German OpenFoam User meetiNg 2018 (GOFUN 2018)

Solver development for the simulation of scour around offshore foundations in waves

Janek Meyer (M.Eng.)

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Yacht Research Unit Kiel

Outline

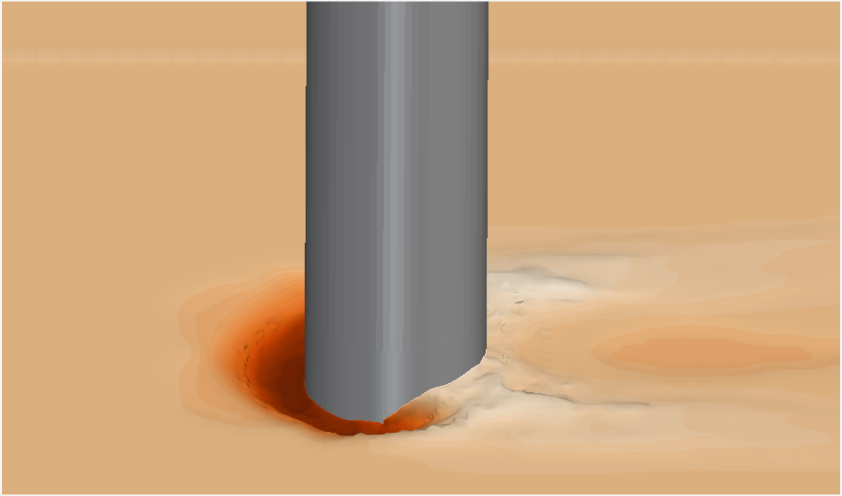
- Introduction - What is Scour?
- Description: free-surface solver (water, waves)
- Description: simulation of scour
- Applications

Introduction

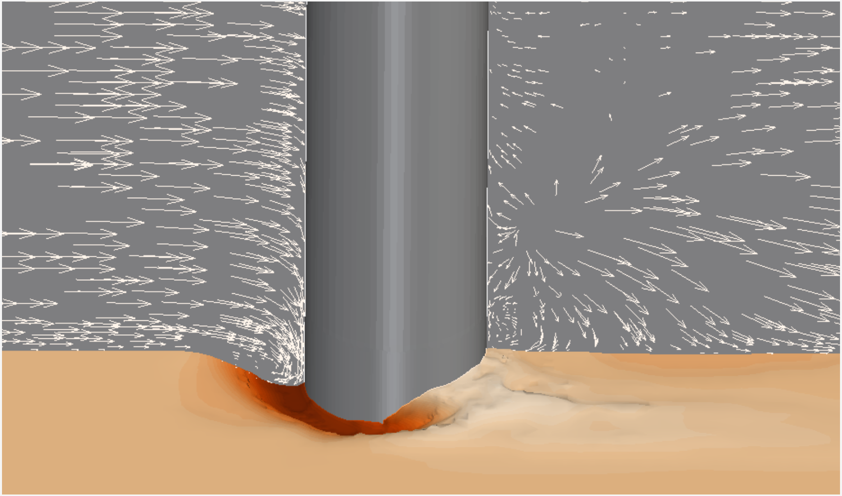
WT.SH

Wirtschaftsförderung
und Technologietransfer
Schleswig-Holstein GmbH

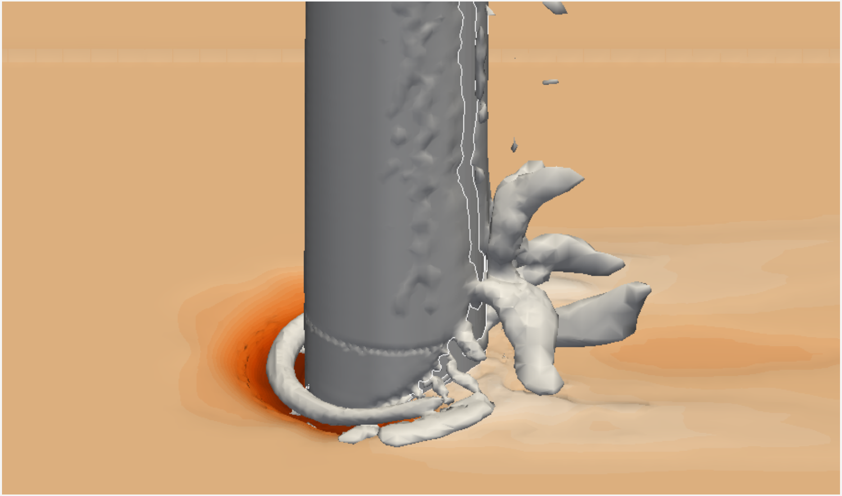
What is Scour?



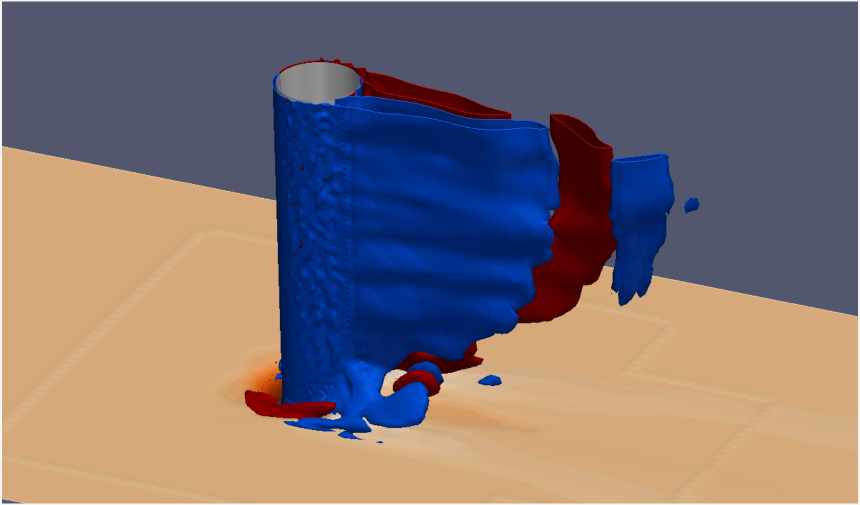
Why Scour?



Why Scour? - Horse-Shoe-Vortex



Why Scour? - Lee-Wake-Vortex



Existing Methods

- often based on Exner Equation and Boundary Deformation
- SedFoam 2.0: Based on VoF-Method and kinetic Theory

$\rightarrow$ not applicable or no good results or computationally too expensive

Governing Equations

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) - \nabla \cdot \mu_e \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) = -\nabla p + \rho \mathbf{g} + \mathbf{q} \quad (1)$$

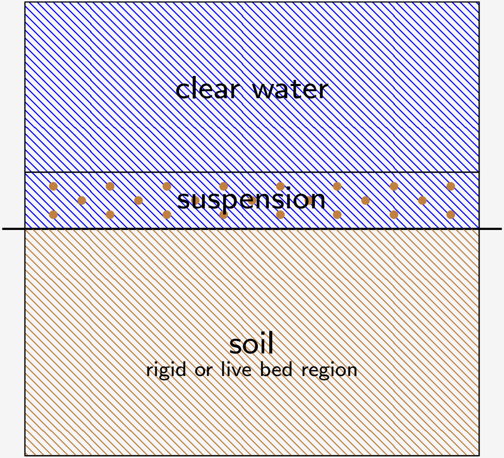
$$\nabla \cdot \mathbf{u} = 0 \quad (2)$$

$$\frac{\partial \alpha_i}{\partial t} + \nabla \cdot (\alpha_i \mathbf{u}) = 0 \quad (3)$$

Methods

InterFoam:	**OurSolver:**
SIMPLE-like algorithm (p_{rgh})	SIMPLE-like algorithm (p)
VoF-method (MULES, explicit / implicit)	VoF-method (implicit)
compression term	High-Resolution Schemes (HRIC, BICS, BRICS)
No reconstruction	Reconstruction of free-surface Discontinuities
Motion (unsuitable unstable)	Motion (robust)
	Improved turbulence models
	wave generation / wave damping
	velocity acceleration
	non-oscillating 2nd order time discretization
	anisotropic grid refinement (SHM)

Sediment Regions



$0.0 < \alpha_s \leq 0.2$

$0.2 < \alpha_s \leq 0.6$

sediment surface: $\alpha_s = 0.6$

$0.6 < \alpha_s \leq 1.0$

Bingham Approach

Additional viscosity as withstanding force:

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) - \nabla \cdot \left(\mu_e + \mu_{\text{bingham}}\right) \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) = -\nabla p + \rho \mathbf{g} + \mathbf{q} \tag{4}$$

Final form:

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) - \nabla \cdot (\mu_e + \mu_{\text{susp}}) \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) - \nabla \cdot \mu_{\text{soil}} \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) = -\nabla p + \rho \mathbf{g} + \mathbf{q} \tag{5}$$

Estimation of Bingham-Viscosity

Soil viscosity (Combined von Mises and Mohr-Coulomb yield criteria):

$$\mu_{\text{soil}} = \frac{p_{\text{rel}}\ \sin(\phi) + c\ \cos(\phi)}{(4j)^{0.5}} \tag{6}$$

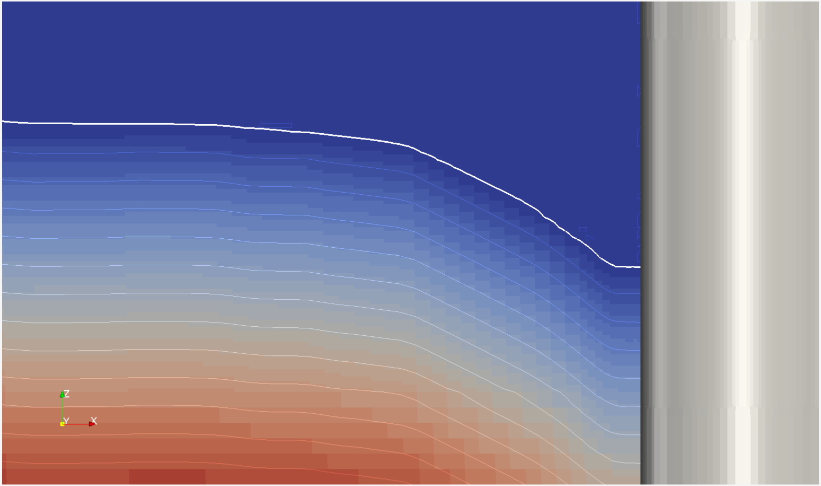
Suspension viscosity:

$$\mu_{\text{susp}} = \frac{C_f \rho_G \mathbf{u} \cdot \mathbf{u}}{(4j)^{0.5}} \tag{7}$$

ϕ = internal friction angle
c = cohesion
p_{rel} = relative pressure (see next slide)
C_f = empirical friction coefficient = 0.01
j = 2nd invariant of strain rate tensor $= 0.5\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) : \left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right)$

Völkner, S., Wriggers, W. R., Luo-Theilen, X., Rung, T. (2015), *An Overset-Grid Three-Phase Flow Model For Offshore Operations*, VI International Conference on Computational Methods in Marine Engineering MARINE 2015, Rome.

Relative Pressure



Methods

Basic Idea:

$$\nabla \cdot \left(\mathbf{Z} \cdot \nabla p^*_{\text{rel}}\right) = \nabla \left(\tilde{\rho}\mathbf{g}\right) \tag{8}$$

$$\tilde{\rho} = \begin{cases} \rho_{\text{rock}} \left(1.0 - \epsilon\right) & \text{if } \alpha_s \geq \alpha_{\text{wall}} \\ 0 & \text{if } \alpha_s < \alpha_{\text{wall}} \end{cases} \tag{9}$$

$$\epsilon = 0.6 = \text{porosity} \tag{10}$$

$$\mathbf{Z} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{11}$$

Deferred correction for stability:

$$\nabla \cdot \left(\nabla {p^*_{\text{rel}}}^{q+1}\right) = \nabla \left(\tilde{\rho}\mathbf{g}\right) + \nabla \cdot \left(\nabla {p^*_{\text{rel}}}^{q}\right) - \nabla \cdot \left(\mathbf{Z} \cdot \nabla {p^*_{\text{rel}}}^{q}\right) \tag{12}$$

Explicit post-hoc correction:

$$p_{\text{rel}} = \begin{cases} p^*_{\text{rel}} & \text{if } \alpha_s \geq \alpha_{\text{wall}} \\ 0 & \text{if } \alpha_s < \alpha_{\text{wall}} \end{cases} \tag{13}$$

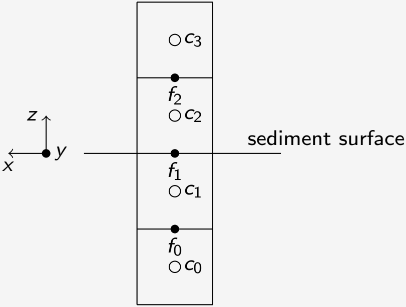
Interpolation of soil viscosity

Additional diffusive term:

$$-\nabla \cdot \mu_{\text{soil}} \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) \tag{14}$$

harmonic mean interpolation:

$$\phi_f = \frac{2}{\frac{1}{\phi_N} + \frac{1}{\phi_P}} \tag{15}$$



Internal Wall Function

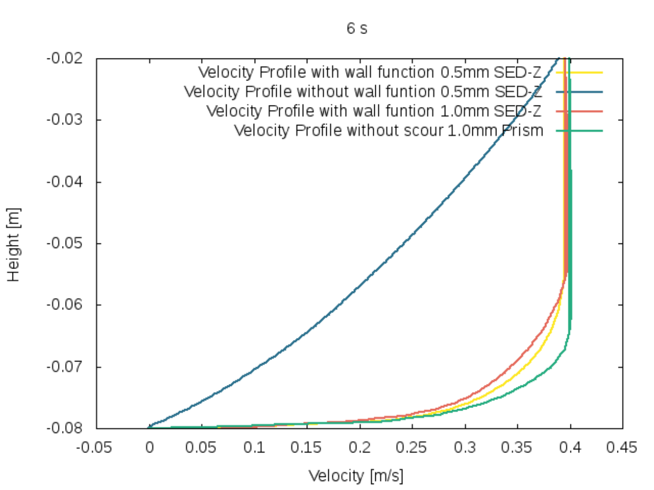
Common wall functions at domain boundary:

- near wall cell: different calculation of turbulent production rate
- near wall cell: explicit calculation of ω
  manipulation of equation system to force this solution
- boundary face: different calculation of ν_t

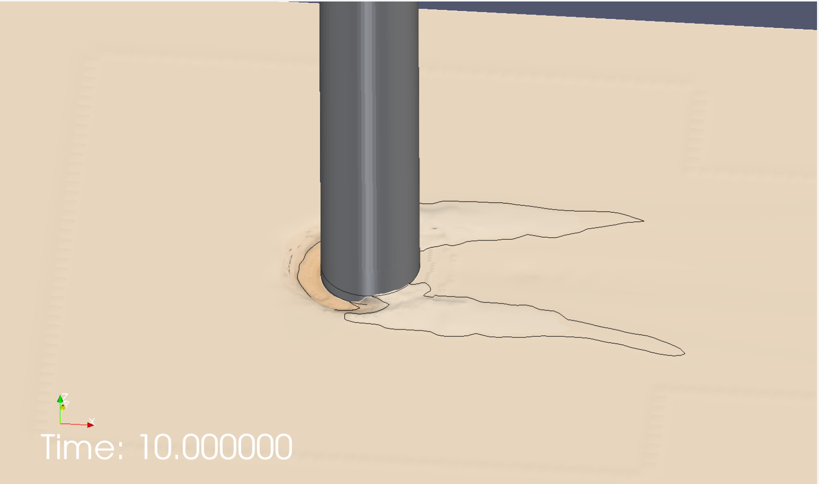
New wall function inside domain:

- mark internal sediment wall cells
- water wall cell ($\alpha_s > \alpha_{\text{wall}}$): different calculation of turbulent production rate
- water wall cell ($\alpha_s > \alpha_{\text{wall}}$): explicit calculation of ω
  manipulation of the equation system to force this solution (implicit relaxation to target value)
- sediment wall cell ($\alpha_s \leq \alpha_{\text{wall}}$): different calculation of ν_t

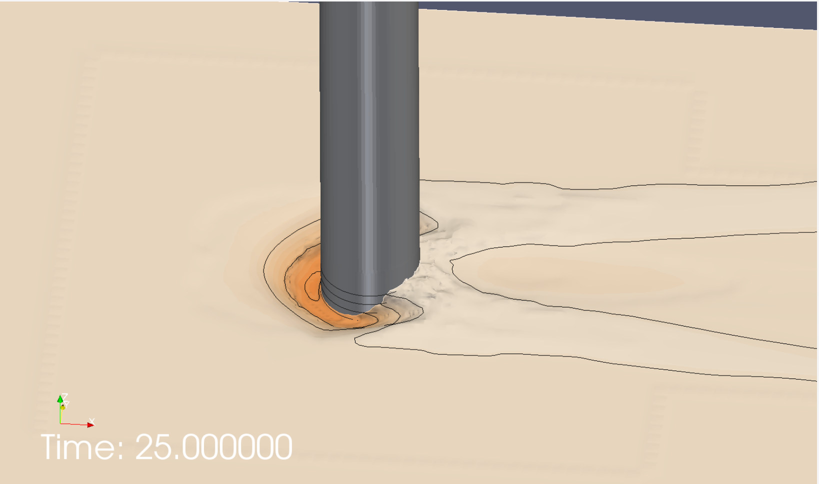
Wall Function - Horizontal Velocity



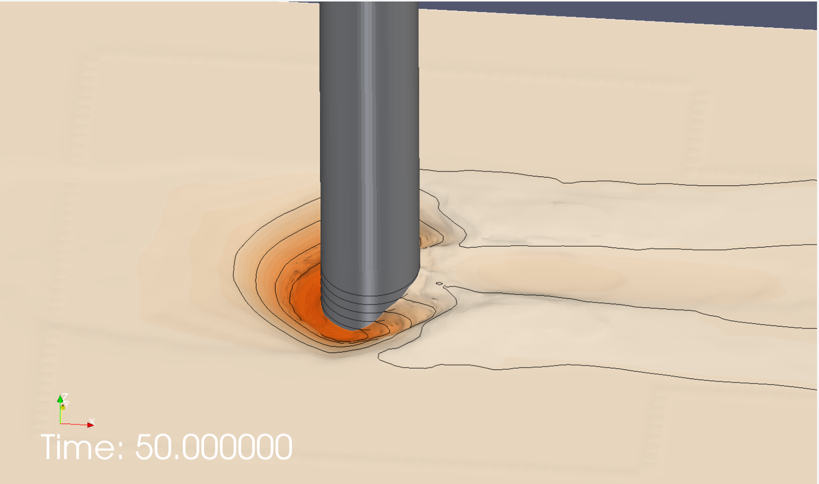
Roulund - Normal Flow Velocity



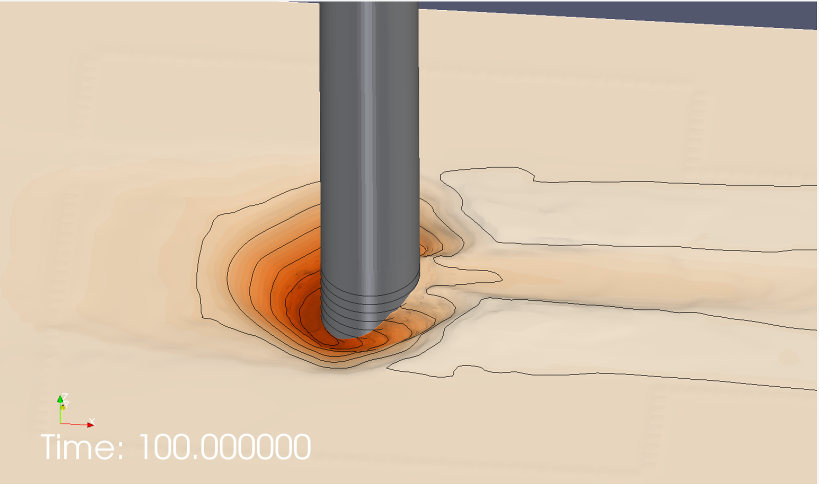
Roulund - Normal Flow Velocity



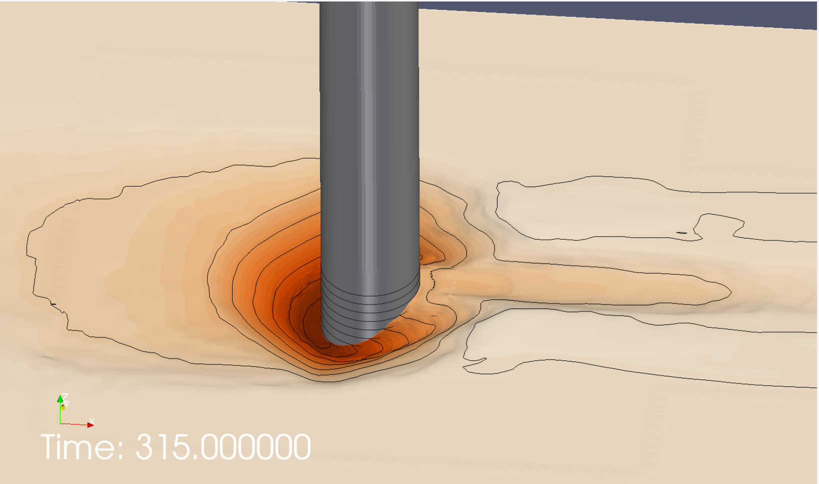
Roulund - Normal Flow Velocity



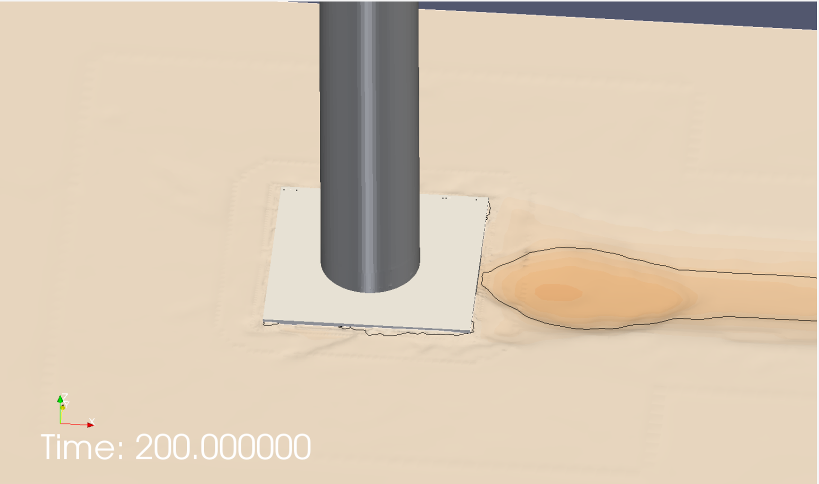
Roulund - Normal Flow Velocity



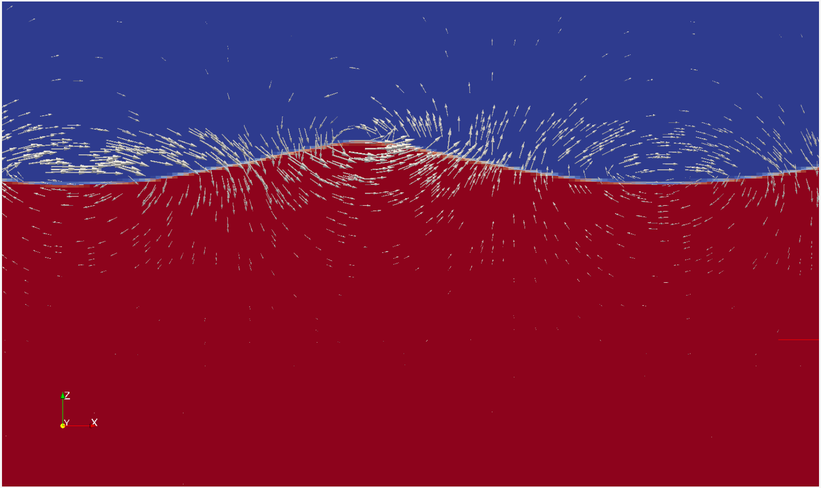
Roulund - Normal Flow Velocity



Roulund - Normal Flow Velocity - Mudplate



Offshore Foundation in Waves



Offshore Foundation in Waves

VIDEO