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Dynamic Elastic-Plastic Analysis of Offshore Framed Structures by Plastic Node Method Considering Strain-Hardening Effects

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ABSTRACT

The Plastic Node Method (PNM) considering combined strain-hardening effects is applied to the dynamic elastic-plastic analysis of offshore framed structures under earthquake loads. In the PNM, a strain-hardening rate for plastic nodes is obtained based on the concept of equivalent plastic work, which gives a reasonable definition of strain-hardening rate for plastic hinges under general loadings. A tangential stiffness matrix of beam-column members can be obtained simply by matrix calculation. Several examples, including the earthquake response of a three-dimensional jacket platform, are presented, and the validity and effectiveness of the proposed method are demonstrated.

INTRODUCTION

Earthquake resistance is one of the most important items to be checked in the design of bottom-supported offshore framed structures in seismic area. For severe earthquakes, the structures may be subjected to cyclic excursions far beyond the elastic range. To obtain a realistic insight into the earthquake response of structures, dynamic elastic-plastic analysis must be performed in time domain. In addition, it is essential to take into account the hysteretic behavior of materials, such as the Bauschinger effect. A finite element method that includes element subdivision and numerical integration may provide accurate predictions of earthquake response considering hysteretic material behaviors. In spite of the recent advance in computing hardware, however, it still requires much computing time and cost from the viewpoint of practical design works.

Many efforts have been devoted to develop more efficient methods for nonlinear earthquake response analysis of framed structures. A lumped plasticity assumption is one possible strategy in such efforts. Here, all the plastic deformations are confined to zero-length plastic hinge at the ends of the beam-column element, while the inside of the element remains elastic.

The major difficulty in considering strain-hardening effects in the lumped plasticity approach is the determination of the strain-hardening rate for the plastic hinge, because it implies infinite strains. To simulate strain-hardening effects Clough et al. (1965) proposed a parallel element model in which a beam-column member consists of an elastic-perfectly plastic element and an element with stiffness equivalent to the strain-hardening rate. Although this model has been justified in the static analysis of frames under monotonous loads, it cannot model a complex hysteretic behavior of materials.

Powell and Chen (1986) introduced a series hinge model where each hinge is subdivided into a series of subhinges. By specifying a load-deformation relationship for each subhinge by bilinear functions, a multilinear relationship for the complete hinge may be produced. Hilmy and Abel (1985) formulated a plastic hinge mechanism based on a bounding-surface kinematic hardening model proposed by Dafalias and Popov (1975) and Krieg (1975). In these methods, however, strain-hardening rates for plastic hinges have been determined experimentally or rather intuitively.

Assuming elastic-perfectly plastic materials, one of the authors developed a new mechanism of a plastic hinge based on the flow theory of plasticity, and derived tangential elastic-plastic stiffness matrix of beam-column members in an explicit form (Ueda et al., 1969). This method was later generalized for plates and solid bodies and named the Plastic Node Method (PNM) (Ueda and Yao, 1982; Ueda and Fujikubo, 1991). Recently, Ueda and Fujikubo (1986) extended the PNM to consider isotropic strain-hardening effects and analyzed several examples of frames and shells. This method was further extended to take into account kinematic and combined strain-hardening effects for the analysis of structures under cyclic loads (Fujikubo et al., 1991).

In the PNM, a generalized hinge mechanism is inserted at the nodes of a finite element. Any type of fully plastic interaction relationship can be introduced. The formulation of strain-hardening rates for the plastic nodes (nodal-point strain-hardening rate) is based on a work equivalence technique, i.e., strain-hardening effects in the element are concentrated at the nodes by equating the plastic work done at the plastic node with that evaluated in the actual plastic region in the element. For framed structures, this nodal-point strain-hardening rate gives consistent definition of strain-hardening rate for plastic hinges. The resulting elastic-plastic stiffness matrix can be obtained simply by matrix calculation.

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