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Direct design of composite structures using practical nonlinear inelastic analysis

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ABSTRACT

The objective of this paper is to present a direct design method using nonlinear inelastic analysis for steel-concrete composite structures subjected to static and earthquake loads. This design approach can eliminate the inaccurate K-factor for static design as well as R-factor for aseismic design. A structural analysis program has been developed to capture accurately and efficiently the strength and behavior of steel-concrete composite structures. Four nonlinear elements considering both geometric and material nonlinearities are implemented into a computer program: (1) fiber beam-column element; (2) beam-column connection element; (3) cable element; and (4) truss element. The proposed program can be used to assess realistically both strength and behavior of a structural system and its component members in a direct manner.

For the fiber beam-column element, the cross-sections of members are discretized into fiber elements to formulate an equivalent effective cross-section, while the geometric nonlinearity caused by the interaction between axial force and bending moment is taken into account using the stability functions. The benefit of employing the stability functions and the fiber hinge model is it can accurately capture the nonlinear effects by modeling one or two elements per member, and hence this leads to a high computational efficiency compared to the finite element method using the interpolation functions. Besides, the plasticity spreading phenomena in the element cross-section are captured at different integration points along the longitudinal direction of the element based on constitutive relations in each fiber.

For the beam-column connection element, a multi-spring element with a zero-length element model is employed to model the nonlinear semi-rigid beam-to-column connections. In the zero-length element model, three rotational and three translational springs are used to connect two nodes that have identical coordinates. The translational springs possess linear stiffness whereas the rotational springs possess linear or nonlinear stiffness to describe the behavior of beam-to-column connection in the analytical model.

For the cable element, the exact analytical expressions of elastic catenary are adopted to derive explicitly the tangent stiffness matrix and internal force vector of the element. The self-weight and pretension of the cable can be directly considered without

any approximations. An elastic-plastic hinge model is used to represent the inelastic behavior of the cable element.

For the truss element, the geometric nonlinearity is considered using an updated Lagrangian formulation, while the material nonlinearity is accounted for by tracing a simple empirical equation of the stress-strain relationship.

To solve the nonlinear equilibrium equation, the generalized displacement control method is adopted herein because of its general numerical stability and efficiency. This algorithm can accurately trace the equilibrium path of nonlinear problems with multiple limit points and snap-back points. An incremental-iterative solution scheme based on the Newmark direct integration method and the Newton-Raphson method is adopted for solving the equations of motion. Based on the aforementioned elements and algorithms, a computer program is developed. It is verified for accuracy and computational efficiency by comparing the predictions with those generated by the commercial packages of ABAQUS and SAP2000, and other results available in the experimental studies. Through a variety of numerical examples and several case studies of large-scale structures, the proposed program proves to be a reliable and efficient tool for daily use in design in lieu of using costly and time-consuming commercial software.