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Nonlinear Behaviour of Free Spanning Pipelines Exposed to Steady Currents: Model Tests and Numerical Simulations

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ABSTRACT

Flexible pipe model tests in steady current, carried out as part of the Submarine Vortex Shedding (S.V.S.) Project, are briefly outlined, as far as the effects on hydroelastic synchronization, induced by the pretensioning level in the models, the static sagged shape and gap ratio are concerned. The results are presented and extensively discussed. The mathematical model set up to interpret the above results is described and the theoretical findings are used to explain possible mechanisms of hydroelastic synchronization, coupled with the nonlinear dynamic behaviour of the model. Applications on real free spanning pipelines are evidenced with examples.

NOMENCLATURE

D : outer diameter
e : minimum clearance between model pipe and bottom
EA : axial stiffness
EJ : flexural stiffness
f_{na} : n-th actual eigenfrequency (quasi-static condition)
f_s : frequency of vortex shedding, calculated from Strouhal's relationship
f_1 : nominal natural frequency (static condition)
f_x : drag average load, per unit length
f_y : lift average load, per unit length
L : length of model
N : axial static pulling force
P : additional axial tensile force due to w and v displacements
q : submerged weight of model, per unit length
U : flow velocity
v : displacement along x axis (quasi-static)
V_r : nominal reduced velocity = $U/(f_1 D)$
V_{r1} : reduced velocity = $U/(f_{1a} D)$
V_{r2} : reduced velocity = $U/(f_{2a} D)$
w : displacement along y axis (quasi-static, relevant to w_s)
w_s : displacement along y axis (static)
x : axis along direction of flow
y : vertical axis transverse to direction of flow
z : axis of undeflected model, transverse to direction of flow
β : bending plane rotation about z axis
α : modal plane rotation about z axis

INTRODUCTION

The S.V.S. Research Project aimed at studying extensively the dynamic behaviour of free spanning pipelines when exposed to hydroelastic phenomena in various flow conditions (Bruschi et al., 1988; Tassini et al., 1989).

Extensive laboratory testing and full-scale in-field data monitoring were carried out as part of the Project activities (Bryndum et al., 1989; Bruschi et al., 1989), from 1985 to 1988.

The tests described herein and used as basis for mathematical modelling were part of those performed in the laboratory with three-dimensional flexible models.

The main objective was to measure the response of the pipeline model when exposed to a steady current flow of varying intensities, with different starting structural and geometrical parameters characterizing the pipe-span.

MODEL DESCRIPTION

The model consisted of a long flexible pipe suspended between two low friction hinges allowing free rotations about x and y axes and restraining the torsion about z axis.

Translations were fully restrained along x and y, while a translational stiffness was present along z; such stiffness could be adjusted, to simulate different pipe-soil interactions at the free-span shoulders.

The model pipe was built using an inner aluminium pipe giving stiffness and strength, and outer plastic shells providing the external (hydraulic) diameter and surface roughness.

The pipe was suspended from a frame that offered the possibility of varying the static tension of the model and its vertical position with respect to the flat plate simulating the seabed.

The pipe model was instrumented to measure:

- in-line and cross-flow displacements
- in-line and cross-flow accelerations
- in-line and cross-flow hydrodynamic loads at different locations along the pipe
- in-line and cross-flow reactions
- axial force
- torque at pipe-ends

The near-bed boundary layer was created by towing the seabed and the pipe together; two series of tapered spires were placed on the leading edge of the model seabed in order to let a fully developed boundary layer take place notwithstanding the limited dimension of the flat plate along the flow stream.

The overall characteristics of the pipe and seabed model are given in Table 1; a cross section is shown in Fig. 1.

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