Numerical Simulation of Local Scour Under Pipelines

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ABSTRACT

A finite difference model based on potential flow theory is proposed for estimating the equilibrium scour hole underneath offshore pipelines. The model solves the Laplace equation for velocity potential in a curvilinear coordinate system to cope with the irregular and free boundaries involved in this problem. A local method is used to determine the free boundary formed by the eroded seabed via the equilibrium of all forces acting on a sediment particle on a slope bed. The major features of the present model are: 1) that it takes into account the nonlinear interactions between the flow, pipe and the changing bed topography in calculating the equilibrium scour hole, 2) that the shear stress on sediment particles is represented in terms of a characteristic near-bed velocity, creating a dynamic link between the flow and the sediment movement, and 3) that the model predicts the equilibrium scour hole without using any sediment transport formula, which usually contains many empirical parameters or constants. The maximum scour depth and the upstream part of the scour hole predicted by the model compare well with the experimental data published in the literature.

KEY WORDS: Local scour, potential flow, pipelines

INTRODUCTION

Many offshore pipelines are directly laid on the erodible sea bed and are exposed to currents, waves, and storms. Even with moderately strong currents, local scour can occur, and this will cause the pipelines to be suspended in water. As the scour hole develops, the flow around the pipe will exert a downward force on the pipe instead of an uplifting force. This force together with the self-weight of the pipe will tend to sink the pipe section into the scour hole and cause additional stress on the pipe joints. Consequently, the excessive deflection of the pipeline may result in damage and failure. Therefore, the prediction of local scour around pipelines is of great importance to pipeline design.

There are mainly three methods available for the prediction of local scour under pipelines. These are: 1) empirical models based on experimental data, 2) numerical methods based on potential flow theory, and 3) numerical models based on viscous/turbulent flow theory. The pioneering research in scour prediction under pipelines was conducted by Chao and Hennessy (1972). Chao and Hennessy proposed an analytical method for estimating the maximum scour depth under offshore pipelines caused by subsurface currents. The discharge through the gap between the pipe and the eroded seabed was estimated by potential flow theory with the assumption of a flat seabed at any depth of scouring. It was assumed that when the velocity in the scour hole is greater than the free stream velocity, which is always specified as the critical velocity, erosion will occur. The maximum scour depth is reached when the velocity difference decreases as the enlargement of the scour section. The boundary shear stress is estimated using the relationship proposed by Streeter (1971), by assuming that the sea bed is flat and the flow in the eroded section resembles open-channel flow characteristics. The friction factor is determined using the Reynolds number relationship reported by Lovera and Kennedy (1969). Since too many assumptions have been made in the derivation of the model, the method can only provide an order of magnitude estimate of the possible scour hole depth. Subsequently, several empirical methods for estimating the maximum scour depth under pipelines were proposed by different research groups, based on extensive flume experiments with a variety of pipe diameters and a range of flow velocities. The major methods among these include those proposed by Kjeldsen (1973), Ibrahim and Nalluri (1986), and Bijker and Leeuwestein (1984). Chiew (1991) conducted a detailed review on these methods. The major advantage of the analytical and empirical methods is that they are simple and easy to use. They are useful in obtaining a quick estimate. The principal disadvantage of the empirical methods is that they are not very accurate.

Mao (1986) conducted a series of experiments in a water flume of 2 m wide, 23 m long and 50 cm deep. Two smooth pipes of diameters 50 mm and 100 mm were used in the tests. The water depth was 350 mm for the 100 mm pipe, and 230 mm for the 50 mm pipe, respectively. Uniform sand of a d50 = 0.36 mm was used throughout the tests. Mao measured the shape of the scour holes formed under the pipeline for a variety of flow velocities. Two important features of the local scour around pipelines were highlighted. 1) the equilibrium scour depth is only a weak function of flow Shields parameters when the sediment entrainment condition is exceeded; 2) the equilibrium scour depth is less than the diameter of the pipe. Mao also observed that there are two different stages of the scour process, i.e. the jet period and the