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A Practical Approach to Numerical Modeling of Pipe-Soil Interaction

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ABSTRACT

This paper presents a macroelement force-resultant model (termed as UWAPIPE) to numerically simulate pipe-soil interaction. It utilizes bounding surface theory as its framework to describe the combined vertical and horizontal load-displacement behavior of a pipe in calcareous sands. By numerically attaching numerous force-resultant elements to structural nodes and by taking a balanced approach between structural and foundation sophistication, the analysis of long pipeline becomes computationally feasible. A method based on three dimensional beam theory and the Finite Element (FE) displacement concept to implement the UWAPIPE into FE program is described in this paper. It assembles the structural stiffness matrix by discretizing the pipeline as beam elements. The contribution of the pipe-soil is incorporated into the structural stiffness matrix according to the FE displacement method. An example calculation case of an offshore pipeline demonstrates the feasibility and efficiency of the proposed analysis approach.

KEY WORDS: Pipe-soil interaction; subsea pipeline; bounding surface; macroelement.

NOMENCLATURE

D	=	pipe diameter
$\mathbf{D}^e$	=	elastic stiffness of UWAPIPE model
$\mathbf{D}^{ep}$	=	elastoplastic stiffness of UWAPIPE model
EI	=	bending stiffness of pipe element
F	=	bounding surface
f_s	=	sub-loading surface
g	=	plastic potential surface
H	=	horizontal force
K	=	plastic modulus
$\overline{K}$	=	hardening modulus of the image point
$\mathbf{K}_f$	=	footing model stiffness
$\mathbf{K}_{gs}$	=	global structure stiffness matrix
K_O	=	plastic modulus at origin when loading (big value)
Ku	=	plastic modulus when begin unloading (big value)
Kr	=	plastic modulus at origin when unloading
k_{he}	=	elastic horizontal stiffness
k_{ve}	=	elastic vertical stiffness
k_{vp}	=	plastic vertical stiffness
L	=	loading criterion
l	=	element length
m	=	aspect ratio of plastic potential surface
u	=	horizontal displacement
u^p	=	horizontal plastic displacement
V	=	vertical force
V_0	=	intersection of bounding surface and vertical load axis
Vs	=	intersection of sub-loading surface and vertical load axis
w	=	vertical displacement
w^p	=	vertical plastic displacement
β	=	shape parameter of yield surface
ε	=	displacement vector
κ	=	gradient of μ with vertical embedment
μ	=	shape parameter of yield surface
μ_0	=	initial μ when no embedment into the seabed
μ_t	=	shape parameter of plastic potential surface
ρ_1	=	plastic modulus parameter
ρ_2	=	plastic modulus parameter
σ	=	force vector

INTRODUCTION

Traditional approaches of modeling pipe-soil interaction are empirically based on bearing capacity and frictional models, which attempt to relate lateral resistance solely to the submerged weight of the pipeline. These theories are adequate, though somewhat conservative, in predicting the failure of pipe-soil system under monotonic loading conditions. However, they are too theoretically simplistic to understand the mechanism of pipe-soil interaction and are incapable of describing the behavior process of pipeline under complex hydrodynamic conditions. At the other extreme, finite element models with elaborated contact and interface elements between the pipeline and the foundation create numerical difficulties, as the significant nonlinearity do not allow for comprehensive modeling of long pipeline systems with current computational power. The macroelement approach, nevertheless, provides an effective alternate as highlighted by Wood (2004) and Cathie et al. (2005). Using a plasticity framework, models