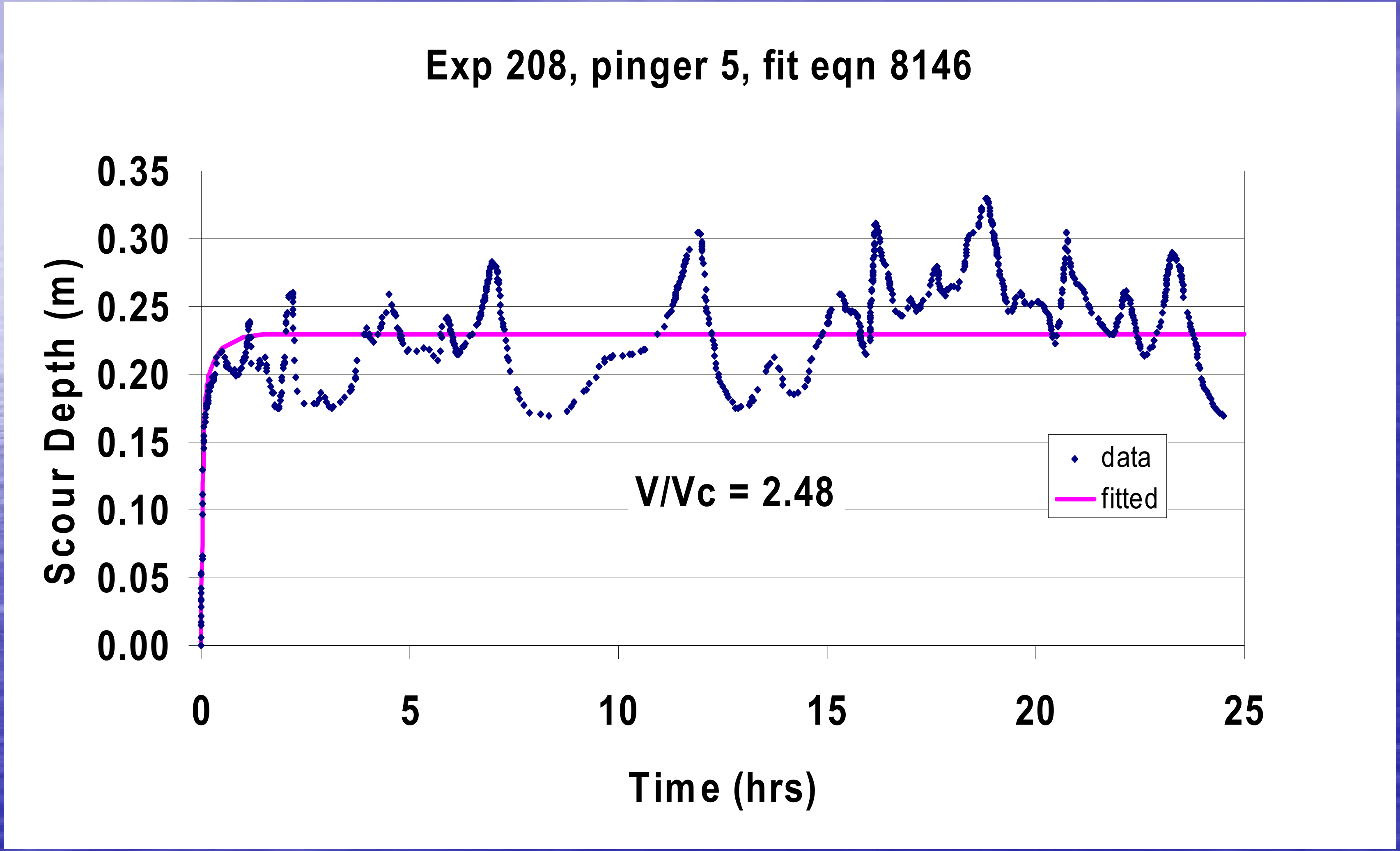
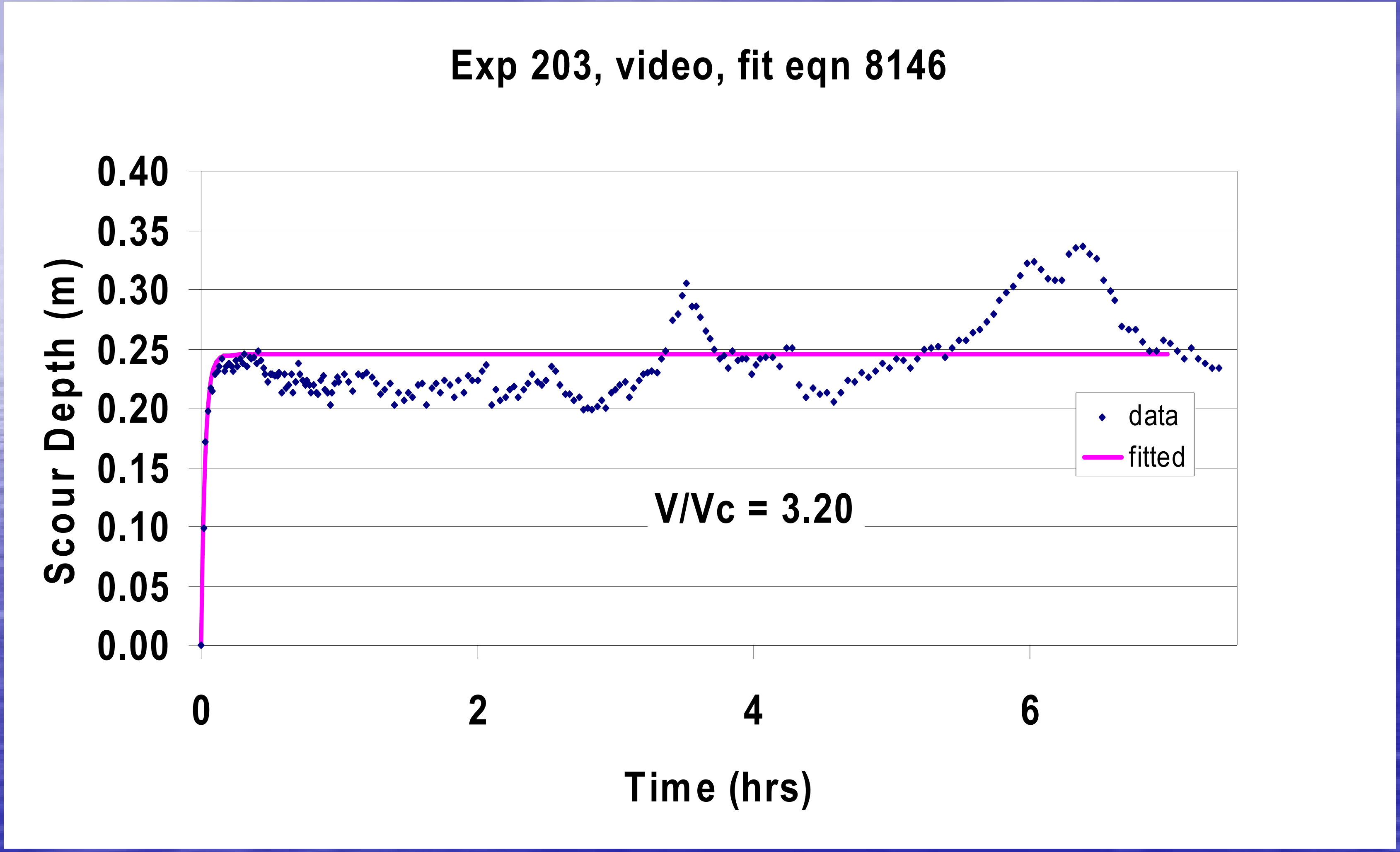
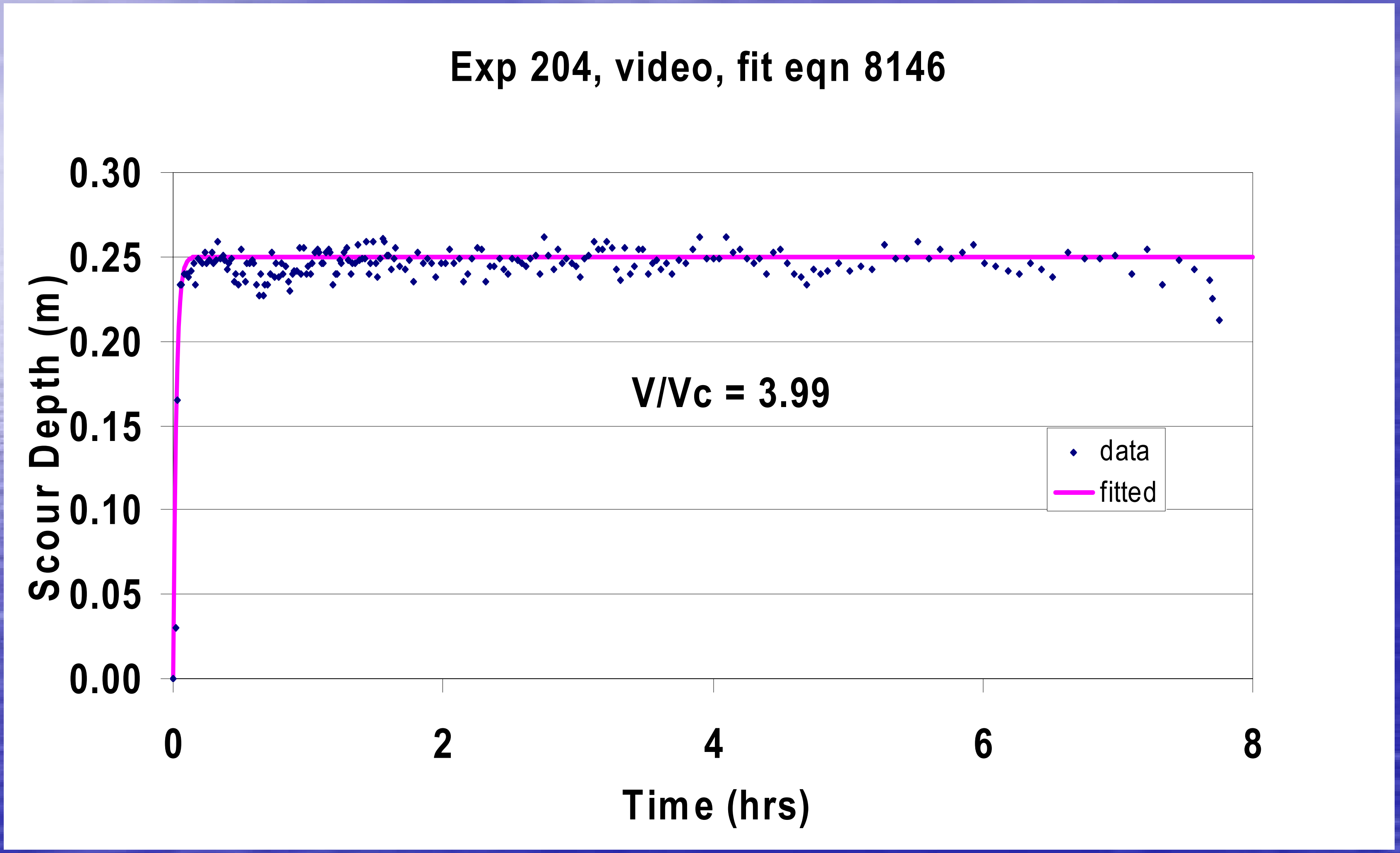


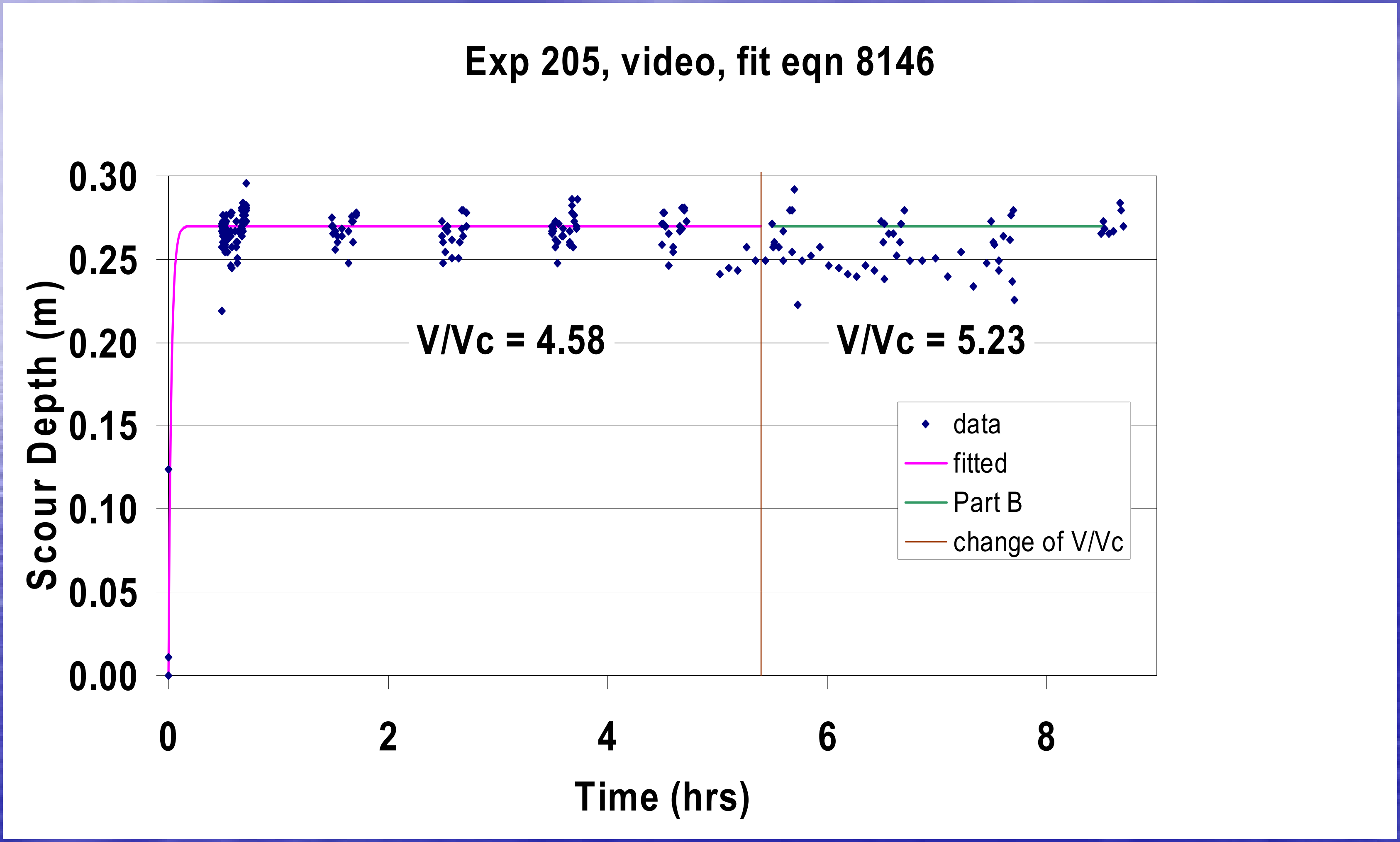
Live Bed Scour Data



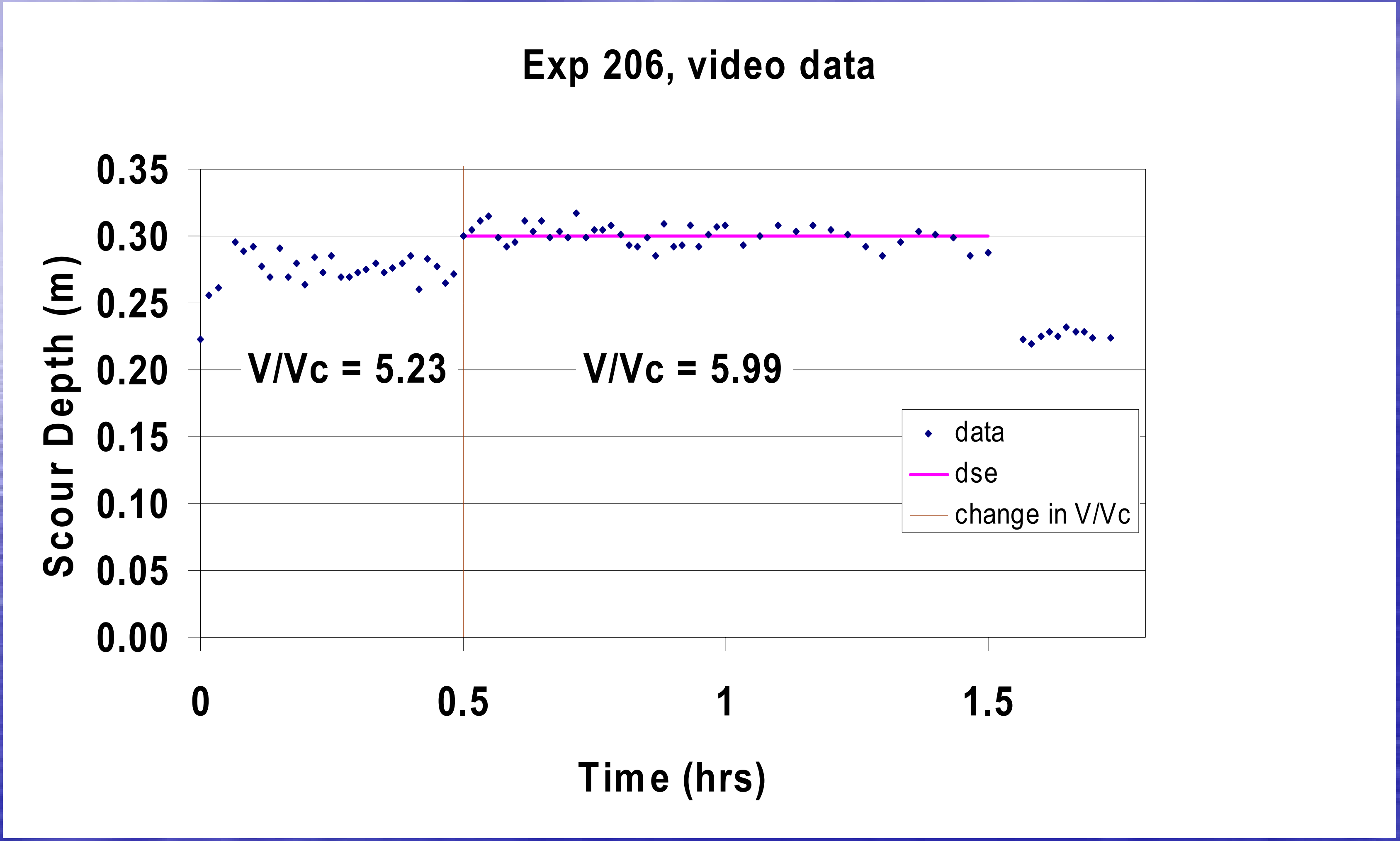
Live Bed Scour Data



Live Bed Scour Data



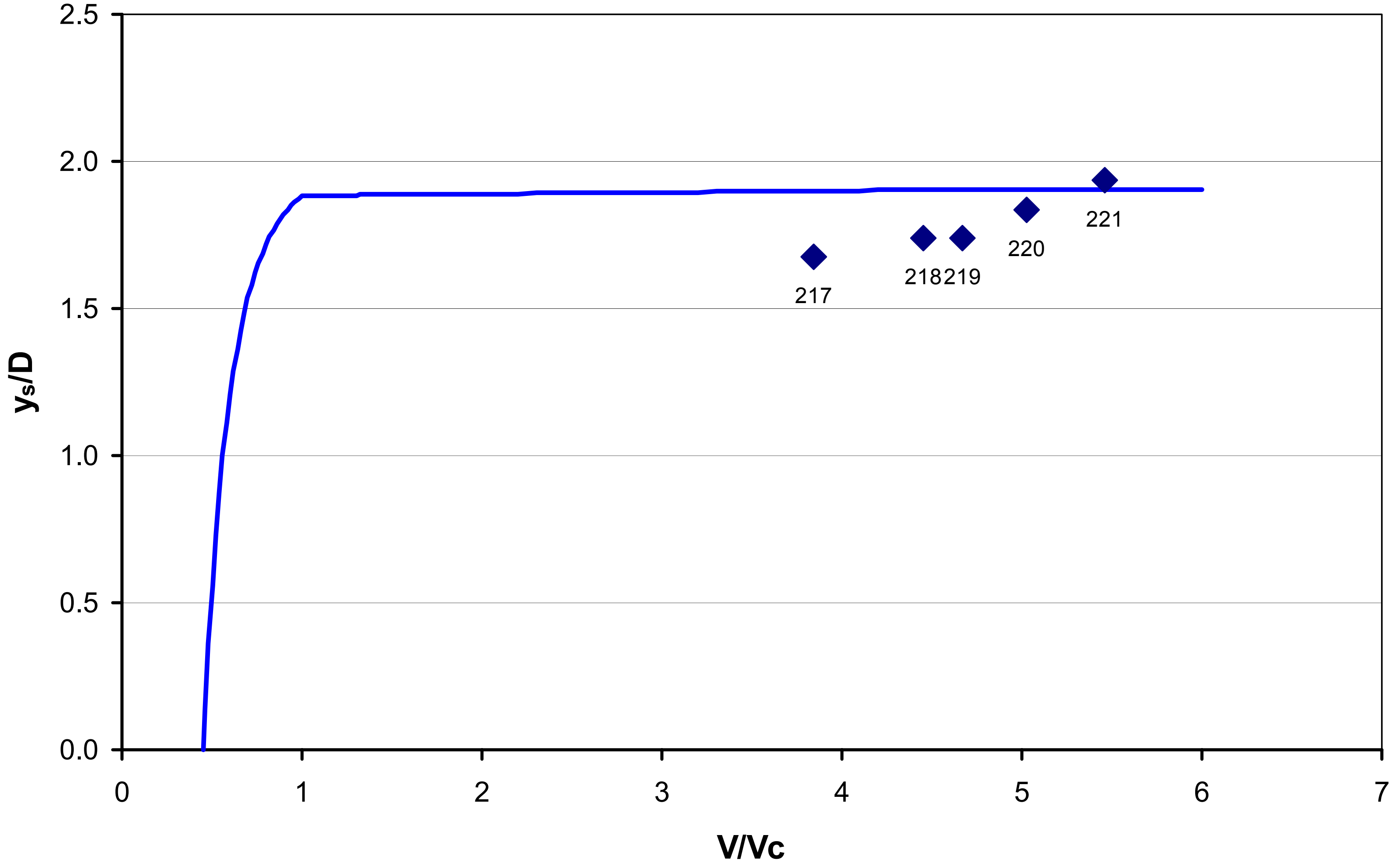
Live Bed Scour Data



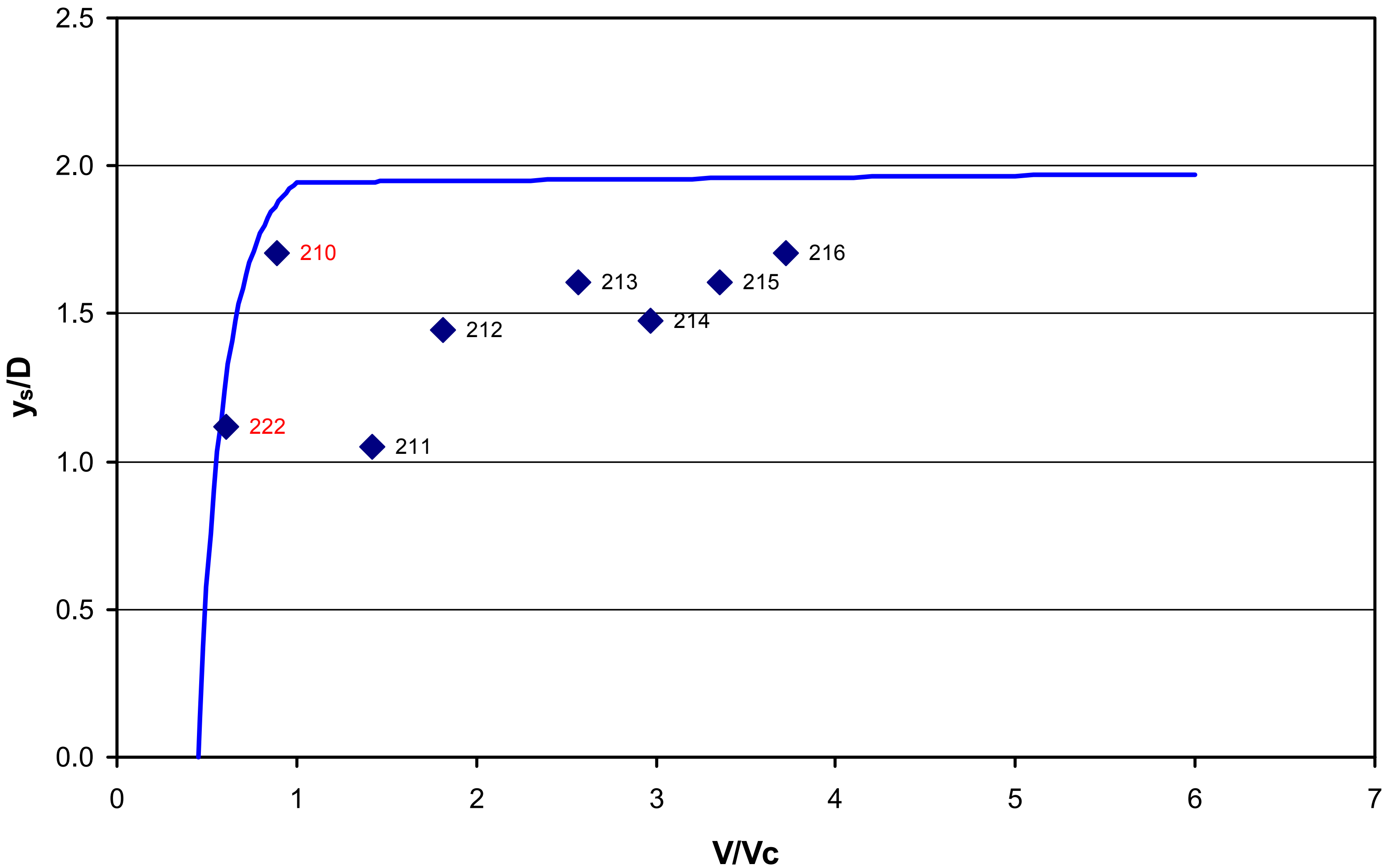
Predicted Vs Measured

- Using equations shown earlier equilibrium scour depths were predicted for
  - Our clearwater tests
  - Our live bed tests
  - Data from Sterling Jones
- Results on following plots

y_s/D vs V/V_c, D/D_{50} = 181, y_0/D = 2



y_s/D vs V/V_c, D/D_{50} = 181, y_0/D = 2.5



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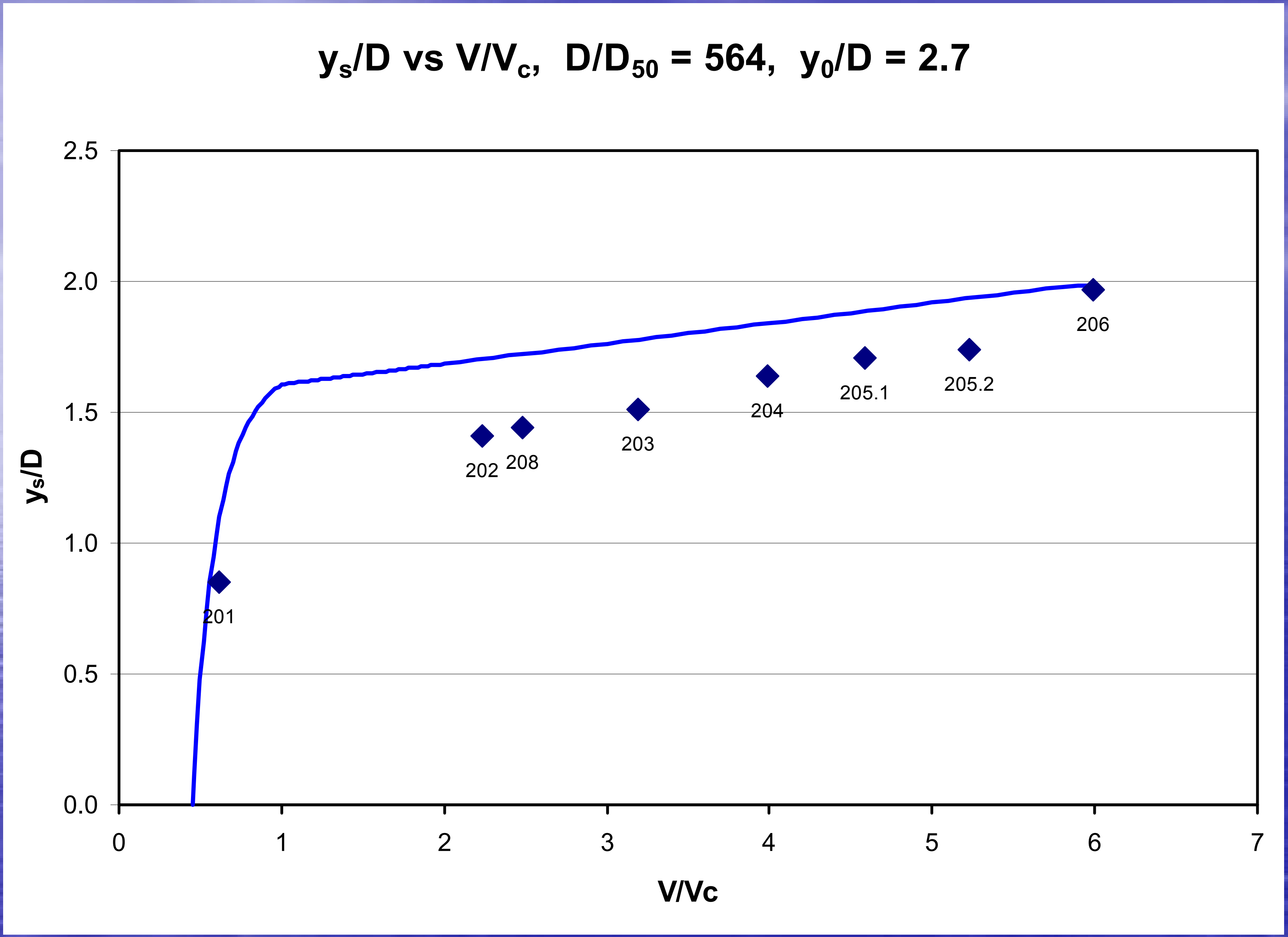

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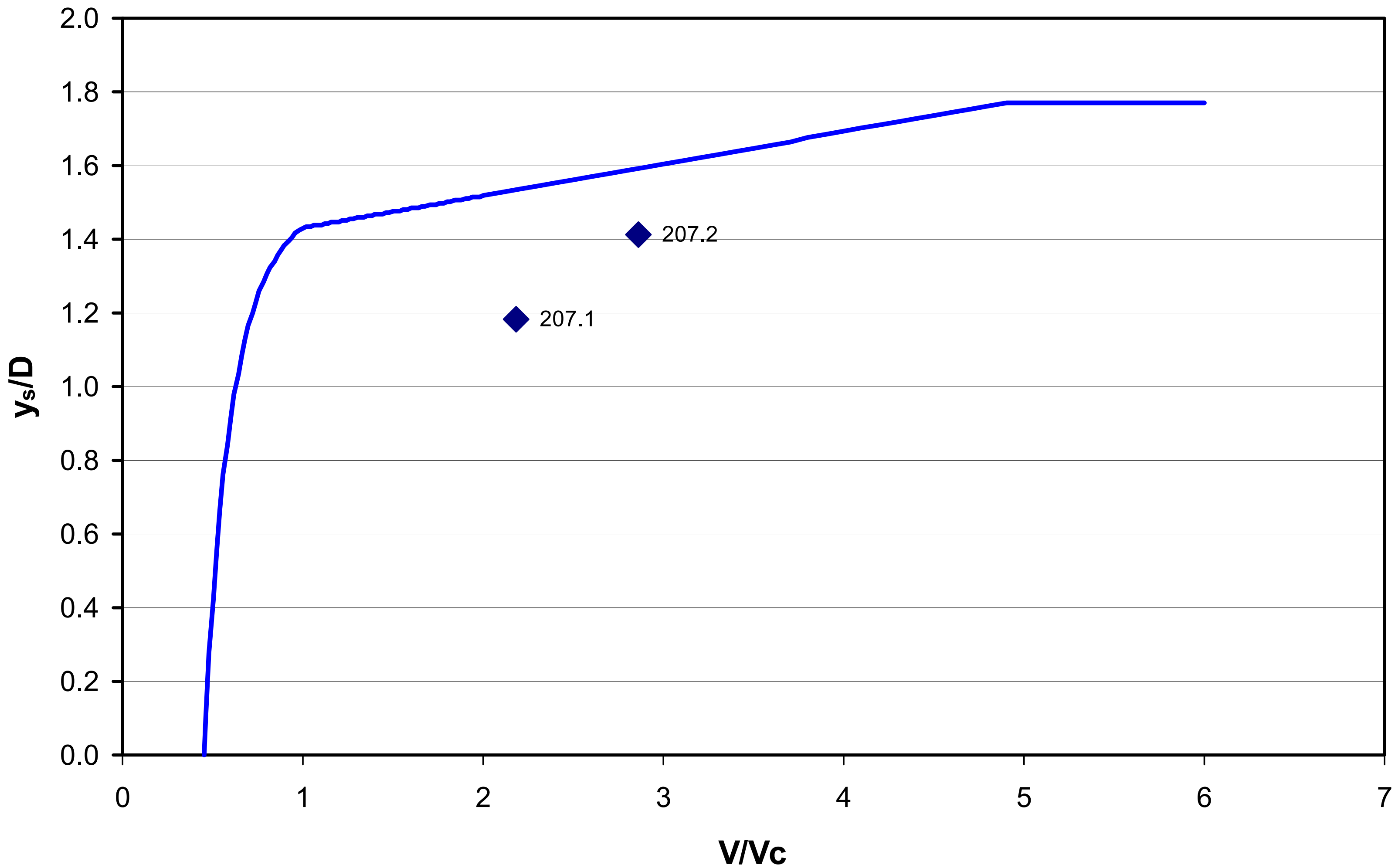
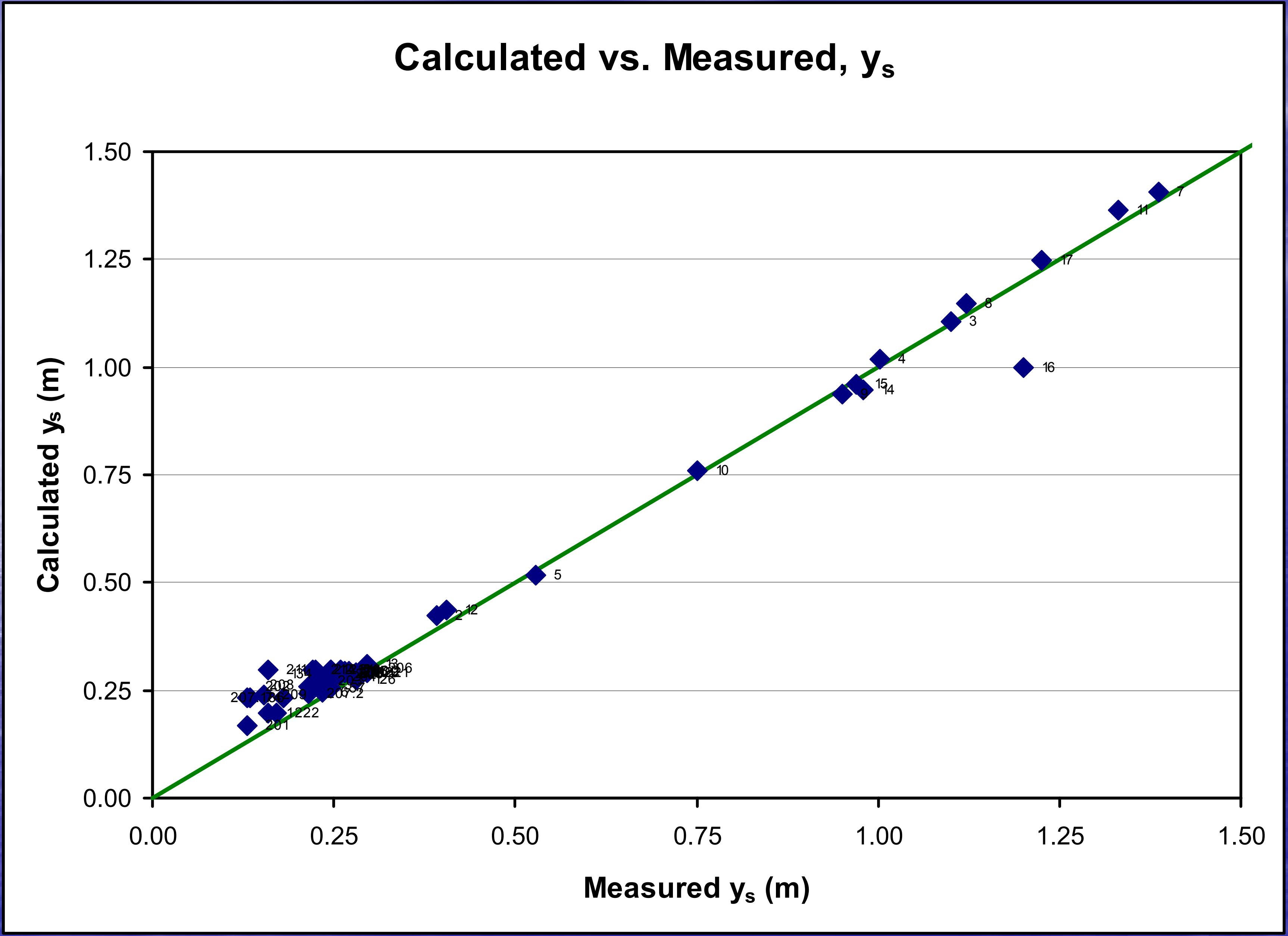
y_s/D vs V/V_c, D/D_{50} = 564, y_0/D = 1.3





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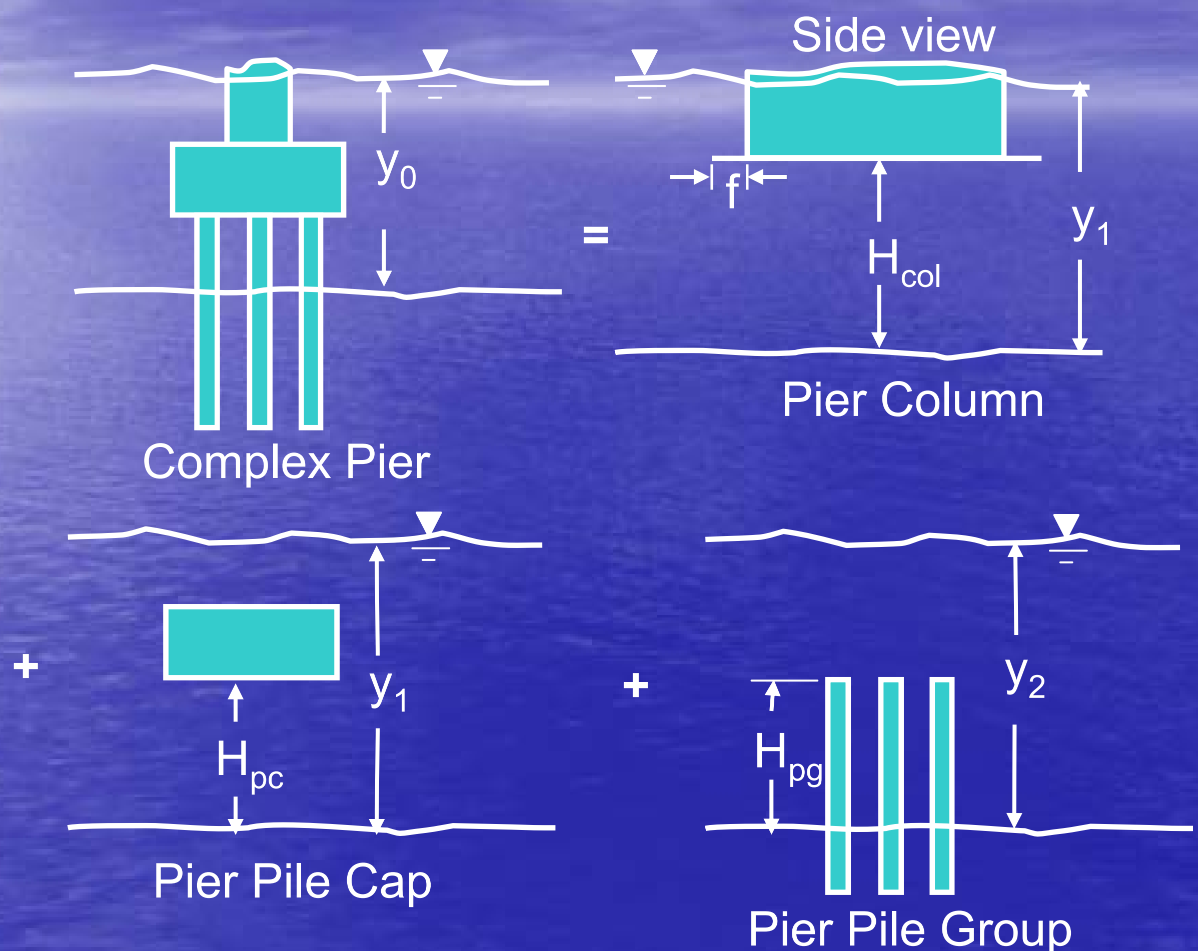
FIELD DATA VERIFICATION

- Application of equations to a prototype structure shows good agreement
- Subject of second presentation

COMPLEX PIERS WITHOUT MODEL TESTS

- Decompose pier into its components
- Determine the "effective diameter", D*, of each component
- Compute the contribution to the total scour depth by each component
- Sum the component scour depths to obtain the total



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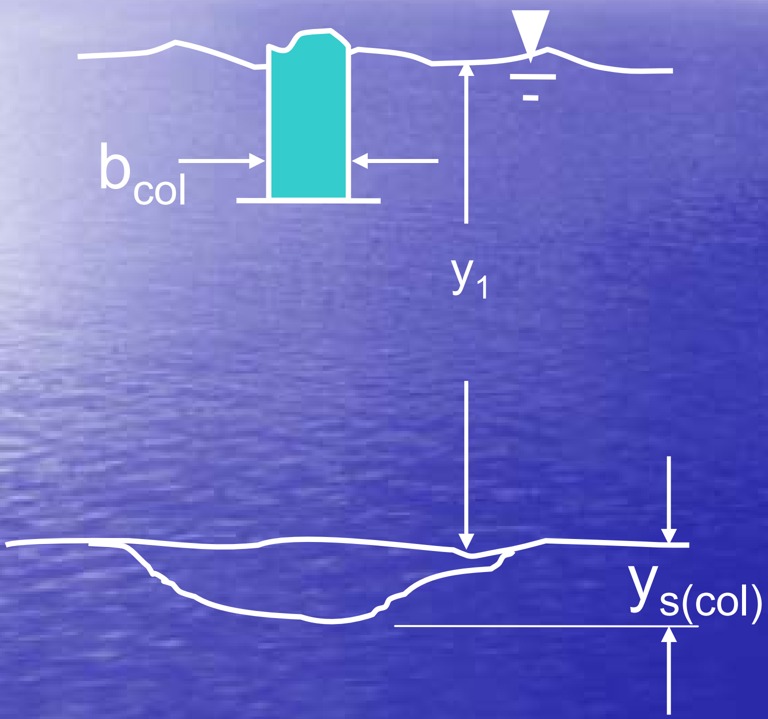
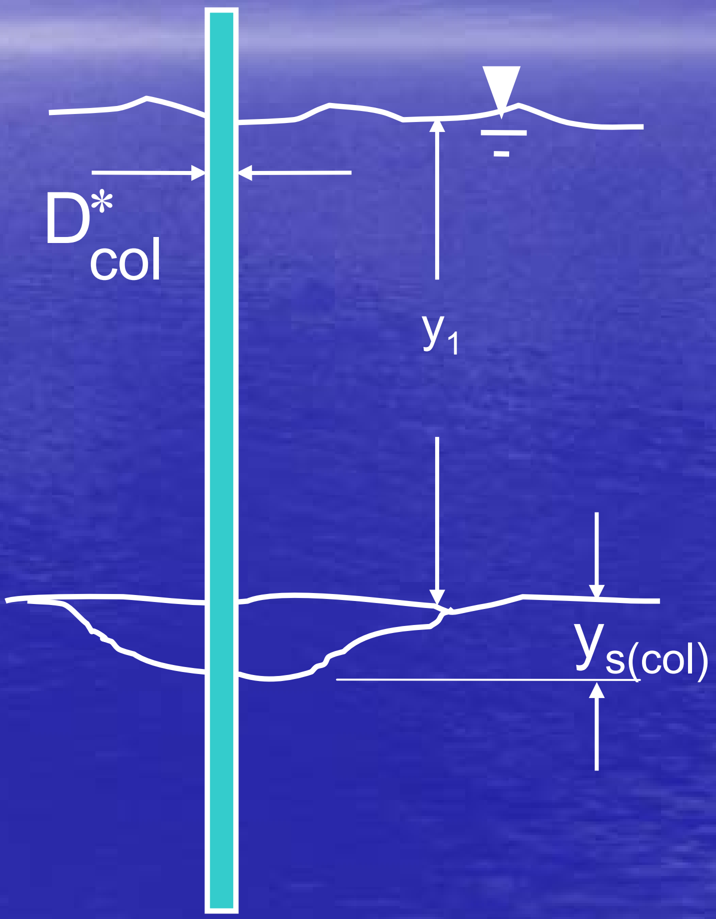
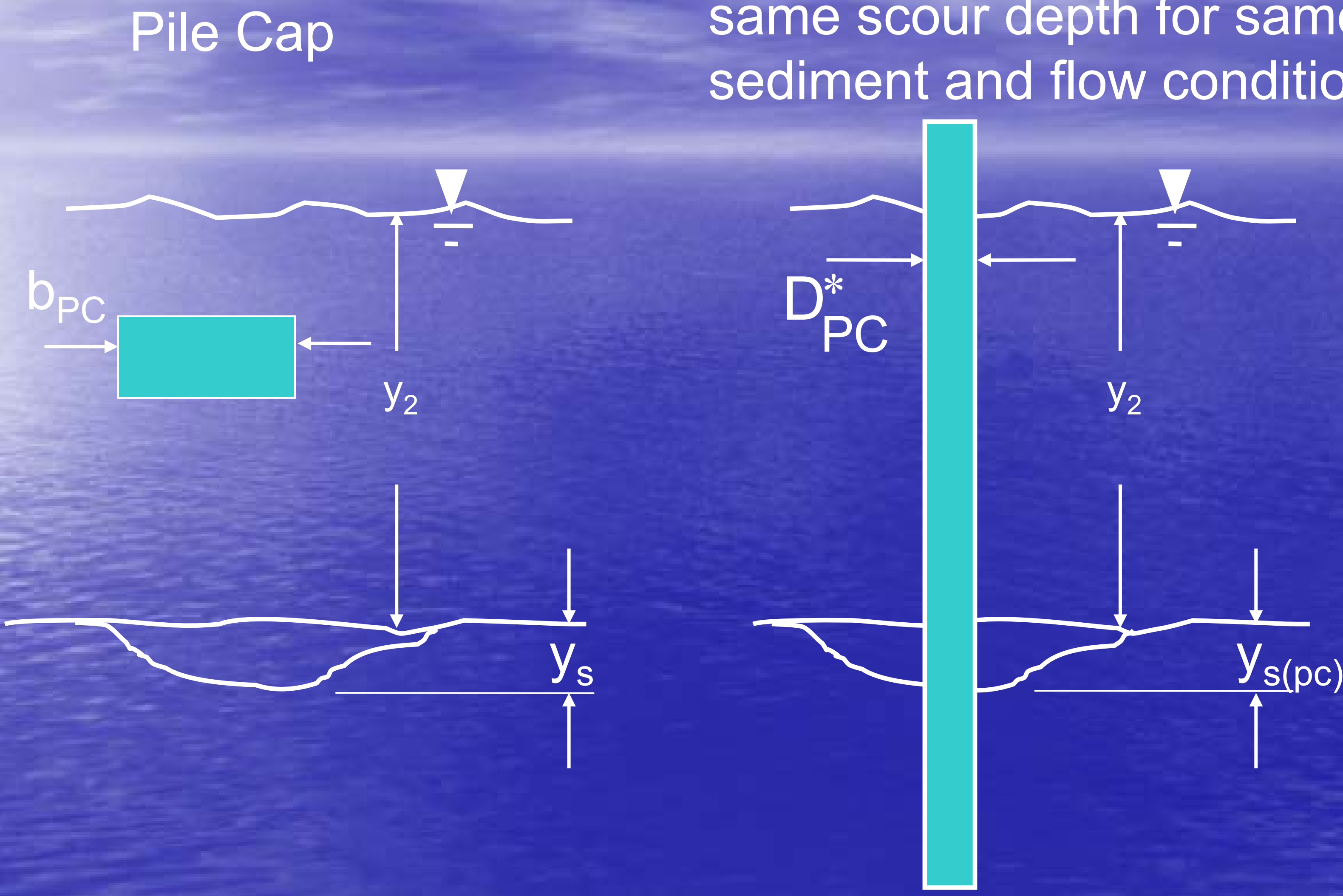
Pier Column



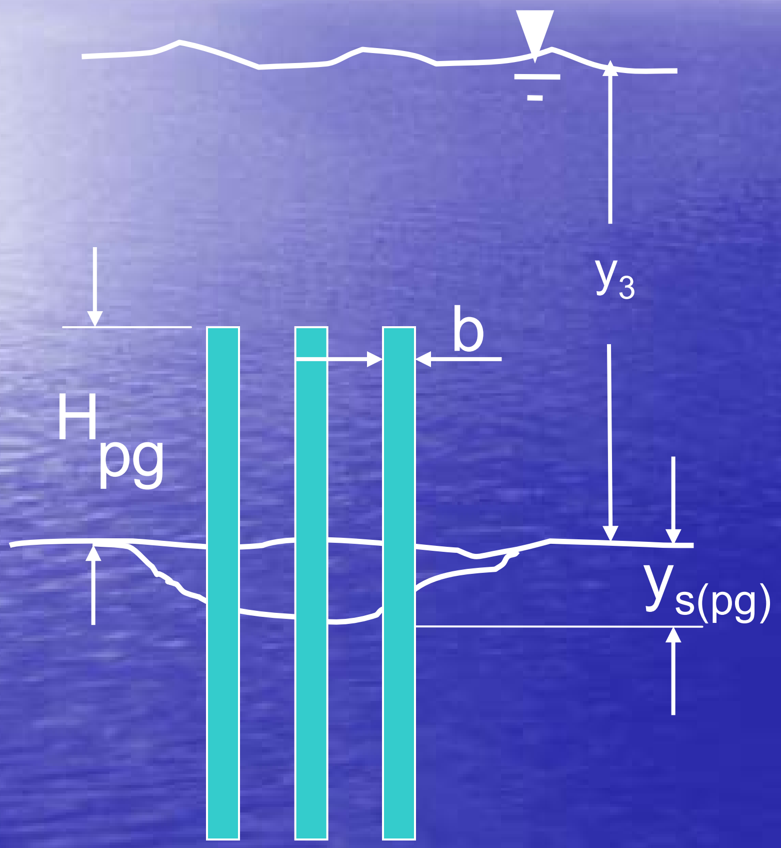
Single Pile that will have same scour depth for same sediment and flow conditions



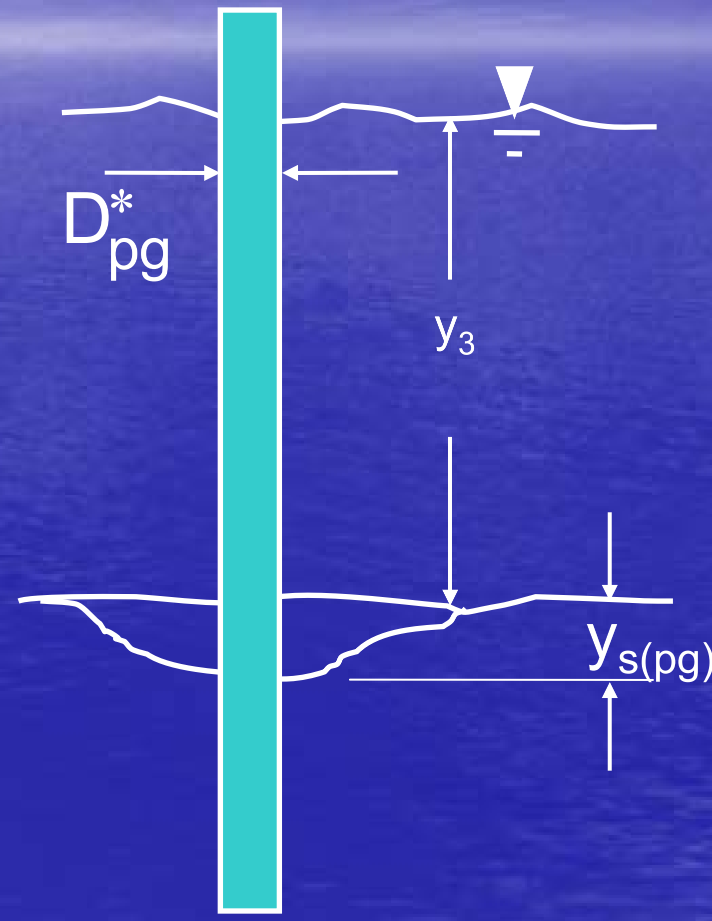
Single Pile that will have same scour depth for same sediment and flow conditions



Pile Group



Single Pile that will have same scour depth for same sediment and flow conditions



Total Scour Depth

$$y_s = y_{s(col)} + y_{s(pc)} + y_{s(pg)}$$

Design Scour Depths with Physical Model Tests

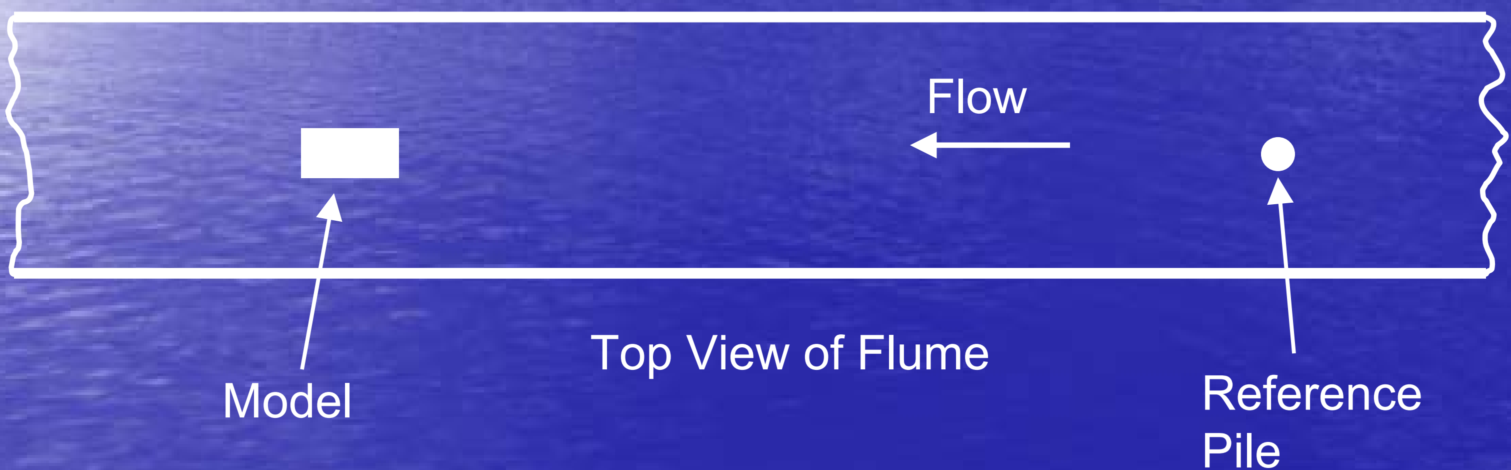
- For pier designs significantly different from the generic shape shown in the previous analysis Physical Model Tests are recommended
- Model test design
- Interpretation of model results

Physical Model Test Design

- Models as large as flume will allow
- D/D_{50} >~50
- Sufficient test duration
- Reference pile if possible
- Low suspended sediment in water
- Small distribution of sediment size (small sigma)

Physical Model Test Design

Reference pile



Physical Model Test Design

- Reference pile
  - Use scour at reference pile to correct for:
    - Flume sediment size distribution
    - Suspended fine sediment in water
    - Duration of test less than required to reach equilibrium scour depth

Interpretation of Physical Model Test Results

- Compute equilibrium scour depth for reference pile
- Compute Scour Depth Correction Factor:

$$SDC = \frac{\text{Computed Scour Depth at Reference Pile}}{\text{Measured Scour Depth at Reference Pile}}$$

Interpretation of Physical Model Test Results

Compute model pier equilibrium scour depth:

$$y_{s(model)} = \text{SDC*(Measured scour depth at model pier)}$$

Interpretation of Physical Model Test Results

- Compute effective diameter of model pier, D_m^*, using single, circular pile equation, i.e. solve for D_m^* in the following equation:

$$\frac{y_s}{D_m^*} = 2.5\,K_s \left\{ \tanh\left[\left(\frac{y_0}{D_m^*} \right)^{0.4} \right] \right\} \left\{ 1 + \frac{0.25\,\ln\left(V/V_c\right)}{\left(V/V_c\right)^2} \right\}$$

$$\left\{ \frac{2.95}{2.5\exp\left[0.45\left(\log\left(\frac{D_m^*}{D_{50}}\right) - 1.64\right)\right] + 0.45\exp\left[-2.5\left(\log\left(\frac{D_m^*}{D_{50}}\right) - 1.64\right)\right]} \right\}$$

Interpretation of Physical Model Test Results

- Next compute the effective diameter of the prototype pier, D_p^* D_m^*

$$D_p^* = \text{(Geometric Scale of Model)}\, D_m^*$$

Interpretation of Physical Model Test Results

- Knowing the prototype effective diameter and the design flow and sediment conditions the prototype scour depth can be computed using the single structure scour equations presented above.

Summary

- Design local scour depths for complex bridge piers can be computed without physical model tests for a large number of pier designs
- Pier designs that differ significantly from the generic shape require physical model tests as part of the analysis

Summary (cont.)

- A good physical model test design and execution is essential
- Care must be taken in the interpretation of the model scour results and their use in arriving at design scour depths for the prototype pier

Questions?
Comments

Required Shear Profile Points