International Journal of Offshore and Polar Engineering
Vol. 2, No. 1, March 1992 (ISSN 1053-5381)

Time Scale for Wave/Current Scour Below Pipelines

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ABSTRACT

A nondimensional formula has been developed for the time scale of the scour process below a marine pipeline, based on the presently available data. The main part of the data originates from ISVA. Both the current case and the pure-wave case are considered. The results indicate that the nondimensional time scale is proportional to the -5/3 power of the Shields parameter. In the study, the time scale of scour, involving a change in the wave climate, has also been investigated. The results indicate that the time scale is governed by the Shields parameter plus the two Keulegan-Carpenter numbers corresponding to the waves before and after the change takes place.

NOMENCLATURE

d	: sand size
D	: pipe diameter
f	: friction factor
f_w	: wave frequency
g	: acceleration due to gravity
KC	: Keulegan-Carpenter number (Eq. 2)
KC_{final}	: KC number following change in wave climate
$KC_{initial}$	: KC number prior to change in wave climate
s	: specific gravity of sediment
S	: scour depth
S_o	: equilibrium scour depth
t	: time
T	: time scale of scour process
T^*	: nondimensional time scale of scour process (Eq. 6)
T_w	: wave period
U	: flow velocity
U_f	: bed shear velocity
U_m	: maximum outer flow velocity in waves
U_{fm}	: maximum bed shear velocity in waves
ν	: kinematic viscosity
θ	: Shields parameter (Eq.1)
θ_{final}	: Shields parameter following change in wave climate
$\theta_{initial}$	: Shields parameter prior to change in wave climate

INTRODUCTION

When a pipeline is laid on an originally plane bed, scour will take place below the pipeline due to the action of waves and current, where the scour process will eventually attain a fully developed stage.

The scour depth corresponding to this fully developed stage has been studied quite extensively for steady currents — Kjeldsen et al. (1973), Bijker and Leeuwestein (1984) and Mao (1986), among others, for a fixed pipe, and Sumer et al. (1988) and Kristiansen (1988) for a vibrating pipe — and more recently for waves — Sumer and Fredsøe (1990).

The purpose of the present study is to investigate the time scale of the scour process. The study covers also the transitional scour processes involving changes in wave climate.

FULLY DEVELOPED STAGE OF SCOUR PROCESS

In steady currents, the fully developed stage of the scour process is governed by three parameters, namely the Shields parameter θ, the relative roughness k/D, and Reynolds number UD/ν. Here U = the flow velocity, D = the pipe diameter, ν = the kinematic viscosity, and the Shields parameter is defined by:

$$\theta=\frac{U_f^2}{g(s-1)d} \quad (1)$$

in which U_f = the friction velocity, g = the acceleration due to gravity, s = the specific gravity of sand, and d = the sand size. However, the data indicate that the dependence on the Shields parameter is quite weak (when the scour takes place on a live bed), while the dependence on the relative roughness and Re number is insignificant. See Sumer and Fredsøe (1990), which collected the data from Kjeldsen et al. (1973), Lucassen (1984), Mao (1986) and Kristiansen (1988). For all practical purposes, the following relation can be used as the design equation, to predict the equilibrium scour depth in steady currents:
$S_o/D = 0.6 \pm 0.1$ in which the second figure indicates the standard deviation.

In waves, on the other hand, there is one additional parameter, namely the Keulegan-Carpenter number, KC. Here KC is defined by:

$$KC=\frac{U_m T_w}{D} \quad (2)$$

in which T_w = the wave period and U_m = the maximum outer flow velocity. Sumer and Fredsøe (1990) present the data plotted as a function of KC number, which indicate that there is a strong correlation between the equilibrium scour depth and the KC number. Based on the data, a design equation was established for the equilibrium scour depth. This equation reads:

$$S_o / D=0.1\sqrt{KC} \quad (3)$$

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Received November 27, 1990: revised manuscript received by the editors January 14, 1992. The original version (prior to the final revised manuscript) was presented at The First International Offshore and Polar Engineering Conference (ISOPE-91), Edinburgh, United Kingdom, August 11-16, 1991.
KEY WORDS: Scour, pipeline, time scale.