

Numerical Modeling of Onset Conditions of Scour below Offshore Pipeline in Steady Currents

Liang Cheng^{a}, Zhipeng Zang^b, Ming Zhao^a and Bin Teng^b*

^a School of Civil and Resource Engineering, The University of Western Australia,
Perth, WA, Australia.

^b State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology,
Dalian, Liaoning, China.

ABSTRACT

A numerical model is developed to predict the onset condition of local scour below a partially embedded offshore pipeline subject to steady currents. The pressure difference over the pipeline induced by steady currents is calculated by solving Reynolds Averaged Navier-Stokes (RANS) equations with a $k-\omega$ turbulence model closure. The onset condition for scour is defined as the moment when the seepage flow pressure gradient at any point in the seabed below the pipeline exceeds the floatation gradient of the seabed soil. In this numerical model, the average seepage pressure gradient along the buried pipe surface is employed to evaluate the onset condition. It is found that numerical results agree well with experimental data available in literature. The effects of flow Reynolds number, incoming flow boundary layer thickness, water depth and embedment on pressure drop coefficient are examined.

KEY WORDS: onset of scour; pressure drop coefficient; steady currents.

INTRODUCTION

It is understood that local scour around a partially embedded pipeline occurs when the seepage pressure through the seabed soil below the pipeline exceeds the floatation pressure of the soil. This phenomenon is referred to as piping in literature (Chiew, 1990; Sumer, Truelsen, Sichmann and Fredsøe, 2001). Chiew (1990) conducted a series of experiments investigating initiation of scour below a partially buried pipeline subject to steady currents. It was found that the piping is the dominant cause for the initiation of scour. The existence of the high pressure upstream and the low pressure downstream of the pipeline induces a seepage flow through underlying sediments. When the exit pressure gradient in the soil exceeds the floatation gradient of the sand, scour takes place. Sumer, Truelsen, Sichmann and Fredsøe (2001) conducted a number of experiments to investigate the onset of scour in currents/waves. It was confirmed that the excessive seepage flow and the resulting piping are the major factor causing the onset of scour. In their study, the onset condition for scour was determined both in the case of currents and in the case of waves.

Numerical study reported in literature on onset of local scour below pipelines is rare. Liang and Cheng (2005) proposed a numerical model to simulate the onset condition of scour of a partially buried pipeline subject to steady currents. In this work, the force equilibrium on a small soil volume at the exit point of seepage flow on the pipeline surface was analyzed in the tangential direction of the pipeline at that point. Average pressure gradient along the buried pipeline surface was employed to determine the onset condition of local scour. Since the exit point of seepage flow on the pipeline surface is singular due to the use of Darcy's law, the onset conditions determined at that point do not represent the general onset conditions of the seabed near the pipeline.

This paper aims to develop a numerical model for evaluating the onset conditions of a partially buried pipeline under steady currents conditions. The pressure difference over the pipeline induced by the environmental flow is calculated by solving Reynolds Averaged Navier-Stokes (RANS) equations with a $k-\omega$ turbulence model closure. The critical condition is determined based on the pressure drop coefficient and the average seepage gradient through the seabed.

THEORETICAL CONSIDERATIONS

When an environmental flow passes a partially buried pipeline, a stagnation zone and a wake zone will form upstream and downstream the pipeline respectively (see Fig. 1). The hydrodynamic pressure in the stagnation zone in front of the pipeline is expected to be higher than the hydrodynamic pressure in the wake zone behind the pipeline. The pressure difference between upstream side and downstream side of the pipeline induces a seepage flow underneath the pipeline. The seepage flow in the seabed exerts a hydraulic gradient force on soil particles if the underlying soil is permeable. A mixture of sand and water breaks through at the downstream side of the pipeline when the seepage pressure gradient exceeds the floatation gradient of the sand grains. This phenomenon is referred to as piping. Piping can occur on either sides of the pipeline if the pipeline is subjected to wave-induced oscillatory flows.