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Practical nonlinear analysis of steel–concrete composite frames using fiber–hinge method

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ABSTRACT

A fiber–hinge beam–column element considering geometric and material nonlinearities is proposed for modeling steel–concrete composite structures. The second-order effects are taken into account in deriving the formulation of the element by the use of the stability functions. To simulate the inelastic behavior based on the concentrated plasticity approximation, the proposed element is divided into two end fiber–hinge segments and an interior elastic segment. The static condensation method is applied so that the element comprising of three segments is treated as one general element with twelve degrees of freedom. The mid-length cross-section of the end fiber segment is divided into many fibers of which the uniaxial material stress–strain relationship is monitored during analysis process. The proposed procedure is verified for accuracy and efficiency through comparisons to the results obtained by the ABAQUS structural analysis program and established results available from the literature and tests through a variety of numerical examples. The proposed procedure proves to be a reliable and efficient tool for daily use in engineering design of steel and steel–concrete composite structures.

1. Introduction

Steel–concrete composite structures comprised of steel, reinforced concrete, and steel–concrete composite members have widely used for constructing buildings and bridges due to their efficiency in structural, economic and construction aspects. Therefore, extensive experimental and theoretical studies have been conducted to provide a better understanding on the behavior of the composite structure and its components under applied loading. Together with the more and more application of the composite structures, there are increasing needs in having a reliable structural analysis program capable of predicting the second-order inelastic response of steel–concrete composite structures. Recently, as the design profession moves towards a performance-based approach, the accurate detailed information on how a structure behaves under different levels of loads is necessary in evaluation of the expected level of performance. Obviously, this requires a comprehensive analysis procedure that can consider all key factors influencing the strength of structure and produce results consistent with the current design code requirements with sufficient accuracy. For daily design purpose, the nonlinear analysis program should be able to get the reliable results in a minimized time, especially in a time-consuming earthquake-resistant design. The degree of success in predicting the nonlinear load–displacement response of frame structures significantly depends on how the nonlinear effects to be simulated in numerical modeling.

The steel and concrete components can be modeled separately using plate, shell and solid elements of available commercial three-dimensional nonlinear finite element packages or self-developed programs of researchers and then are assembled together by some connection or interface elements to simulate the shear connectors/interaction between these components, as recently presented by Baskar et al. [1] and Barth and Wu [2], among others. This continuum method can best capture the nonlinear response of the composite structures and is usually used instead of conducting the high cost and time-consuming full-scale physical testing. However, in order to model a complete structure, so many shell, plate, and solid finite elements must be used and, as a result, it is too time-consuming.

To reduce the modeling and computational expense, "line element" method has been proposed and it can be classified into distributed and lumped plasticity approaches based on the degree of refinement used to represent inelastic behavior. The distributed method uses the highest refinement while the lumped method allows for a significant simplification. The beam–column member in the former is divided into many finite elements and the cross-section of each element is further modeled by fibers of which the stress–strain relationships are monitored during the analysis process, as recently presented by Ayoub and Filippou [3], Salari and Spacone [4], Pi et al. [5], McKenna et al. [6], among others. Therefore, this method is able to model the plastification spreading throughout the cross-section and along the member length. The residual

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