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Approximate method for estimation of collapse loads of steel cable-stayed bridges

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ABSTRACT

This paper proposes a new and simple method for estimating the collapse load of a steel cable-stayed bridge. A new convergence criterion for iterative eigenvalue computations is suggested to consider the beam–column effect of a cable-stayed bridge system. The collapse loads of two example bridges representing medium and long-span models are evaluated by the proposed method and compared to a nonlinear inelastic analysis. The results demonstrate that the proposed method is a good substitute for a complex nonlinear inelastic analysis to approximately evaluate the collapse loads as well as failure modes of steel cable-stayed bridges.

1. Introduction

A cable-stayed bridge is distinguished from conventional highway bridges by special features, including the use of a longer center span without intermediate piers, as well as light-weight girders and high strength cables. In a cost sense, bridge engineers and researchers had considered this kind of a bridge to be superior to medium and short-span bridges with several intermediate piers, for constructing long-span bridge crossings. As the center span of cable-stayed bridges increases, two major issues are naturally addressed: buckling instability and wind instability. The buckling instability of steel girder and tower members is caused by the large axial forces that are transmitted by cables under dead and live loads, whereas the wind instability of steel girder members comes from lateral wind loads. In particular, the buckling instability of girder and tower members may be a fundamental problem that should be checked in the preliminary design of a cable-stayed bridge because it directly controls the geometric dimensions of structural members and the practical limitation of the center span length.

The buckling instability problem of steel cable-stayed bridges had been traditionally evaluated by elastic buckling analysis based on the bifurcation-point stability concept. Since Tang [1] calculated the buckling load of the two-dimensional cable-stayed bridge by the simple energy method in his seminal paper, many researchers have studied various aspects of the buckling instability problem of cable-stayed bridges, such as the overall safety by eigenvalue analysis [2], the effect of cable numbers and the center-span length [3,4], the span lengths and the cable arrangement [5], and the effect of the ratio between girder and tower stiffness and load rating [6,7]. The application of these studies is currently discarded to estimate the collapse loads of a cable-stayed bridge because they cannot take into account both geometric and material nonlinearities that largely affect the load-carrying capacity of such a slender bridge system. Relevant references show that an elastic buckling analysis based on the bifurcation-point stability concept is inadequate to estimate the collapse loads of steel framed structures [8,9] and steel cable-stayed bridges [10,11].

As computer resources and algorithms have improved, rigorous nonlinear inelastic analysis based on the limit-point stability concept became common among many researchers for obtaining the collapse loads of cable-stayed bridge systems. Corresponding studies include modeling techniques for structural members using nonlinear beams and plates [12], a sophisticated analysis method considering both geometric and material nonlinearities [13], the individual effect of nonlinearities [14,15], and a feasibility study for a super long-span bridge with respect to static and dynamic instabilities [16]. Because the nonlinear inelastic analysis used in these studies could rigorously consider both geometric and material nonlinearities of structural members, this method has gained general acceptance as an exact approach to predict the collapse load of a cable-stayed bridge. However, this method obviously requires the preparation of adequate analysis tools and efficient computing machines as well as a wide range of understanding of the complex nonlinear theory. In practical situation, especially in the preliminary design stage, the stability of several bridge systems should be checked for various load cases as much as possible in order to determine the optimum bridge system among proposed designs. Frequent use of this nonlinear inelastic analysis seems to still be a burdensome task for most engineers in this practical situation due to limitations of time and cost. In fact,

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