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Geometric Nonlinear Modelling of Submarine Pipeline Crossings

Constantine Kalliontzis
Computational Hydraulics Office, Athens, Greece

ABSTRACT

The bending stress variation along the subsea route of two highly pressurized pipelines is identified with the aid of a seventh order finite element model. The equation governing geometric nonlinear pipeline deformations is derived from first principles. By casting the equation of flexure into a quasi-linear stiffness and a nonlinear load component the complexity of form is significantly reduced. A 4 d.o.f. nodal formulation enables a direct evaluation of the nonlinear load vector, using element average derivative functions. A successive overrelaxation method is adopted for the simultaneous identification of the pipeline-seabed contact points and the vertical displacements at the interim spans. Nonlinear axial force calculations, due to horizontal motion restraint at the boundary points, are further carried out. Pipe bending along a hypothetical crossing is investigated in order to test the efficiency of the proposed numerical scheme. The model is subsequently applied to the bending stress analysis for the installation phase of two submarine pipelines connecting the island of Revithoussa with the Aghia Triada peninsula in Greece. The final in-situ corrected seabed profiles prior to pipeline launching are adopted in all relevant calculations. A thorough examination of the effect of surcharge load variation upon the critical stress and pipe lifting during pressurization is additionally carried out.

INTRODUCTION

The routine laying upon irregular seabed profiles of submarine pipelines transporting vital commodities such as water, oil or natural gas, requires the use of accurate methods for predicting the bending stresses along the complete subsea course of the line structures. The problem of unknown pipeline-seabed contact points constitutes the main obstacle that any simulation method must surpass, so as to obtain accurate and reliable bending stress results. The random appearance of support points, which directly depend on the loading conditions, has led a number of researchers (Maier and Andreuzzi, 1978; Stavroulakis et al., 1986; Chuang and Smith, 1992) towards the adoption of optimization techniques for the solution of this complex structural problem. Bianchi and Oliveri (1988) proposed a successive negative reaction node elimination method for obtaining the final random distribution of positive-only seabed reactions, which in turn enable the bending stress identification along the structural system. The advantages offered by the alternative calculation approach involving a relaxation solution methodology has been pointed out in a static (Kalliontzis et al., 1996 and 1997) and a dynamic analysis context (Kalliontzis, 1998). Assuming known support positions along the pipeline subsea route, Pranesh and Johnson (1995) obtained stress solutions using analytic functions.

So far, linear constitutive laws were assumed to be valid by the majority of researchers with the exception of Maier and Andreuzzi (1978), who considered plastic pipeline deformations, and Kalliontzis et al. (1997), who concentrated their analysis on nonlinear bending moments and tensile forces. A frequent application of geometric nonlinear analysis may be found in laybarge-seabed S-curve submarine pipeline configurations, e.g., Palmer et al. (1974), Mousselli (1981) and Datta (1988). The governing equation that describes nonlinear deformation of the pipelines involves high order derivatives, which are difficult to handle in a finite element context as opposed to finite differences. In particular, it is the third order elevation derivative, which is imbedded in the load vector, that led the author towards the formulation of a seventh order finite element structural model. Both the detailed derivation of the governing nonlinear flexure equation and the numerical procedure necessary for the discrete transformation of the mathematical problem are presented here.

Development plans in Greece will be greatly enhanced by the introduction of natural gas, which constitutes an economic alternative source of energy. The bulk of the natural gas supply will originate from Russia, whereas subsidiary reserves will be transported by sea from Algiers to the deserted island of Revithoussa in liquid form. This paper focuses mainly on the optimal stress analysis design of two concrete-coated, submarine steel pipelines conveying natural gas from Revithoussa to the mainland's Aghia Triada peninsula (Fig. 1). The design of the pipelines was carried out in three stages:

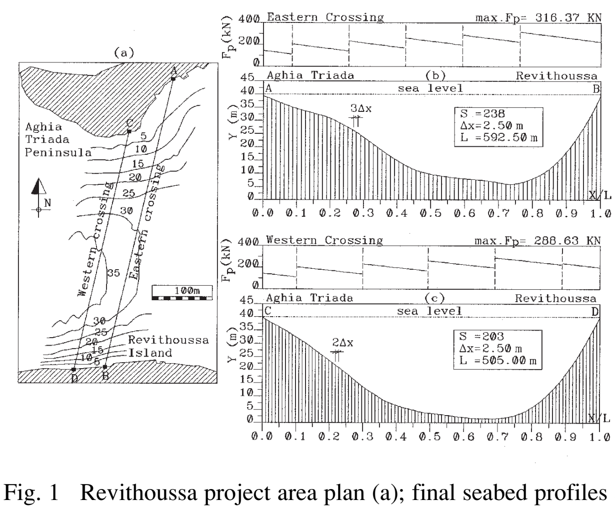

Fig. 1 Revithoussa project area plan (a); final seabed profiles and pulling force variation along subsea route for Eastern (b) and Western (c) crossings

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