Wave and Wave-Current Loading on a Bottom-Mounted Circular Cylinder

Ian A. R. Neill and Jon B. Hinwood
Australian Maritime Engineering CRC, Monash University, Melbourne, Australia

ABSTRACT

Prediction of hydrodynamic forces acting on submarine pipelines lying on the seabed is essential for on-bottom stability calculations. Classical methodology is based on Morison's equation, for which nondimensional inertial, drag and lift coefficients must be found from the vast array in the public domain or from relevant model tests. Generally the lift force is poorly predicted. More recently a wake model has been formulated, based on field data to which empirical constants were fitted; much of this has remained proprietary information and limited in application to pipelines with diameter greater than 400 mm. An experimental programme, using regular waves and currents with extensive flow visualization, has provided an insight into the physics of the problem. Traditional dimensionless force coefficients obtained using Stokes fifth order wave theory are compared to data from previous research and joint industry programmes. Analysis of flow visualization has produced correlations between the near field flow incorporating vortex motions and features in the force traces not predicted by conventional theory.

NOMENCLATURE

C_{AW}	:	added mass coefficient of wake
$C_{M,D,L}$	:	inertial, drag, lift force coefficients
$C_{H,V}$	:	horizontal, vertical peak force coefficients
D	:	cylinder diameter
$F_{H,V}$	:	horizontal, vertical forces
H	:	wave height
K_c	:	Keulegan-Carpenter number
Re	:	Reynolds number
T	:	wave period
Uc	:	steady current
U_e	:	effective velocity
u_m	:	maximum horizontal flow velocity
$u(t)$	:	horizontal wave flow velocity at time t
u_0	:	horizontal velocity amplitude
W	:	wake velocity
α	:	current ratio
β	:	Re/Kc
ρ	:	fluid density
ω	:	wave frequency

INTRODUCTION

Many offshore oil and gas operations rely upon subsea pipelines to export their products to land. Extreme storm events have caused severe damage to many offshore pipelines around the world, due to gross vertical and horizontal displacements of the pipeline. Most recently Hurricane Andrew damaged 454 subsea pipelines in the Gulf of Mexico in 1992 (Collins, 1995).

Prediction of the hydrodynamic forces acting on submarine pipelines in contact with the seabed is essential for accurate on-bottom stability analysis. Confident design necessitates accurate prediction of the hydrodynamic loading over a large range of flow parameters. Models used for calculating such forces are briefly presented.

Morison Force Model

Traditional hydrodynamic force prediction is based on the Morison (Morison et al., 1950) force formulation that treats the loading as a summation of a drag force and an inertial force. The common representation of the in-line force for a horizontal cylinder due to waves and current is given in Eq. 1, neglecting the effects of the vertical component of the wave velocity near the seabed. The lift force is given by classical aerodynamic formulation in Eq. 2:

$$F_H(t) = \frac{\pi}{4}\rho D^2 C_M \frac{du}{dt} + \frac{1}{2}\rho D C_D |Uc+u(t)|\,[Uc+u(t)] \qquad (1)$$

$$F_V(t) = \frac{1}{2}\rho D C_L [Uc+u(t)]^2 \qquad (2)$$

Selecting the appropriate force coefficients can become a contentious issue with large scatter in laboratory results and even more in those derived from field data. Apart from the difficulty in selecting the appropriate force coefficients, it is generally accepted that this classical representation poorly predicts the lift force.

Peak Force Model

The peak model uses only the flow velocity, neglecting inertial terms, to obtain peak coefficients of both the horizontal and vertical forces. These peak coefficients are obtained by nondimensionalising the peak force in each wave cycle by the peak dynamic pressure times area:

$$C_{(H,V)} = \frac{F_{(H,V)max}}{1/2\rho D u_m^2} \qquad (3)$$

Wake Model

The Morison force model, using constant force coefficients and undisturbed flow kinematics, does not accurately predict the time series of the hydrodynamic forces. In the presence of a pipe on or