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SCOURING BELOW PIPELINES: THE ROLE OF VORTICITY AND TURBULENCE

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ABSTRACT

A numerical study on the turbulence and vorticity of local scour underneath an offshore pipeline placed on a non-cohesive sandy seabed and forced by a steady flow current is presented. The numerical model solves the Navier-Stokes equations using an innovative Level Set technique. The model predicts the behavior of the movable sediments through both drift and lift force components. Mean and turbulent flow quantities were extracted by temporal averaging. Results on the distribution and evolution of turbulent kinetic energy and vorticity will be illustrated at the conference.

INTRODUCTION

The seabed scouring below pipeline has received large attention during the last three decades. Pipeline laid on the seabed interact with currents and waves, generating a local velocity field and pressure gradients between the upstream and downstream sides of the pipe. If the pipe is laid on a sandy bottom, the interaction of pressure gradients with the bottom can drive a seepage flow, which may lead to suspended free spans of the pipeline.

Various numerical models for predicting two-dimensional scour processes have been developed in the last years. The first numerical algorithms were based on the potential flow theory [2], even though such a theory is not able to represent the vorticity generated downstream of the body of interest, the results were encouraging because the front deformation was successfully predicted. Later on, full Navies-Stokes solvers with turbulence models and sediment transport equations [1-3] were introduced. The main limits of these algorithms is in the capturing of the inception of the scouring. The use of a boundary-fitted mesh leads to the use of either (1) an initial infinitesimal gap between the pipeline and the sandy bottom or (2) two simulations: one with the pipeline (i.e. cylinder) initially touching the bottom and once a given threshold is surpassed with a new topology where a gap between the body and the bottom is created. In both cases the inception time of the scour depends on the simulation parameters. In this paper, a new treatment of the boundary of the computational domain enables the capturing of the topological change which occur in the domain, making the prediction of the freespan initiation more reliable.

A Navier-Stokes solver coupled with a model of the granular sand layer is developed. No turbulent closure model is introduced, because a stretching of the mesh is adopted and the fine resolution close to the bottom enables a DNS [5]. The computational domain is divided into three parts according to the physical features of the local flow: 1) a pure-water domain, 2) a solid domain with consolidated sand and 3) a water-sand mixture, lying in between, where the sand is trapped into the water because of the friction induced by the water. (See Figure 1).

The fluid regions are modeled as single-fluid domains with variable properties of mass and viscosity and are governed by the mass-conservation and Navier-Stokes equations, discretized on a Cartesian mesh and solved with second-order finite-difference schemes; an approximate projection method is used for the pressure.

The boundary of the fluid domain is represented on a Cartesian grid using a level-set function φ which represents a signed distance function either from the compact sand or the cylinder.

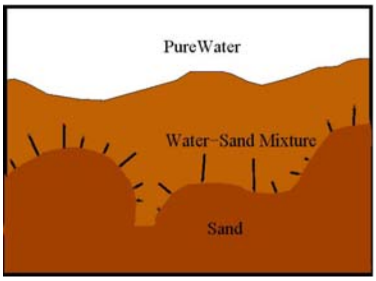


Figure 1: The definition of the three regions of the computational domain.

At these boundaries the fluid velocity satisfies the equation:

$$u = s(\phi)u_{fluid} + (1 - s(\phi))u_{boundary}$$

where s(φ) is a C^1 function, which goes smoothly from 1 into the fluid to 0 inside one of the solid boundaries.

The solver has first been tested on the basis of a dam-break of a reservoir of the water evolving over a sandy bottom, and applied to the analysis of the scouring below the pipeline. A cylinder (the pipeline) of diameter D =0.1m, is placed 0.35m below the free-surface and at a distance of ε=0.005m from the initial compact bottom. An incident constant current U =0.2m/s causes the deformation of the compact-sand bottom. The characteristics of the computed sand are the following: density ρ_{sand} =1.54ρ_{water} , θ_c =0.04, d_{50} =3.6x10^{-4} m. The used computational domain has length L = 10D and height H =5.5D with the centre of the cylinder being at 0.3D downstream of the inlet boundary, the mesh is composed by 200 points in the x-direction and 90 points in the z-direction, with Reynolds number Re= 2x10^4 .(see Figure 2).

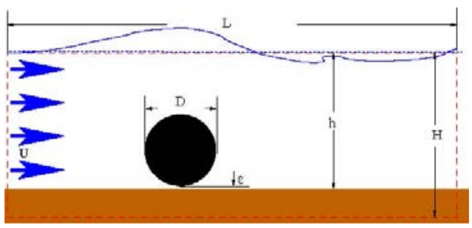
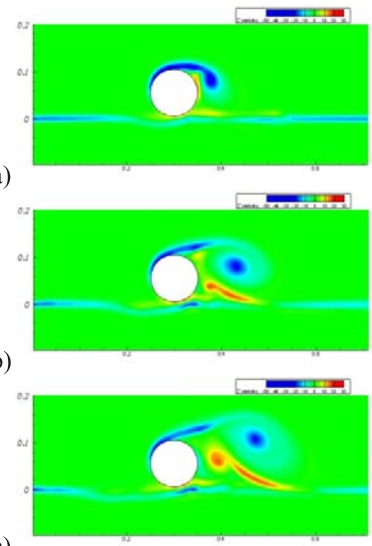


Figure 2: Sketch of the problem of a cylinder slightly off the bottom in a steady currents.

For the characterization of the flow dynamics we analyze the vorticity field with particular interest in the coherent structures generated near the seabed. The vorticity maps elaborated from our numerical data show two vertical structures: one negative is shed at the top of the cylinder and a positive one at the bottom, on the downstream side of the cylinder. The numerical simulation shows the coupling of such vortices and their evolution in time. See Figure 3 for details.



a)
b)
c)

Figure 3: Spanwise vorticity for three different time steps: a) T=0.8 s b) 1.8 s c) 2.8s

To better illustrate the flow dynamics we consider a series of water particles at given points at an initial time and trace their trajectories illustrated in Figure 4.

$$\frac{dr}{dt} = u(x,z,t); \quad r(0) = d$$

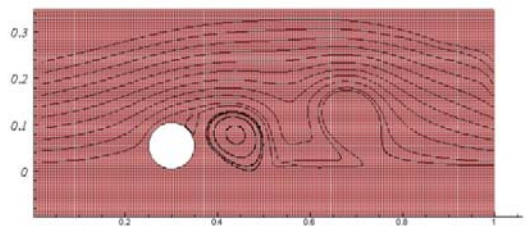


Figure 4: Particle path in the steady current condition.

We investigate the evolution of the turbulent kinetic energy per unit volume $\overline{K_\rho}$ (obtained by multiplying the specific, instantaneous turbulent kinetic energy $K = \frac{1}{2}(u'^2 + w'^2)$ times the water density ρ and taking a moving average). The transport equation of $\overline{K_\rho}$ is:

$$\frac{D\overline{K_\rho}}{Dt} = -\rho\left(\overline{u_i'u_j'}\right)\frac{\partial \bar{u}_i}{\partial x_j} - \frac{\partial}{\partial x_j}\left[\left(\frac{\rho}{2}\overline{u_j'u_i'^2}\right) + \left(\overline{pu_j'}\right)\right] + \nu\frac{\partial^2(\overline{K_\rho})}{\partial^2 x_j} - \mu\overline{\left(\left(\frac{\partial u'_i}{\partial x_j}\right)^2\right)}$$

PRODUCTION - TRANSPORT - DIFFUSION - DISSIPATION where ν, μ and ρ, are respectively, the kinematic viscosity, the dynamic viscosity and the fluid density. The term $\overline{u_i}$ represents the *i*-th component of the mean velocity and u_i' the corresponding turbulent component. The term on the right-hand side of the transport equation are: the production term (that represents the energy transfer from the mean flow to the turbulence), the transport term (that represents the kinetic energy redistribution among different flow scales), the viscous diffusion and dissipation terms.

What is the role of turbulence in the scouring processes? What the role of each contribution to the transport equation? We want to give an answer to these questions and the results will be illustrated at the conference.

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