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Numerical Simulation of Pipeline Local Scour with Lee-Wake Effects

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ABSTRACT

A morphological model for the local scour around pipelines is developed. Based on the Navier-Stokes equation and an erodible boundary adjustment technique, the model predicts the equilibrium scour hole without using any sediment transport formula. The calculation results clearly reveal that the lee-wakes behind the pipeline contribute significantly to the local scour hole development, especially to the gentle scour slope observed in experiments. The predicted maximum scour depth and the shape of the scour hole compare favorably with the experimental data published in the literature.

INTRODUCTION

Local scour around offshore pipelines has significant effects on the stability of the pipeline. So far, the prediction of local scour around pipelines has been mainly based on experimental modeling or empirical formulas derived from experiments. A review of the published results relating to local scour in the last 3 decades can be found in Sumer and Fredsfe (1992), and more recently in Whitehouse (1998). There is no doubt that physical modeling is a fundamental and effective method for understanding the mechanisms of the scouring process. However, it is also associated with high costs and relatively long times. In addition, the inadequate knowledge of the scale effect in the model test poses a question mark on the application of experimental results to prototype. In comparison, the numerical model does not suffer from these defects. This can provide design engineers with an alternative way to evaluate and understand the process of local scour around pipelines. It is therefore imperative that more effort is devoted to developing suitable numerical models.

Over the last 2 decades, mainly 2 kinds of numerical models for scour prediction have been developed. One is based on the potential flow theory, such as Hansen et al. (1986) and Li and Cheng (1998); the other is based on the k-e model, such as Leeuwenstein and Wind (1984). It has been demonstrated that the potential flow models are able to predict the maximum depth and the upstream part of the scour hole correctly. However, none of the potential flow models can explain the gentle slope of the scour hole formed downstream of the pipe. This is mainly due to the fact that the potential flow model can not simulate the vortex shedding process associated with the flow around the pipeline. Sumer et al. (1988) demonstrated in experimental tests that the gentle slope of the scour hole formed downstream of the pipeline is mainly due to the vortex shedding around the pipeline. The vortex shedding generates a fluctuating shear stress field on the seabed. The scouring process downstream of the pipeline is then governed by the maximum shear stress experienced by the seabed, instead of the average shear stress. The potential flow model is not capable of simulating this fluctuating stress field, and thus can not simulate the downstream part of the scour hole correctly.

It was anticipated that numerical models based on the k-e turbulence model would do a better job than the potential flow models. Leeuwestein et al. (1985) developed a numerical model based on a k-e turbulence model and a sediment transport equation. A package named ODYSSEE was used to calculate the turbulent flow field. They failed to obtain a real scour-hole shape by using an empirical bed-load formula, and ascribed this result to the poor representation of the suspended-load contribution in the model.

In the numerical part of the investigation by Sumer et al. (1988), the Cloud in Cell (CIC) method was employed to simulate the flow. It was reported that the CIC method generally gives good prediction of the gross characteristics of the organized wake behind the pipeline. However, there was no evidence in the paper that a numerical model was employed to calculate the seabed deformation. Instead, by comparing the effective Shields parameter with its time average value, an important conclusion was drawn that the organized wake behind the pipeline has strong effects on the profile of the scour hole downstream of the pipeline. It was suggested that the time-averaged bed shear stress is not a suitable parameter to use in predicting the lee-wake scouring behind a pipeline.

More recently, Li and Cheng (1999) developed a local scour model employing a completely different methodology from the traditional equilibrium sediment transport models. This method is based on an assumption that (a) scour takes place when the local shear stress acting on the seabed exceeds the critical shear stress for clear-water scour; and (b) scour ceases when the bed shear stress is equal to (or less than) the undisturbed bed shear stress for live-bed conditions. The scour hole profile is then calculated

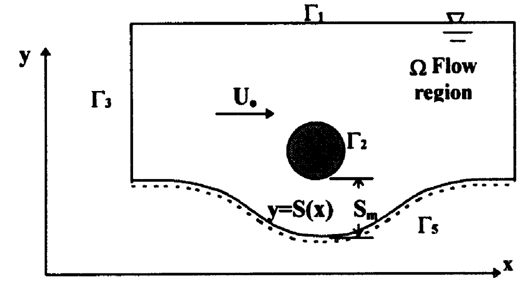

Fig. 1 Definition sketch

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KEY WORDS: Pipelines, local scour, Navier-Stokes equation, LES model.