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An Interface Beam Element for the Analysis of Soil-Structure Interactions and Pipelines

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ABSTRACT

In this paper, an inerface three-dimensional beam element is introduced for the analysis of framed structures which interact with an elastic medium. The formulations of the element are based on the assumption that the elastic medium can be represented by a two-parameter model of the Winkler and the shear type (Pasternak model). It is assumed, in general, that the properties of the elastic medium can be defined in any coordinate directions which may be different from the member coordinate directions. In the element formulation, the effects of shear deformations and a constant axial force of the beam are taken into account. The stiffness matrices of the beam and the elastic medium are explicitly derived and presented. Numerical examples are provided to demonstrate the element introduced.

INTRODUCTION

The finite element formulation of beams, in general, has been a subject for a long time. In the literature, numerous works about beam elements can be found for various analysis purposes. For rigidly connected members, formulations of a 3-D beam element were presented by Tezcan (1966) and Oran (1973) including the derivation of the tangent stiffness matrix. In these works, the Euler-Bernouilli beam theory was used. However, in some works, e.g., Karadeniz (1994) and Suares et al. (1995), joint flexibilities have also been considered in the beam element formulation. Most of the beam elements found in the literature are mainly for the analysis of superstructures. In practice, the effects of underlying, or surrounding, soil medium are represented by massless spring systems at the member ends as presented in Bowles (1974). Formulation of a 2-D beam which may be finite or infinite resting on an elastic foundation has been well established so far, e.g., Miranda and Nair (1966), Selvadurai (1979) and Ting (1982). By using the exact lateral displacement obtained from the solution of the differential equation, the stiffness matrix and consistent force vectors of a 2-D beam on a Winkler-type foundation are presented by Ting and Mockry (1984). In their work, the effects of the shear deformation are not considered,whereas they are taken into account in Aydogan (1995), in which an exact displacement field is used. A finite element formulation of a 2-D Timoshenko beam resting on a two-parameter (Winkler and shear types) foundation has been presented by Yokoyama (1991). However, all these works have a limited number of applications and they may not correctly represent the soil-structure interface characteristics. For an accurate analysis of the soil-structure interaction phenomenon, a continuum finite, or boundary, element modelling is required as described in Boulon et al. (1995), Faruque (1986) and Selvadurai (1995). In reality, since stress-strain relations of the soil are not linear, a nonlinear analysis procedure, e.g., Crisfield (1991), must be used to obtain correct results. However, for small deformations, linear uncoupled constitutive relations for the soil may reasonably be assumed. For space-framed structures, formulation of an interface element is the main objective of this paper since it can find a large number of applications in practice. Before such an element is introduced, some preliminary formulations of a space beam subjected to external loadings and an axial force are presented.

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DIFFERENTIAL EQUATIONS OF 3-D BEAM

In this section, differential equations of internal forces and displacements of a 3-D beam element are presented. It is assumed that the beam is subjected to distributed external loadings, qy and qz, in the local y and z coordinate directions. After the deformation state of an infinitesimal member, the internal force components of the beam are as defined in Fig.1. The displacement components in the local y and z coordinate directions (the x coordinate direction is defined along the member axis) are respectively uy and uz. For a Timoshenko beam, the derivatives of these displacements with respect to x can be stated as:

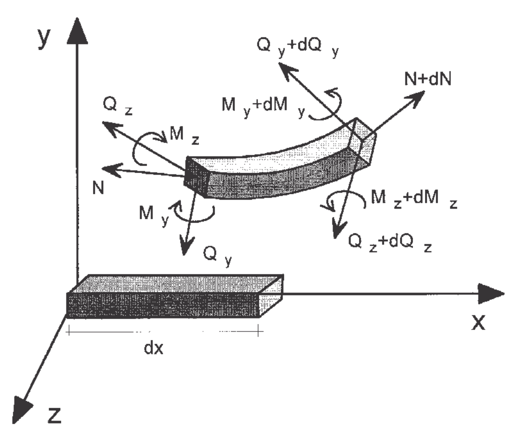

Fig. 1 Force components of an infinitesimal member after deformation state