# ICSE-6 2012, Paris

jp kenny

## Subsea Pipeline Stability Design

# Development of a Novel 2D Pipe-Soil-Fluid Interaction Model

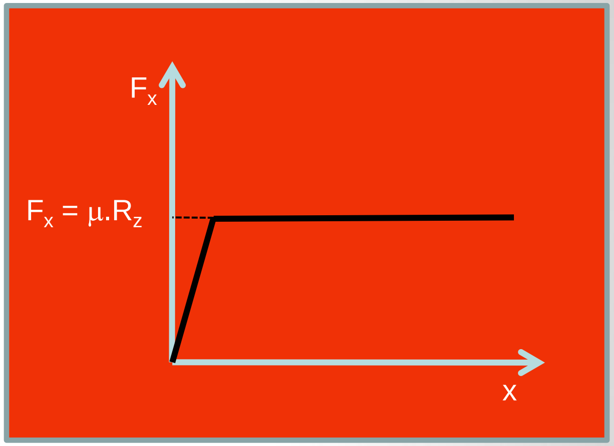
Terry J. Griffiths, Mengmeng XU, Wenwen SHEN, Marvin RAMSAWMY, Amar SHAH
J P Kenny
Perth, Australia

# Background – status quo

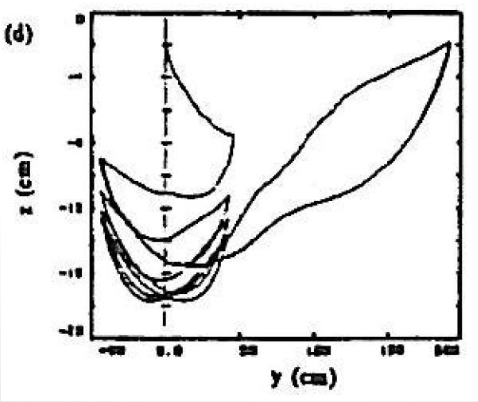
jp kenny

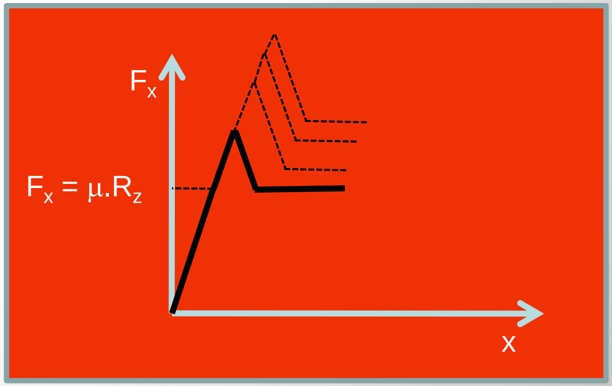
With… present code and design models:

- 'Coulomb' friction pipe-soil model:
  - Ignores passive resistance
  - Ignores fluid effects on soil




- Verley passive resistance pipe-soil model:
  - Ignores fluid effects
  - e.g. scour
  - e.g. piping
  - e.g. liquefaction



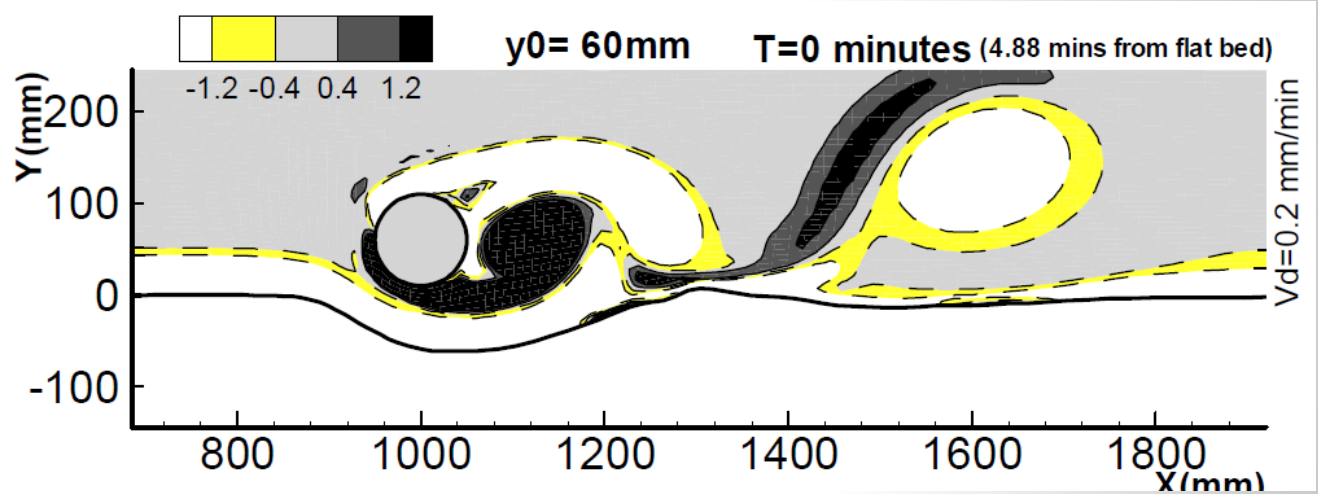



# Background – the problem

Stable pipelines on a mobile seabed?

- Sand unstable
- Pipe embeds
- Pipe stable ☺

(Image courtesy Li & Cheng 2001)




The problem?

*"…it must follow that the seabed must become grossly unstable long before the extreme design conditions. The traditional model is irrelevant: it makes no sense to consider the stability of a stationary pipeline on a stationary seabed…"*

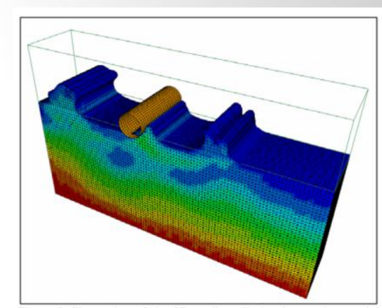
A. Palmer (1996)

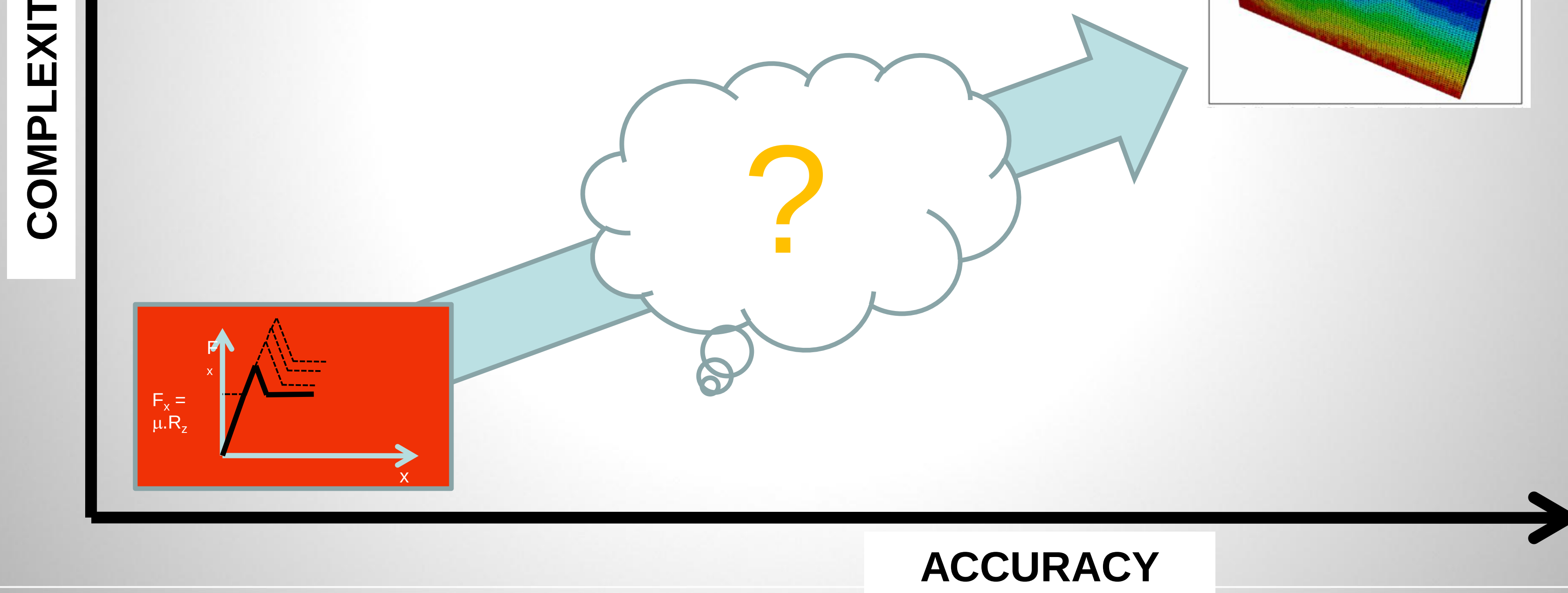
# Pipe-Soil-Fluid Interaction (PSF) Model

We need a model which can bridge the gap between:

- The (too simple) hysteresis friction models and
- The (too expensive) continuum FEA / CFD models

➔ JPK PSF Model

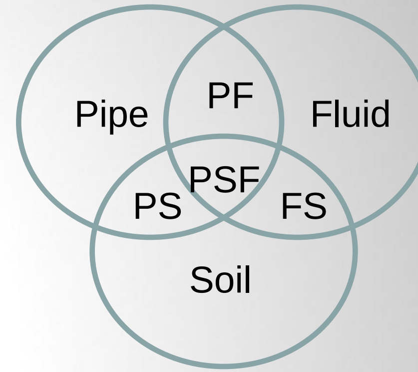


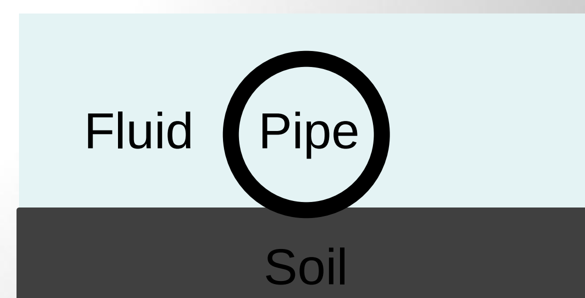


# What is the PSF Model?

Pipe-Soil-Fluid Interaction

- Pipe-Soil Interaction
  - Vertical Reaction Force
  - Soil Resistance
  - Soil deformation due to pipe  movement
- Pipe-Fluid Interaction
  - Pipeline hydrodynamics
- Soil-Fluid Interaction
  - Suspended sediment transport




Rigid Pipeline on Sea Floor

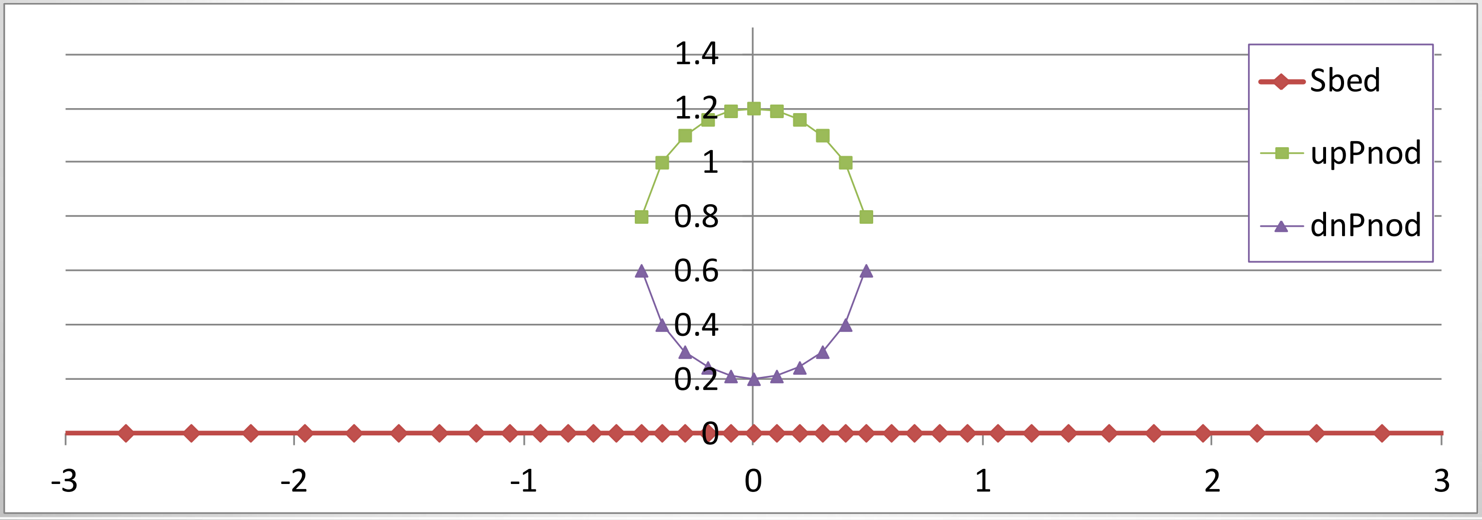
# The PSF Model – Pipe/Soil

## Seabed

- Set of nodes at user defined, symmetric spacing, either side of the pipe
- Node parameters:
  - Seabed elevation
  - Suspended sediment concentration

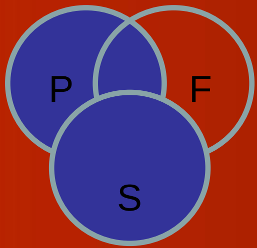
## Pipe

- Set of nodes (up/dn) with the same spacing as the seabed nodes

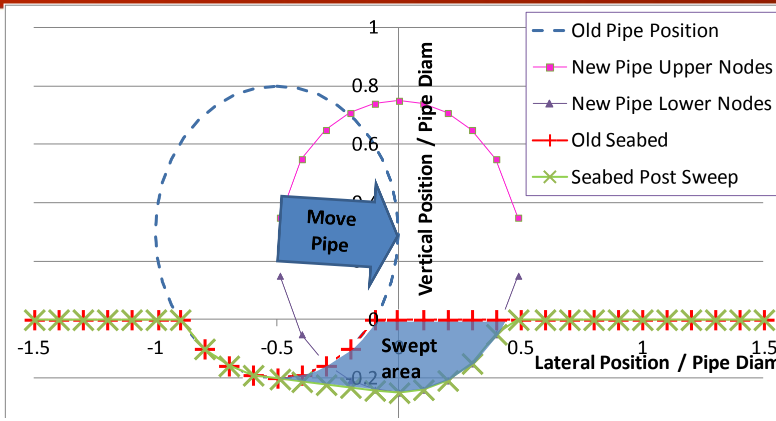


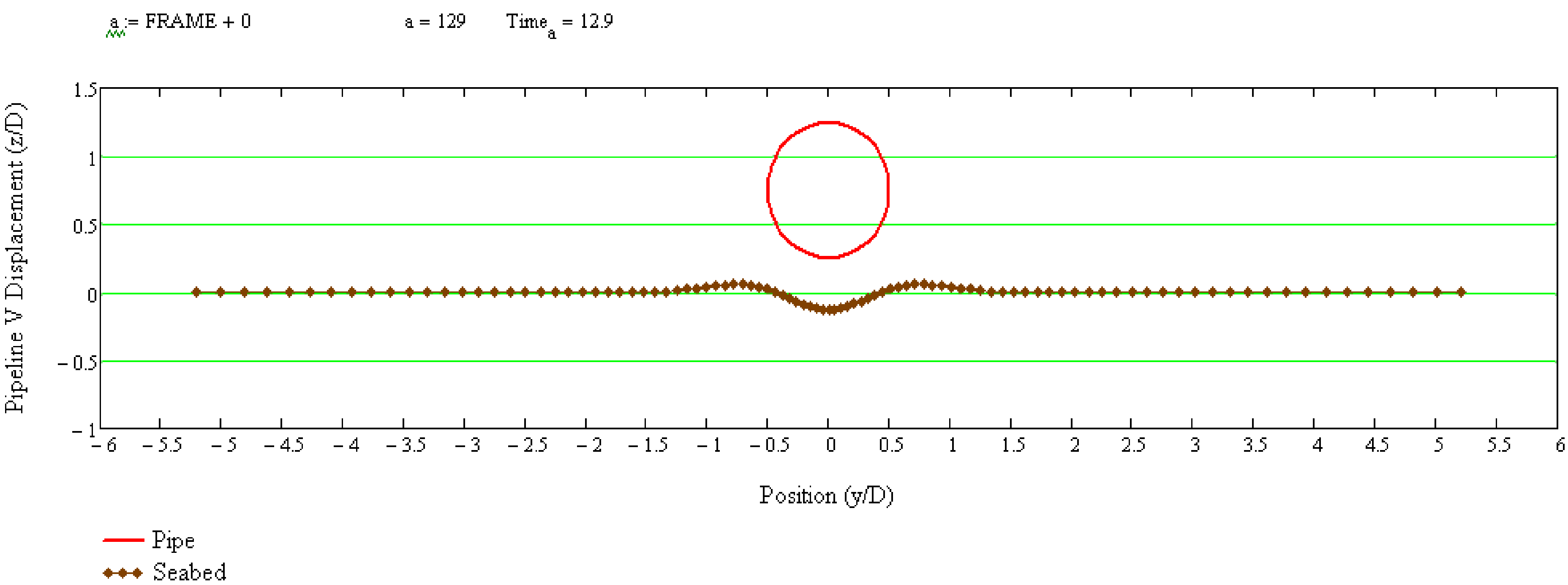
# The PSF Model – Pipe/Soil Step 2

## Update soil profile to account for pipe motion

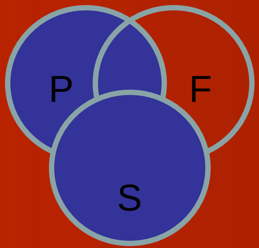



- **<u>RULE 1: Conservation of soil</u>**
- **<u>RULE 2: Soil can’t exist inside pipe</u>**

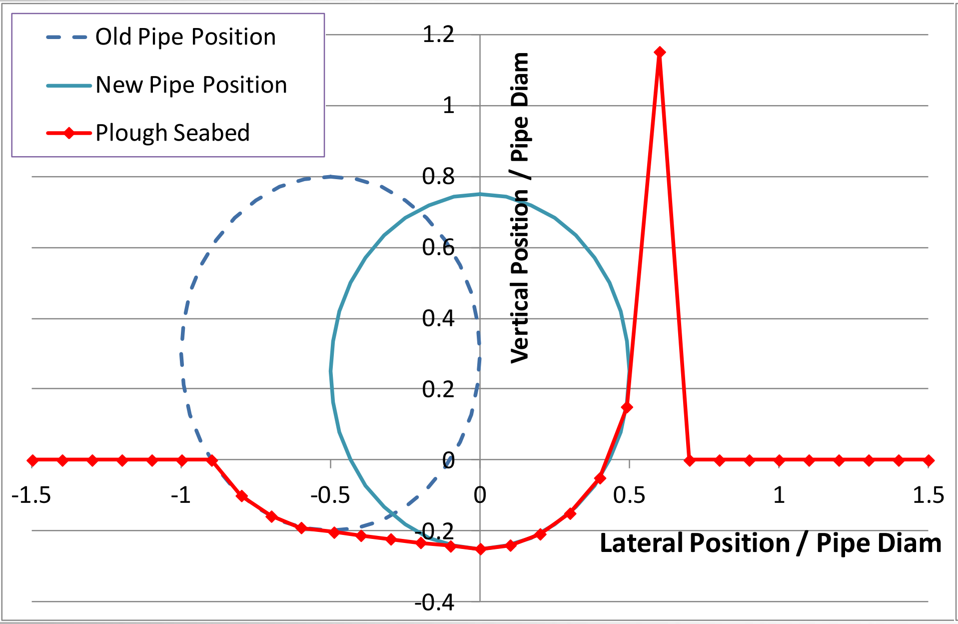


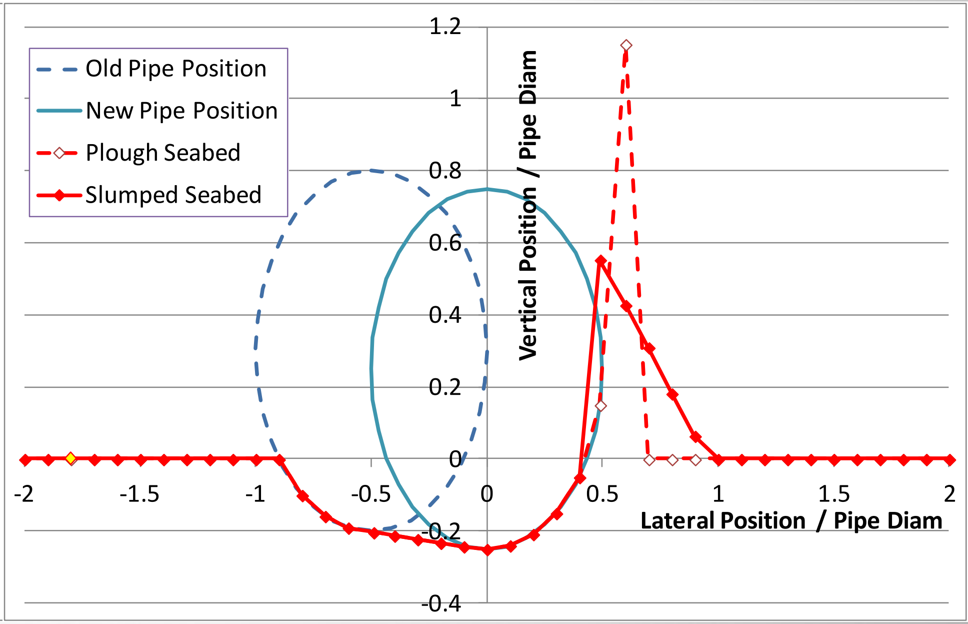



# The PSF Model – Pipe/Soil Step 3
## Account for slope failure (Slumping)




- **RULE 3: Soil cannot exceed its internal angle of repose**
  - "Slumps" down until the soil complies with this requirement
  - Conservation of soil volume

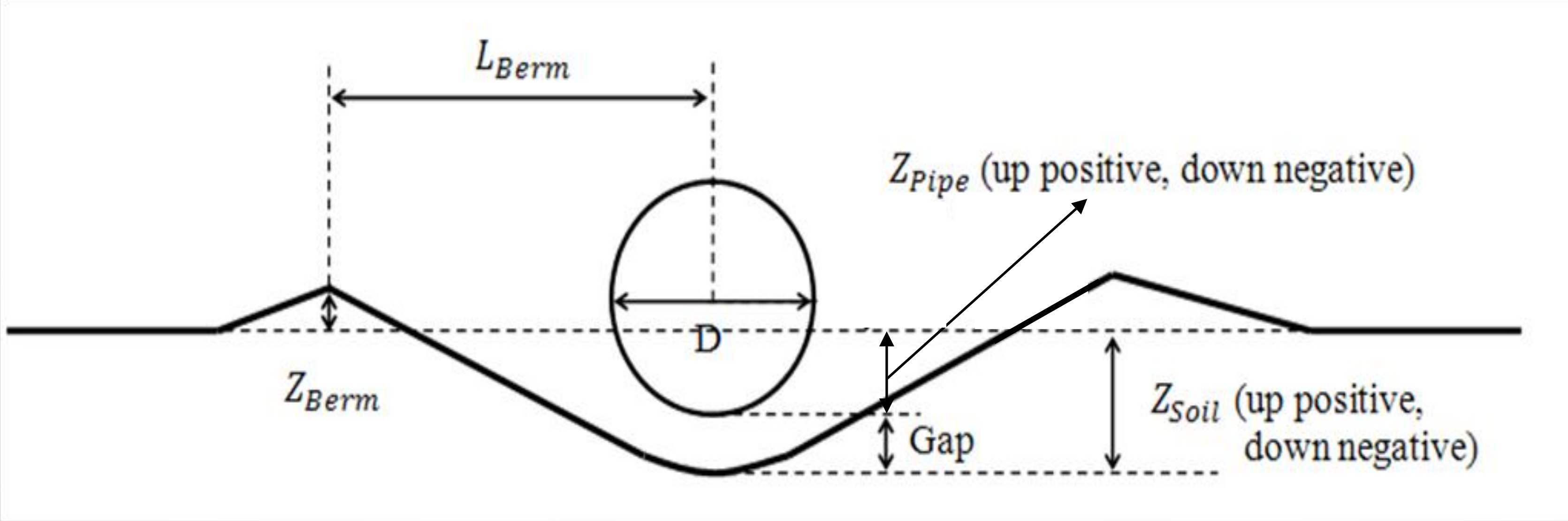


# PSF Model: Sediment Transport

## Algorithmic model

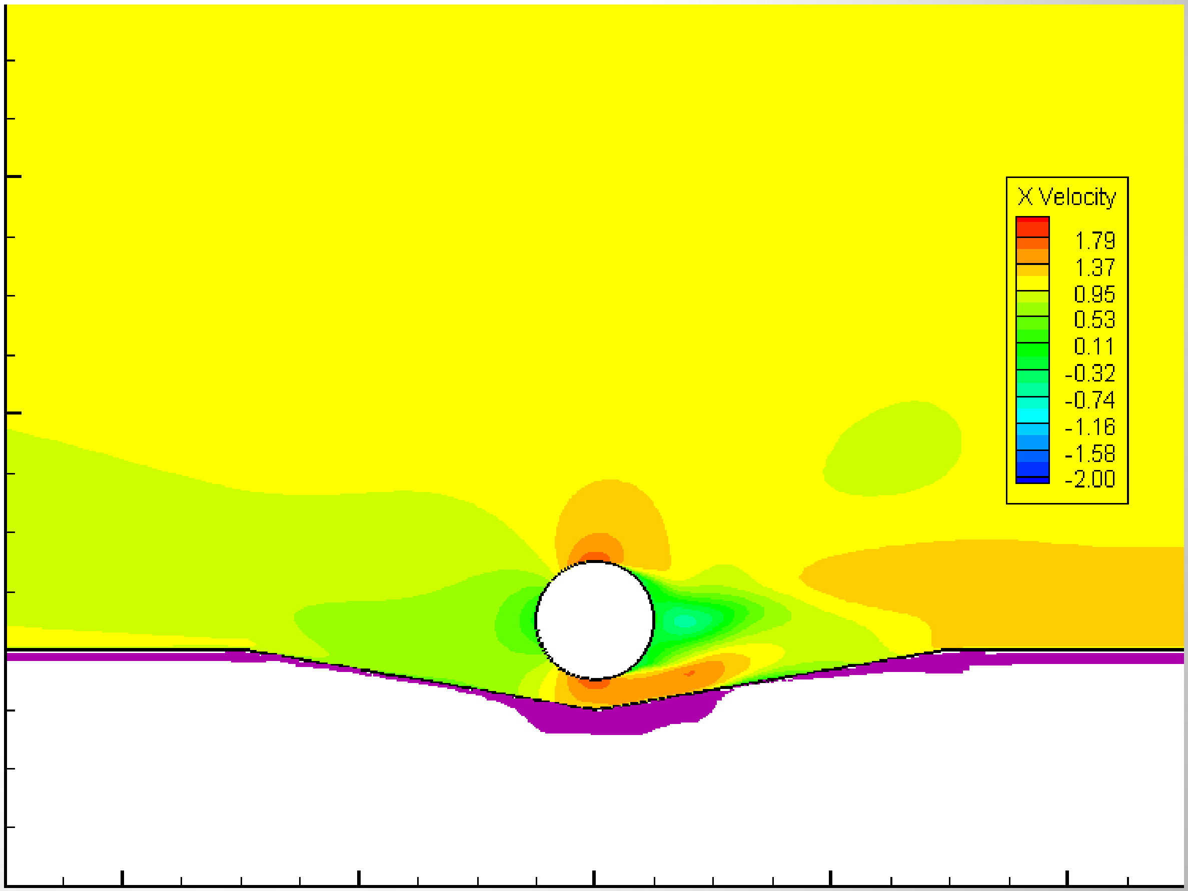
- Representation of seabed shear stress as local velocity
- Parametric based on CFD results



# PSF Model: Sediment Transport

## CFD by UWA CEED Students (Mengmeng Xu, Wenwen Shen)

- Parametric
- 2D initially
- Over 100 cases
  - Geometries
  - Wave and Currents



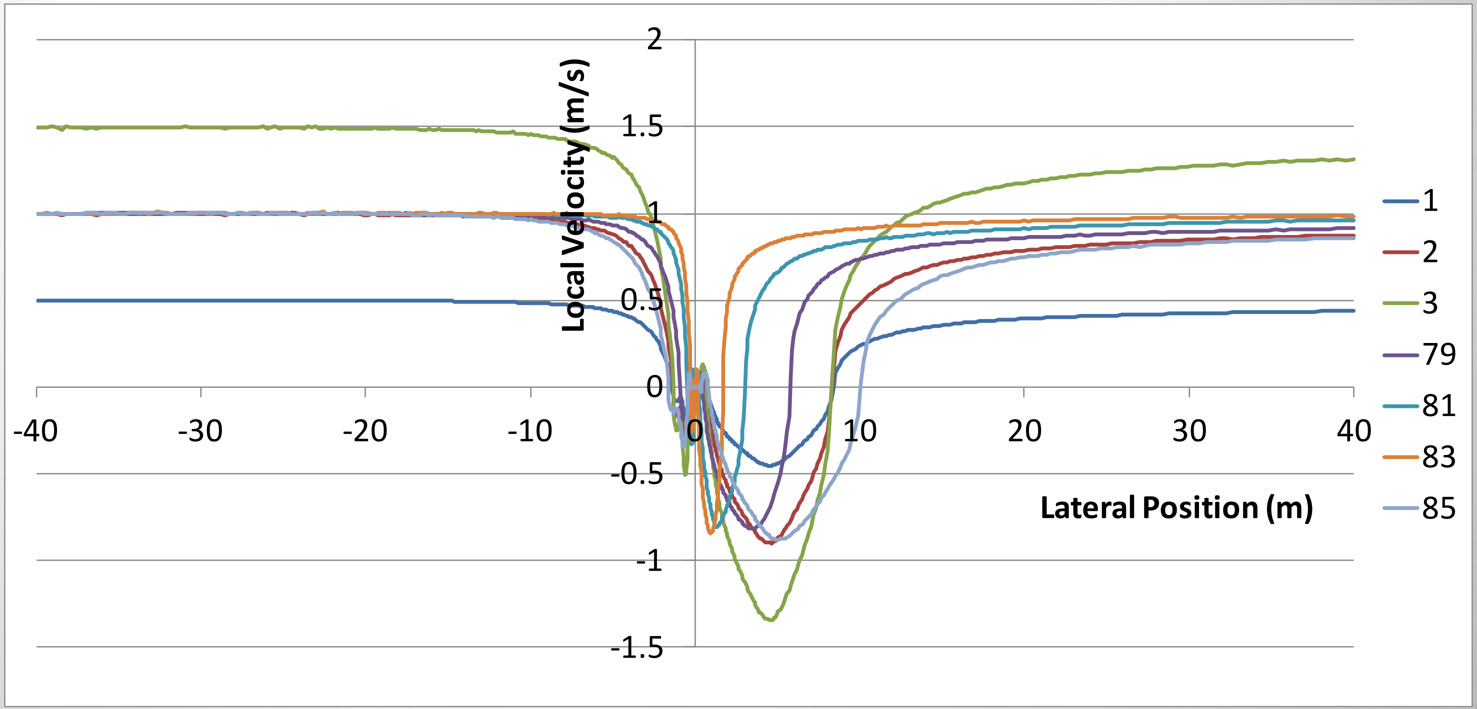
# PSF Model: Sediment Transport

jp kenny

## Study scaling factors

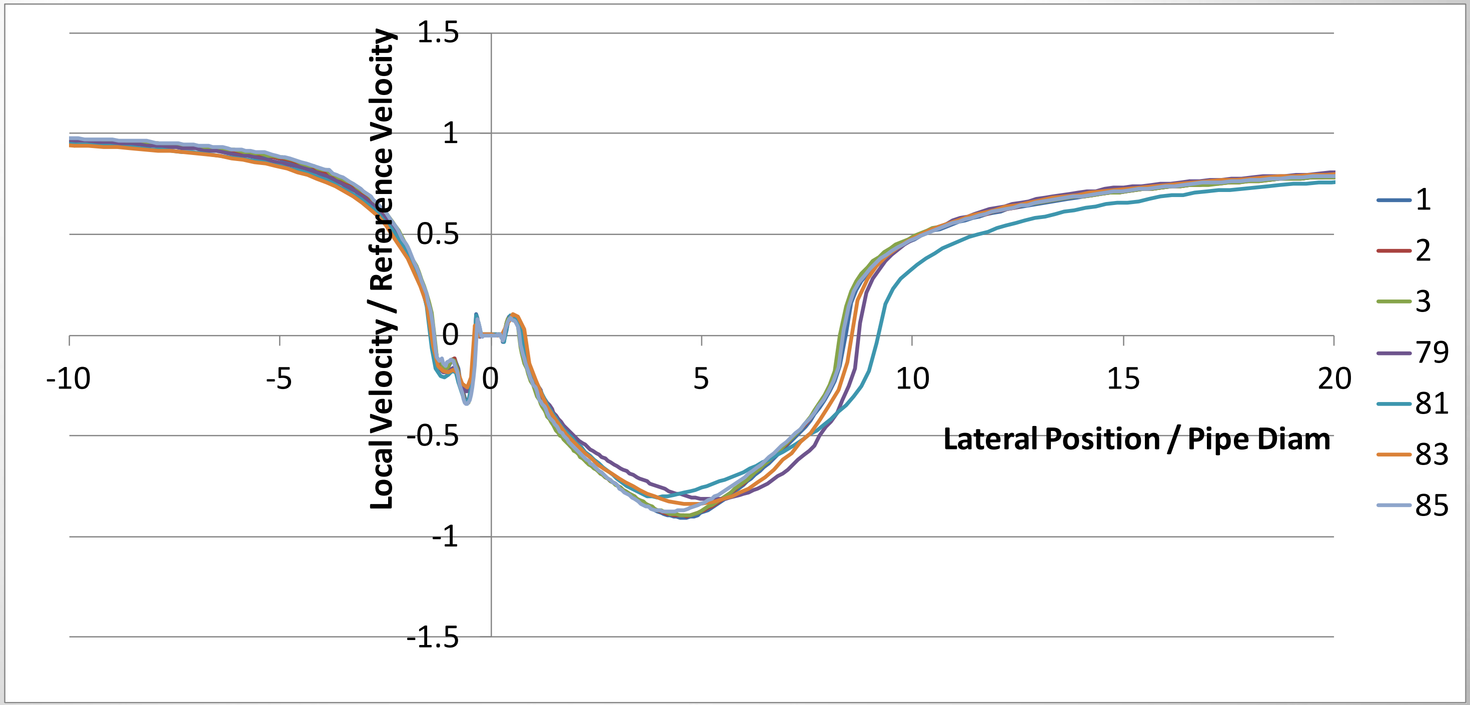
- Vary steady current Uc (up to 1.5m/s)
- Vary pipe diam. D (0.2m to 1.2m)

- Unscaled results:

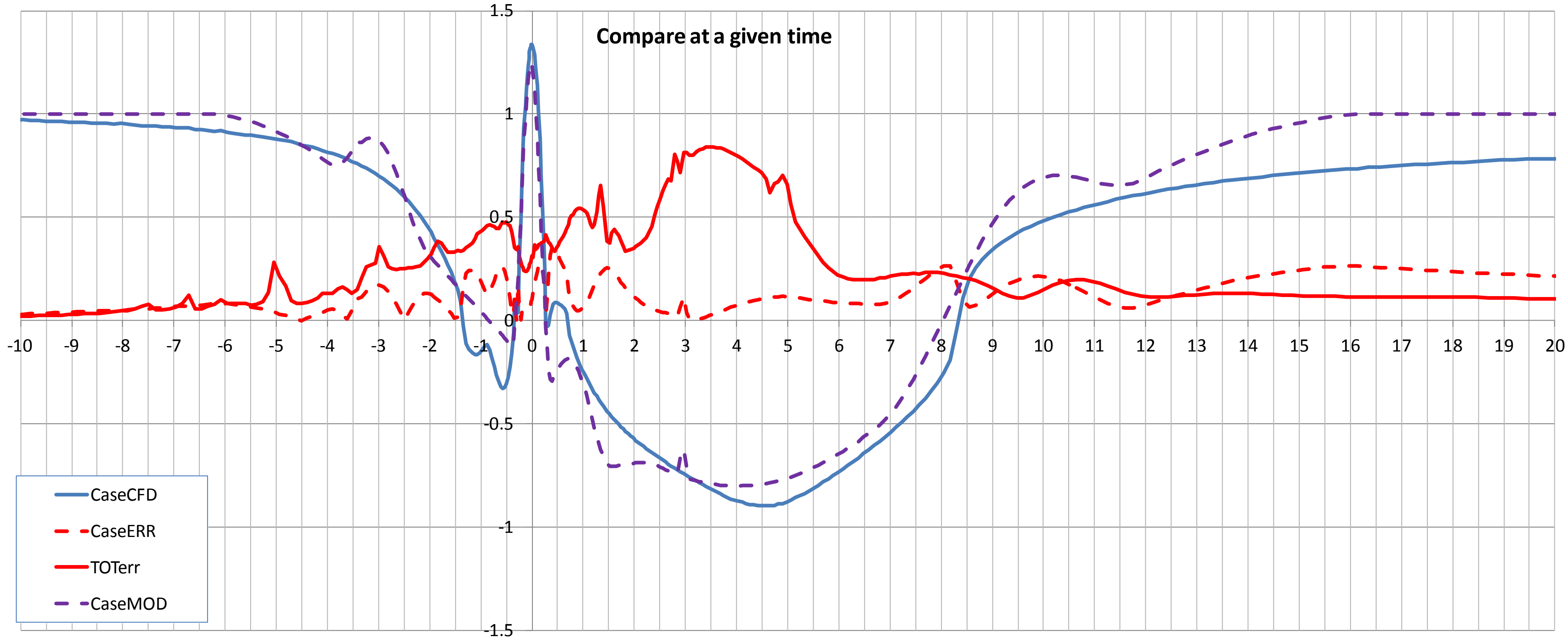


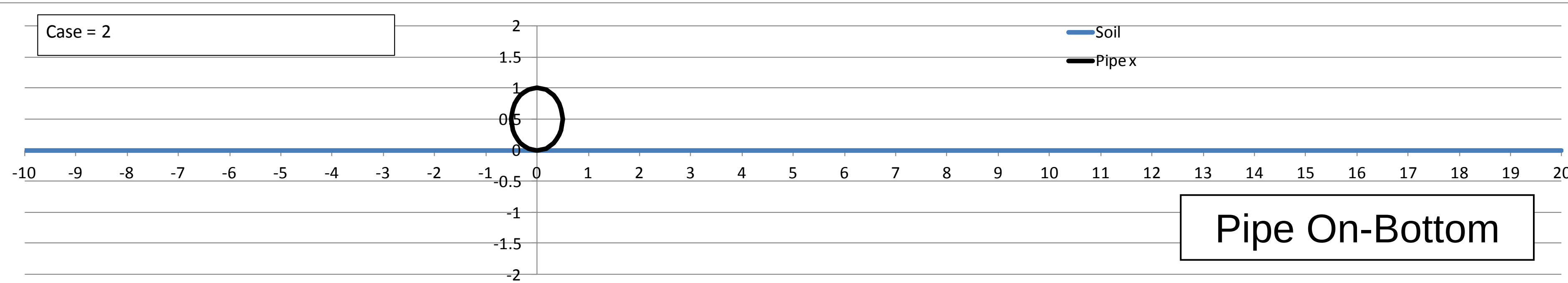
# Study scaling factors

- Vary steady current Uc & Pipe Diam D (pipe on-bottom)
- Scale results by:
  - Uc
  - D



# PSF Model: Sediment Transport

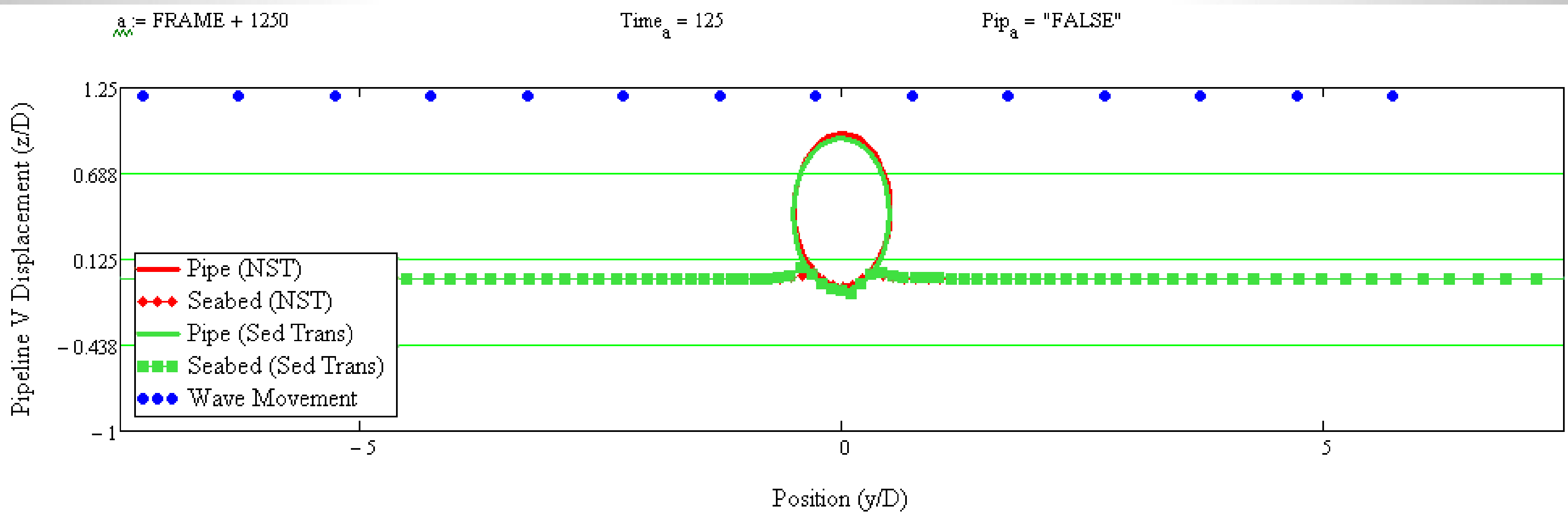



Pipe On-Bottom

# PSF Model: Random Wave Series

- RED pipe =
  - PSF Model but with Sediment Transport switched off
  - Equivalent to & calibrated against Verley Model
- GREEN pipe =
  - PSF model, with Sed. Trans. (looks more like reality?)



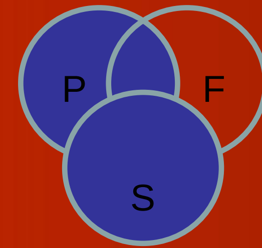
# Thank you

Acknowledgements

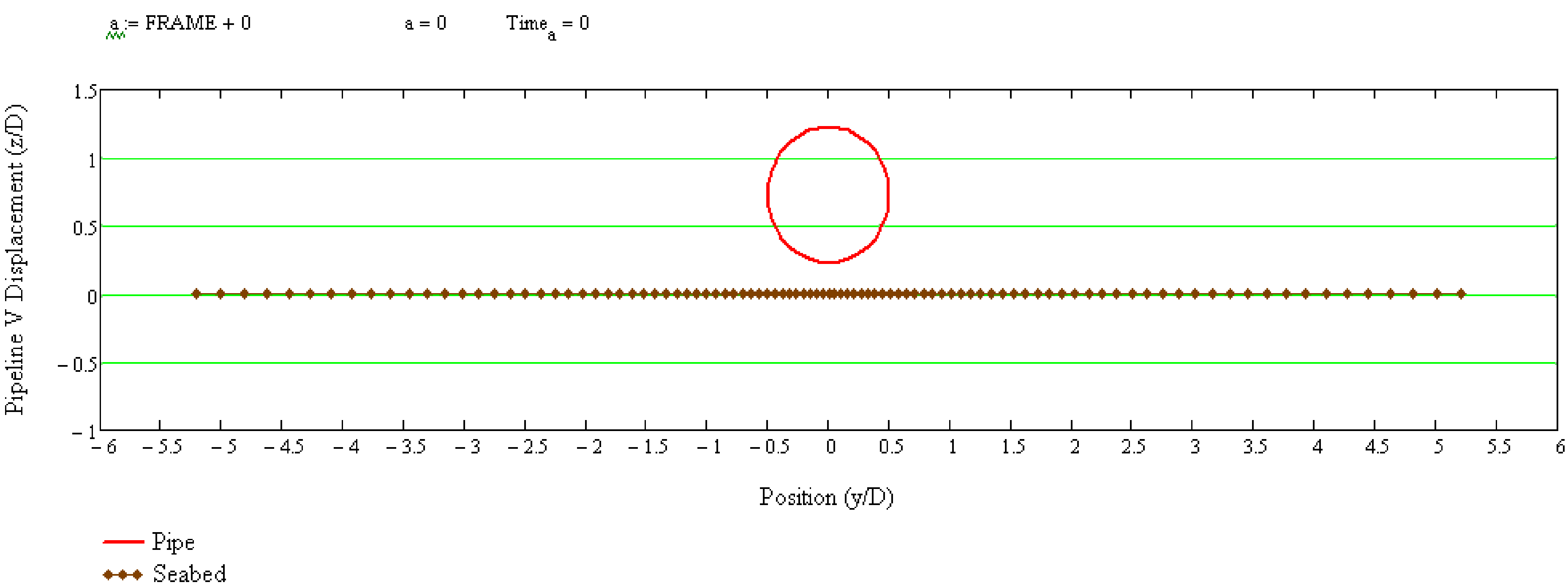
Any Questions?

# The PSF Model – Pipe/Soil Step 1

## Interpolate new profile from old profile



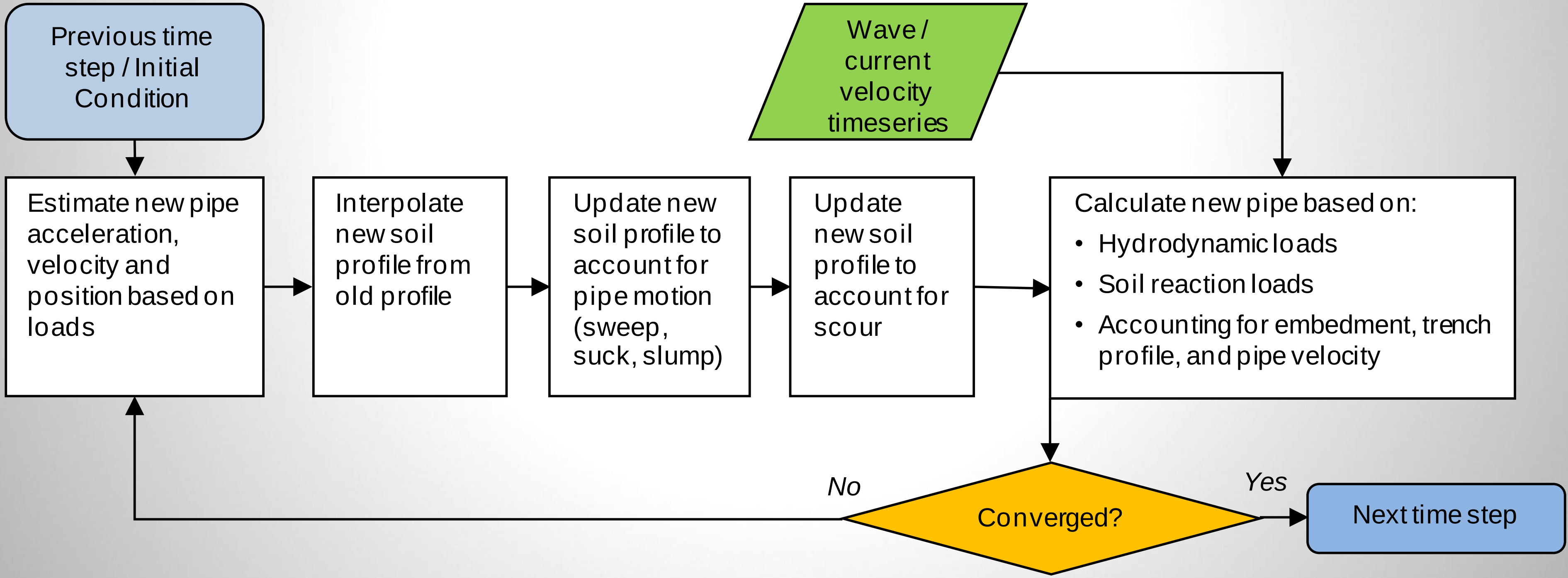

- The pipe acts as the moving reference frame for the soil nodes
- Soil nodes shift with the pipe in the horizontal axis
- Allows for a fine node mesh under the pipe and a coarse mesh for the seabed extremities



# Pipe-Soil-Fluid Interaction Model Flowchart

Options:

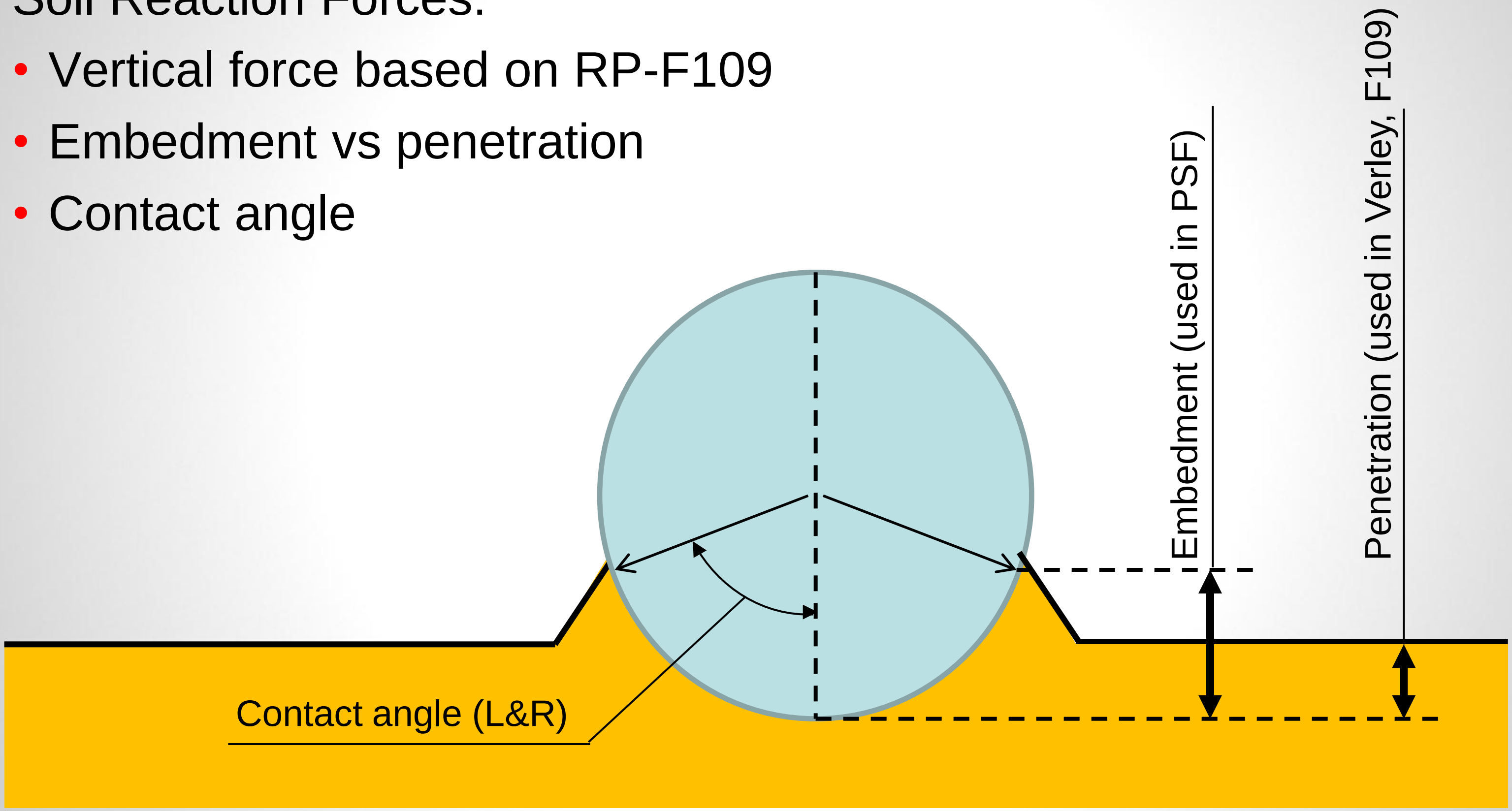
- Iteratively find equilibrium pipe position at each timestep
- Fix horizontal, vertical or both axes for prescribed displacement



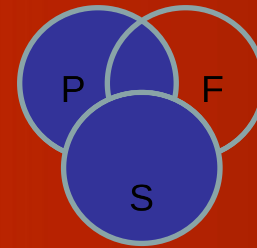
# The PSF Model – Pipe/Soil

Soil Reaction Forces:

- Vertical force based on RP-F109
- Embedment vs penetration
- Contact angle

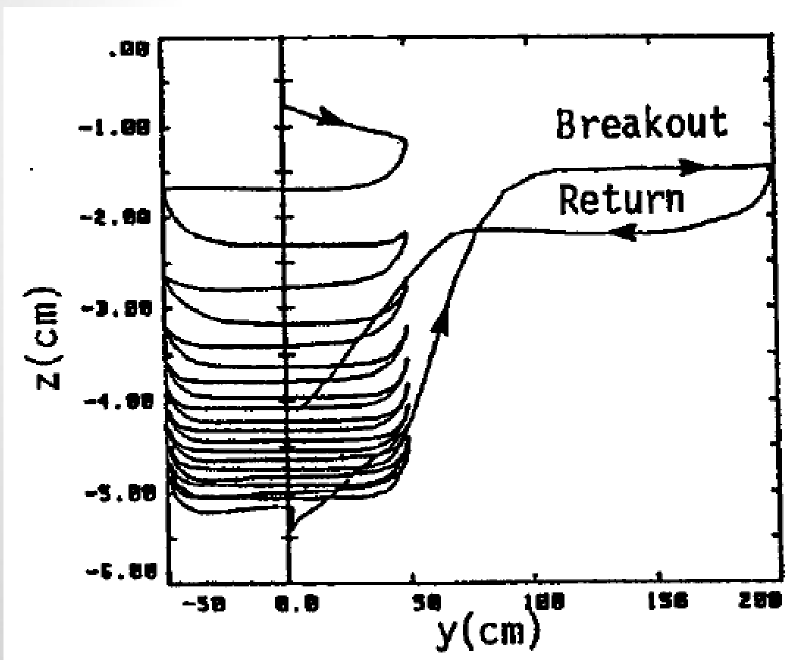


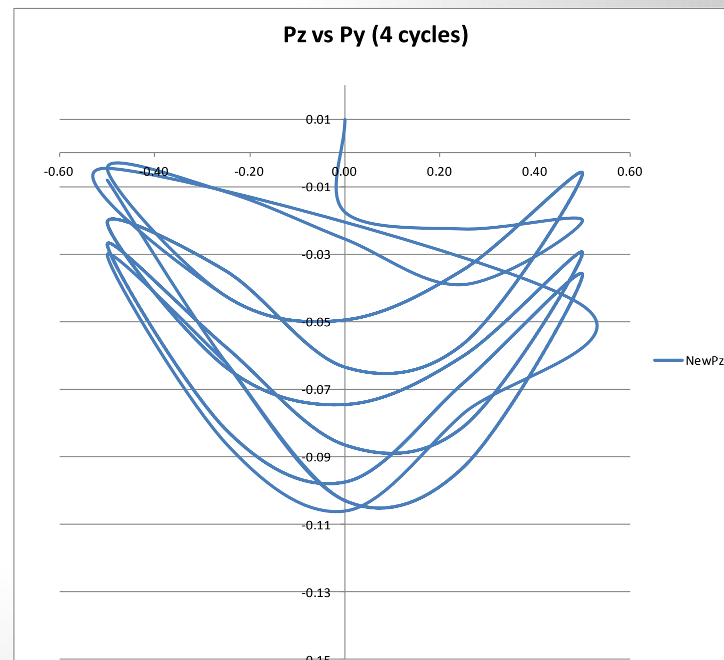
# The PSF Model – Pipe/Soil



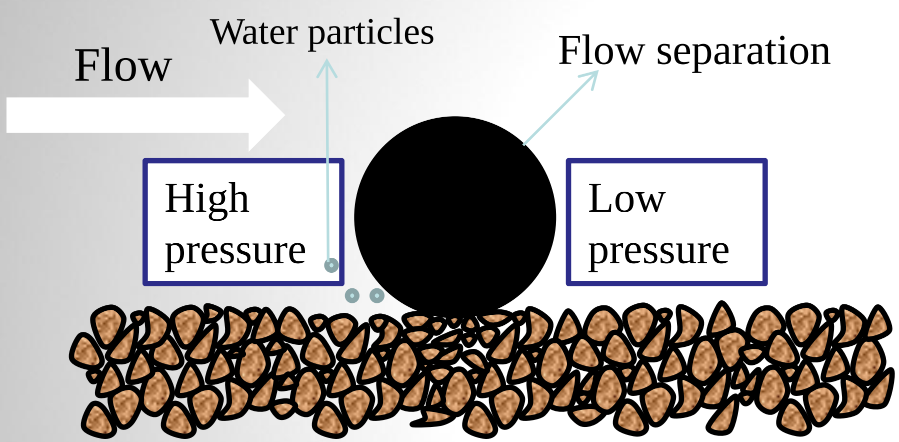

Pipe-Soil Reaction Forces: Benchmark Against Published Model

- Pz vs Py graph
- Imposed lateral displacement
- Compare to Verley (Brennodden et al 1989)

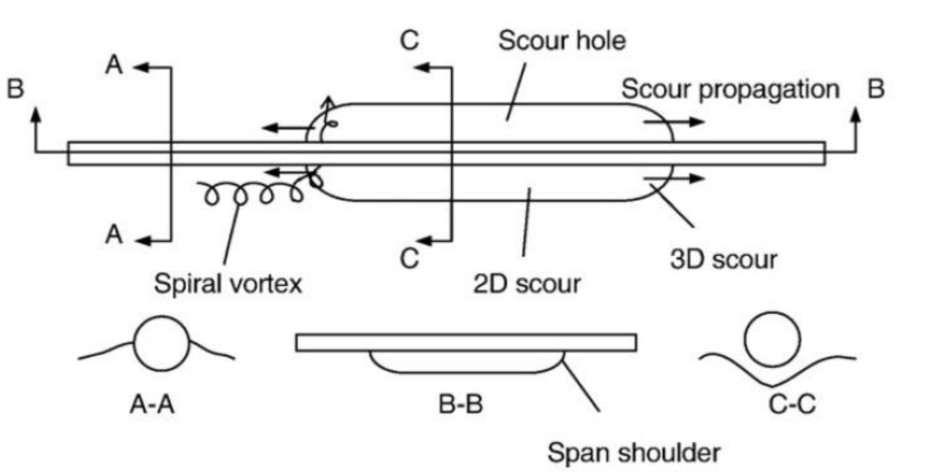


# PSF Model: Scour Mechanisms




(Diagram courtesy Shen 2011)



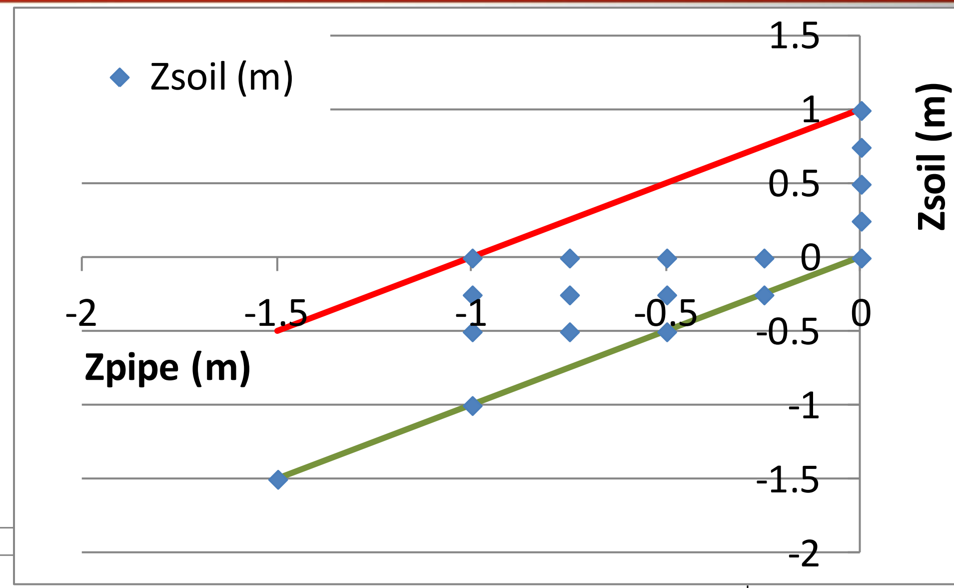

A typical scour process below a pipeline
(Cheng et al.2009)

- Onset of piping based on F109
- (drag force approximate to dp across soil)

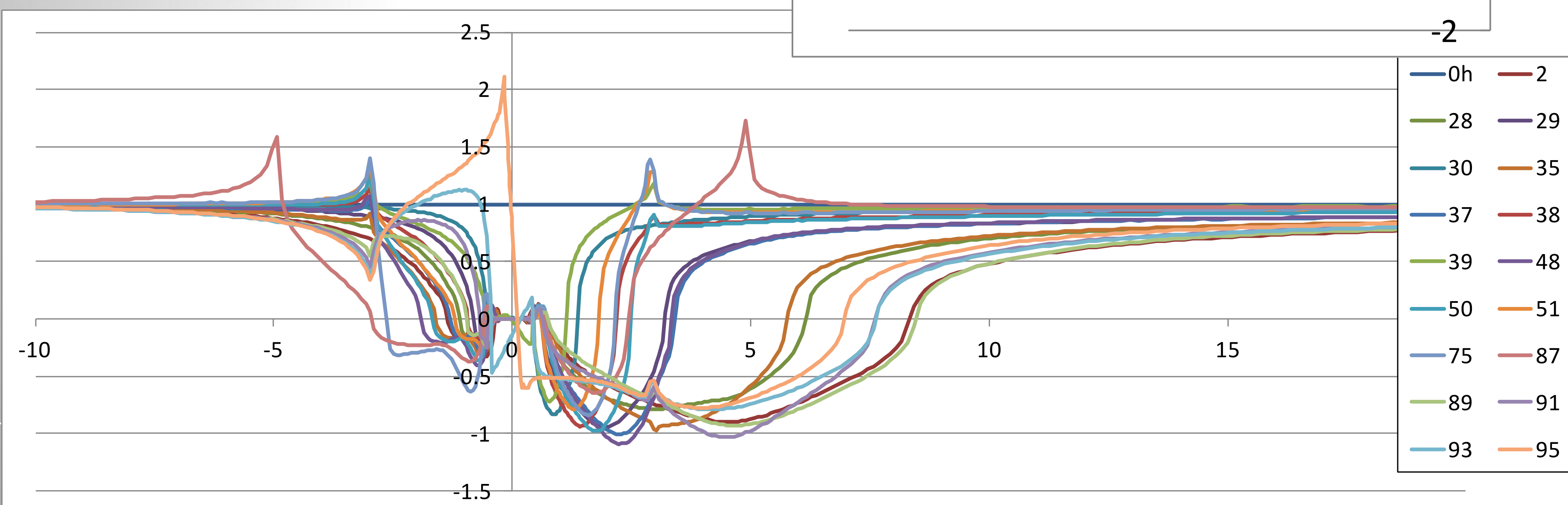
# PSF Model: Sediment Transport

## Study scaling factors

- Vary Zp & Zs
- Unscaled results:




➔ (a.Zp^2+b.Zp+c).(d.Zs^2+e.Zs+f)



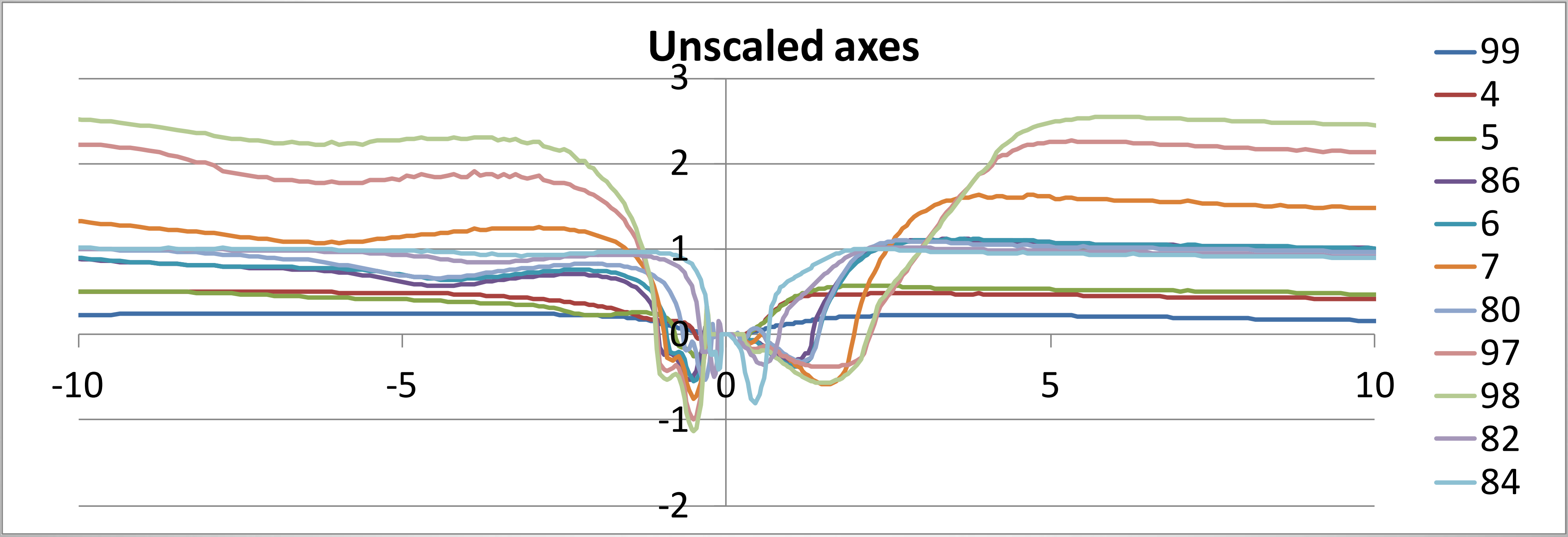
# PSF Model: Sediment Transport

P F S

jp kenny

## Study scaling factors

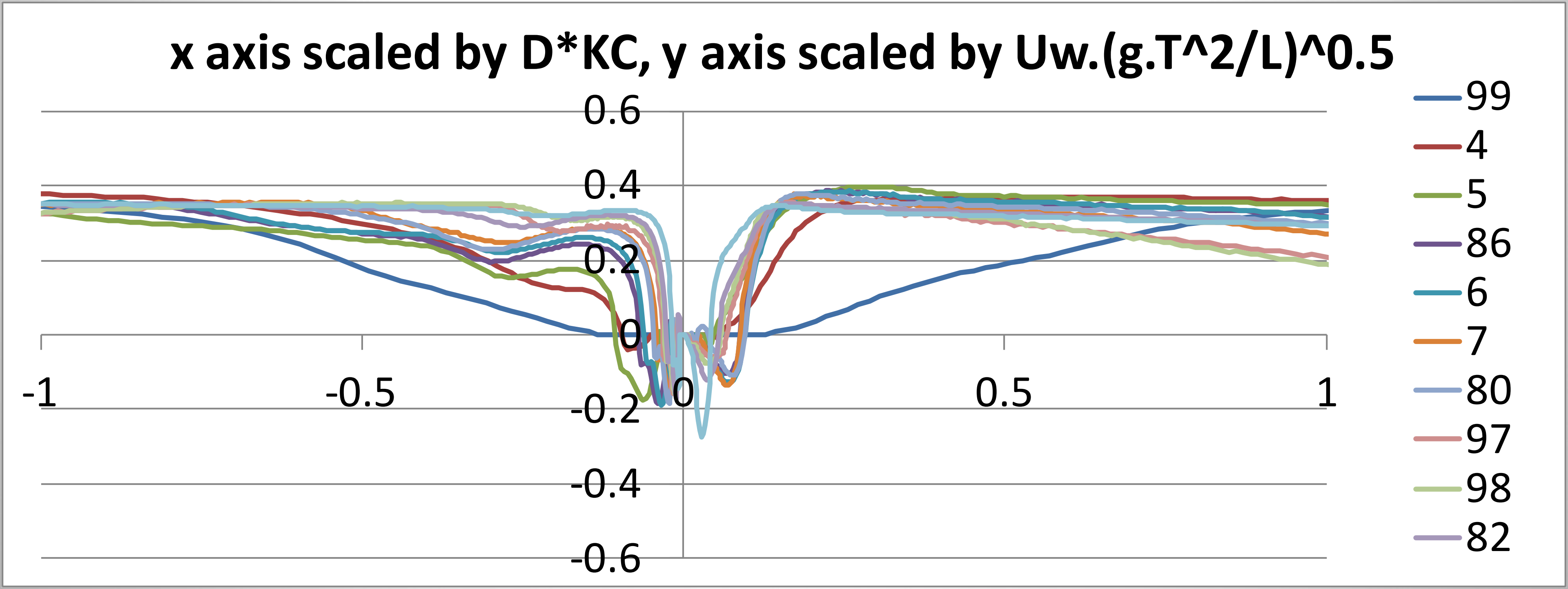
- Vary Uw, T, D
- Unscaled results:



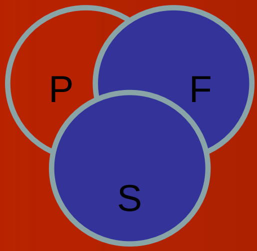
# PSF Model: Sediment Transport

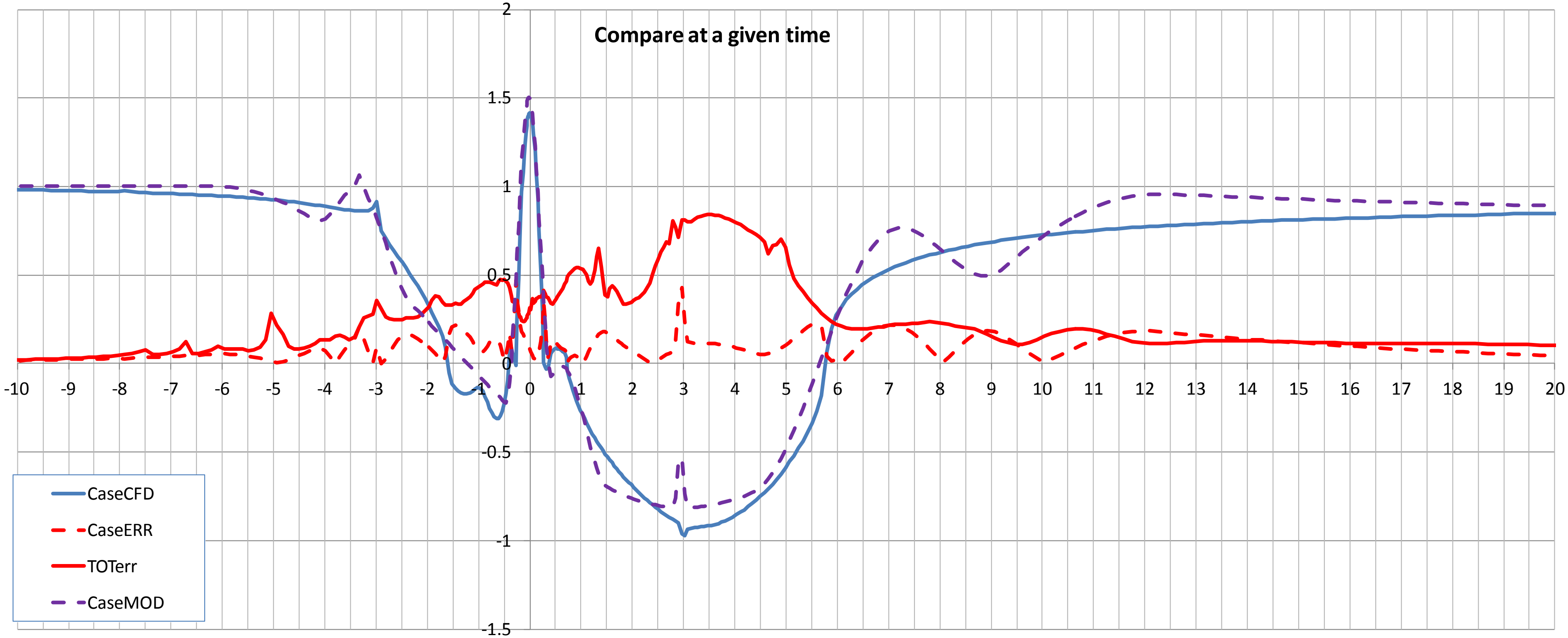
Study scaling factors

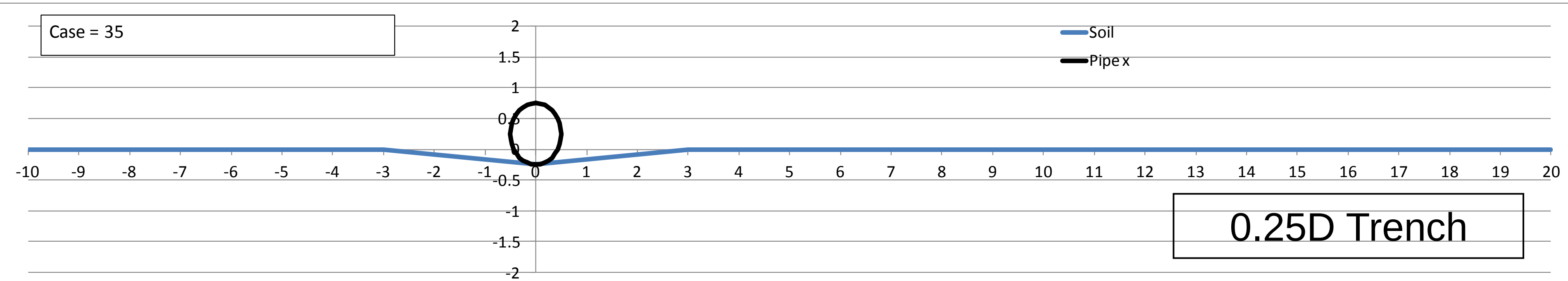
- Vary Uw, T, D
- Scaled results:



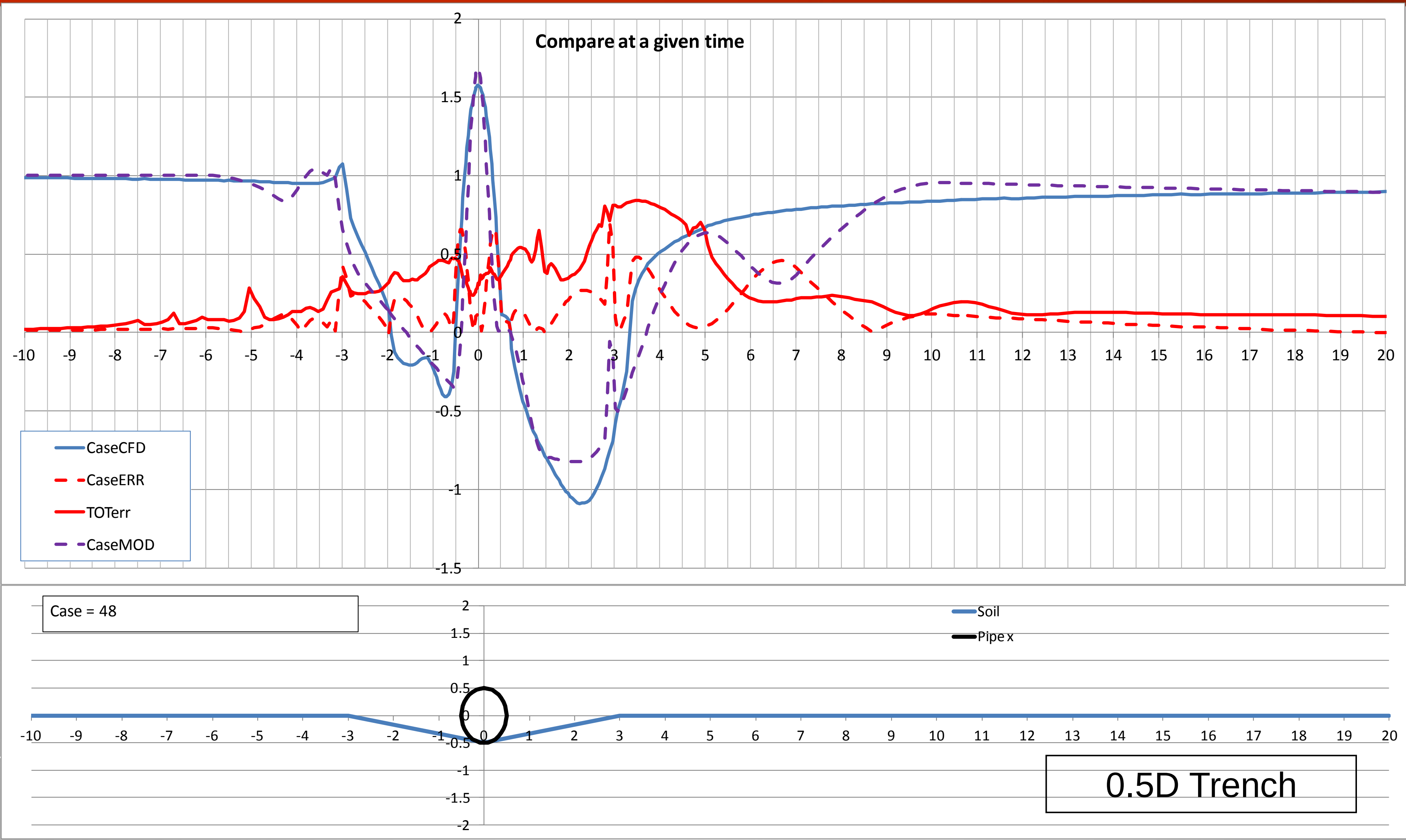
# PSF Model: Sediment Transport



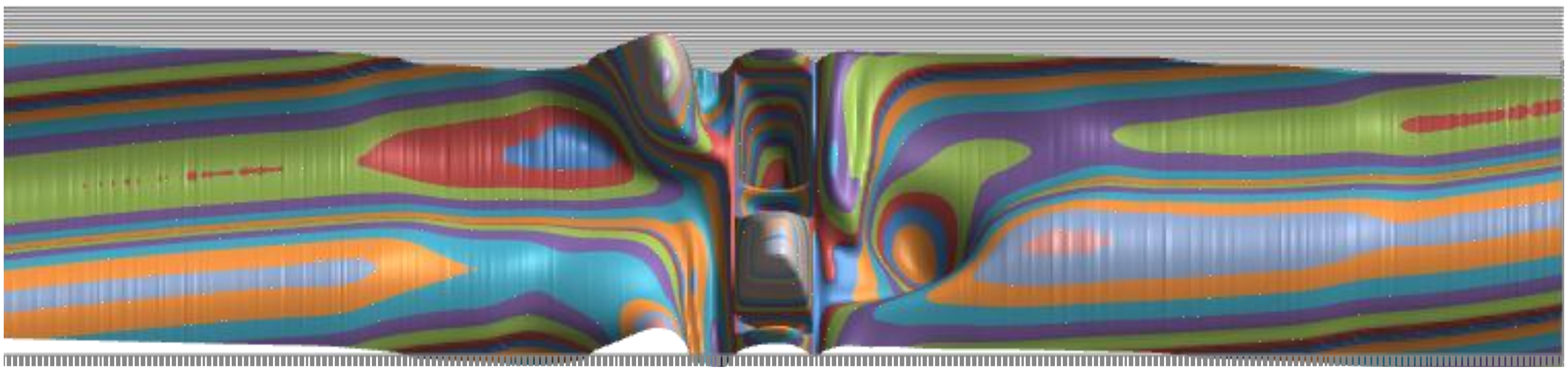



# PSF Model: Sediment Transport

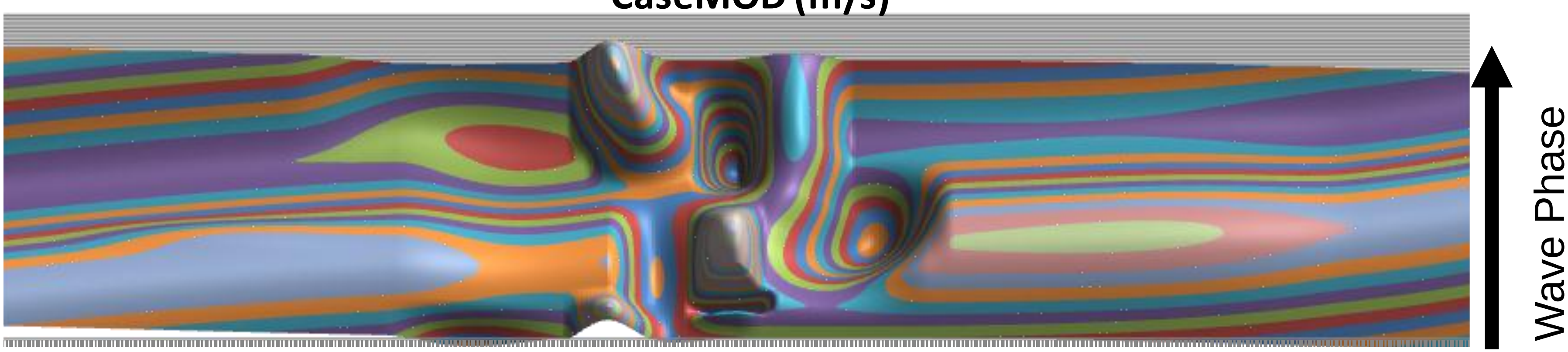


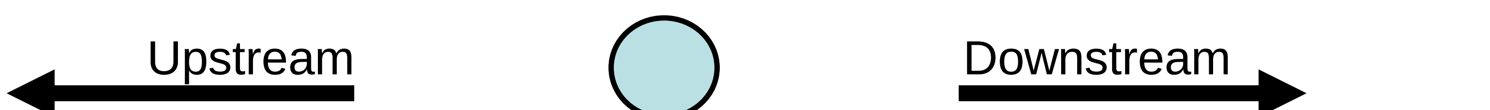
# PSF Model: Sediment Transport

**CaseCFD (m/s)**



**CaseMOD (m/s)**



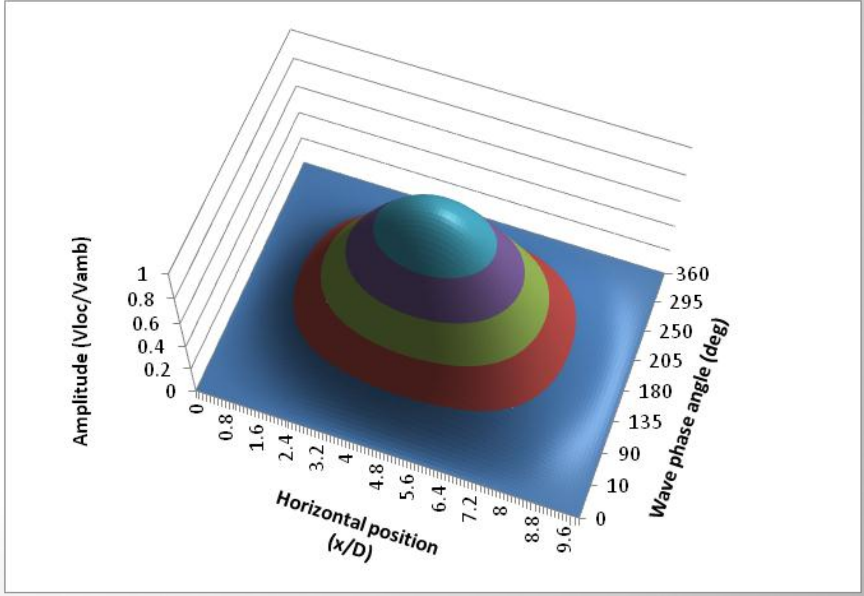



# PSF Model: Sediment Transport

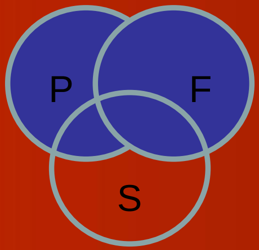
## Model Algorithm Equation:

- Parameter = F(Geom) * F(Flow)
- F(Geom) = (l*Zp^2 + m*Zp+ n) * (o*Zs^2 + p*Zs+ q) * (r*Lb^2 + s*Lb + t) * (u*Zb^2 + v*Zb + w)
- F(Flow) = (a*Uc + b + (c*Uw +d) * (e + f*(g*T^2/L)^0.5) * (g*KC + h) * (i*Alpha^2 + j*Alpha + k))

- Parameters are:
  - WPASP Wave phase start
  - CLM Phase length multiple
  - LSP Position start
  - LSW Position length
  - Amp Amplitude



# The PSF Model – Pipe/Fluid




Pipe Hydrodynamic Forces:

- Near-bed velocity timeseries from JPK WaveForce
- Hydrodynamic force-time history from JPK WaveForce (On-bottom stationary pipe)
- Force correction on-the-fly as per SIMULATOR
  - Pipe horizontal velocity
  - Shielding due to trench
  - Shielding due to embedment
  - Lift force reduction due to spanning