Balanced Three-Dimensional Modelling of the Fluid-Structure-Soil Interaction of an Untrenched Pipeline

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ABSTRACT

Due to economic efficiencies in laying, untrenched pipelines are finding increased popularity in the transportation of offshore oil and gas, though their design for on-bottom stability remains critical. During a storm complex fluid-structure-soil behaviour is exhibited with an integrated assessment of the pipeline load and displacement required. Traditionally, hydrodynamic fluid loading and structural analysis has been conducted independently of the geotechnical assessment. Invariant hydrodynamic loading calculated prior to the analysis for the initial pipe position does not account for any movement calculated. This paper introduces a “balanced” modelling technique to demonstrate and quantify the advantage of a coupled assessment. Soil-pipe interaction and fluid-pipe interaction are modelled with integrated numerical modelling approaches developed for on-bottom pipeline. Both models are implemented into commercial finite element package ABAQUS as user subroutines. ABAQUS structural elements model the pipe itself. This balanced modelling method is quantified for an example 1.0 m diameter pipeline, simulated over a length of 1250 m. Conditions simulated are typical of those found offshore Australia. Comparisons between analysis methods are presented for a range of water depths.

KEY WORDS

Pipeline; on-bottom stability; fluid-structure-soil interaction; plasticity model; Fourier model; ocean waves.

NOMENCLATURE

\( a \) = wave amplitude
\( C_a \) = coefficient of added mass
\( C_d \) = drag coefficient
\( C_l \) = lift coefficient
\( C_m \) = inertia coefficient
\( d \) = water depth
\( D \) = pipe diameter
\( f(,\ ) \) = directional spreading frequency
\( D' \) = elastic stiffness of UWAPIPE model
\( F_i \) = inertia force
\( F_d \) = drag force
\( F_l \) = lift force
\( F \) = force vector
\( F_b \) = bubble (yield) surface
\( g \) = plastic potential surface
\( H \) = horizontal force
\( k \) = wave number
\( k_{hw} \) = elastic horizontal stiffness
\( k_{ww} \) = elastic vertical stiffness
\( k_{vp} \) = plastic vertical stiffness
\( K_C \) = Keulegan-Carpenter number
\( M \) = ratio of current to wave velocity
\( m \) = aspect ratio of plastic potential surface
\( r \) = scale ratio of bubble surface to bounding surface
\( S \) = wave spectrum
\( T \) = wave period
\( u \) = horizontal displacement
\( u^p \) = horizontal plastic displacement
\( U_c \) = current velocity
\( U_e \) = effective near pipe water velocity
\( U_w \) = wave velocity
\( \dot{U} \) = wave acceleration
\( V \) = vertical force
\( V_o \) = intersection of bounding surface and vertical load axis
\( w \) = vertical displacement
\( w^p \) = vertical plastic displacement
\( \beta \) = shape parameter of yield surface
\( \epsilon \) = random phase
\( \eta \) = wave elevation
\( \theta \) = phase angle
\( \kappa \) = gradient of \( \mu \) with vertical embedment
\( \mu \) = shape parameter of yield surface
\( \rho \) = water density
\( \omega \) = angular frequency

INTRODUCTION

Untrenched pipelines are finding increased popularity in the offshore sector due to their ability to be installed economically. However, as pipelines are a critical conduit in the production of offshore hydrocarbons, any defect during operation has severe financial and environmental impact. Accurate prediction of their movement and...