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# Effect of Axial Force on Allowable Free Spans of Submarine Pipelines

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ABSTRACT:

**Analytical solutions are presented for computing allowable static and dynamic free spans of submarine pipelines subjected to axial and transverse loads. The pipeline is considered to be supported on an elastic semi-infinite soil bed at the two ends of the span. The governing equations for both static and free vibration analysis yield nonlinear algebraic equations for the allowable spans, which are solved numerically using Mathematica. Numerical results are presented in nondimensional form so that these can be directly used for any set of pipe data, loading and soil stiffness parameters. Results reveal that the conventional free span design neglecting the effect of axial force and based on span end conditions idealised as simply supported, fixed or with translational and rotational springs, in many cases, lead to either over-conservative or unconservative estimates.**

KEY WORDS: Submarine pipeline, free span, axial force, analytical solution.

## INTRODUCTION

Allowable free span is one of the most important criterion for design of submarine pipelines laid on a sea bed. Pipelines encounter free spans when laid on an irregular sea bed or when the soil beneath gets scoured away exposing a certain length of the line. At these unsupported spans, the pipeline may undergo excessive yielding due to stresses caused by the inplace loads or fatigue due to vortex induced oscillations caused by the cross-flow, which may ultimately lead to a failure. An accurate prediction of the maximum free span of pipeline allowable against these failures is essential for safe and economic design of pipelines. Pipelines at free spans are essentially supported on the continuous soil bed and are subjected to transverse loads due to self weight, hydrodynamic forces etc. as well as axial forces due to internal / external pressures, thermal load etc. The investigations on pipeline free span reported so far idealise the end support conditions as simply supported or fixed ones or with translational and rotational springs. Tsahalis (1983, 1984) and Jacobsen (1984) have studied vortex induced oscillations of submarine pipelines exposed to current and wave action. Chung et al. (1995, 1996) have obtained the three-dimensional response of fixed-fixed and fixed-pinned pipe-spans subject to hydrodynamic and impact loads, considering the external torsional moment induced by the cross-flow current on the sagged pipe-span. Park and Kim (1997) have modelled the soil support at the free span ends with translational and rotational springs and obtained the allowable length of the free span so as to limit the maximum stress in the span within a permissible value and also to prevent any resonant oscillation due to vortex shedding. Salpekar and Sengupta (1987) computed the rotational stiffness at the span end considering the span to be supported on elastic soil bed and used this rotational stiffness to obtain the natural frequency of the free span. These studies do not consider the axial force in the free span calculations, which may have substantial effect on the bending behavior of the line and also on its natural frequency.

This paper presents analytical solutions for allowable static and dynamic free spans of offshore pipelines subjected to axial and transverse loads. The pipeline is considered symmetrically supported on elastic soil bed at the two ends. The governing fourth order differential equation of beam-column theory for the unsupported segment is solved for the cases of (1) zero axial force, (2) compression and (3) tension in the pipeline. The solution involves 4 arbitrary constants. The deflection and rotation at the end of the semi-infinite pipe on elastic foundation caused by shear and bending moment at this end are obtained in terms the soil stiffness coefficient. These two relations and the symmetry conditions for the deflection and rotation at the ends yield a system of 4 nonhomogeneous simultaneous equations which are solved for the 4 arbitrary constants. The allowable static span is found out by limiting the maximum stress in the pipeline to its allowable value.

The dynamic allowable free span is the maximum length for which the natural frequency of the pipeline is greater than an allowable value determined from the vortex shedding frequency. To obtain the natural frequency of the unsupported span, the free vibration equation of beam-column is solved exactly in terms of hyperbolic and trigonometric functions. The boundary and symmetry conditions, similar to the static case, yield a system of homogeneous simultaneous equations for