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Structural dynamic optimal design based on dynamic reliability

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ABSTRACT

In this work, dimension and shape optimization of structures under stochastic process excitation is addressed in the context of element or system dynamic reliability constraints, where the structural gross mass is taken to be the objective function. Firstly, based on the dynamic response analysis of truss structures under stochastic process loads, the dynamic reliability constraints are developed and simplified, and the normalization of design variables is discussed to avoid some variables being drowned by others during optimization due to their different dimensions and orders of magnitude. The optimal models of dimension and shape with element or system dynamic reliability constraints are then presented. Two numerical examples are finally used to illustrate the results of different optimal designs, which demonstrate that the efficiency to solve the structural optimization with dynamic reliability constraints can be significantly improved if the design variables and their initial values are selected properly.

1. Introduction

Compared with the structural conventional optimization, structural reliability optimization is a novel structural design method. Because the modeling of the reliability optimization is more suitable for the engineering application than that of conventional optimization, the optimization results are accordingly more rational and applicable than those of conventional optimization. The structural reliability optimization includes structural analysis, the reliability computation and the optimal design, among which the methods of structural analysis and optimal design are comparatively mature and the solution to structural reliability is crucial.

Structural reliability optimization began in the early 1960s. Hilton and Feigen firstly presented the design of minimum weight based on structural safety, and Kalaba, Switzky and Moses then made great achievements in this field [1]. In recent years, there were some new theories and methods developed such as the random finite element method [2], the new response surface methodology [3], the neural net method [4], the discrete penalty function method [5], etc. Moreover, many engineering application results have been obtained [6–12]. The application of two optimization techniques to solve the mixed (discrete-continuous) reliability-based optimization problem of truss is demonstrated in paper [6], in which the cross-sectional areas of truss bars and coordinates of the specific truss nodes are considered as discrete and continuous design variables, respectively, and the specified allowable reliability indices are associated with limit states in the form of admissible displacements of the chosen truss nodes, admissible stress or local buckling of the elements as well as a global loss of stability. Frangopol [7] presented a brief review of the life-cycle reliability-based optimization field with emphasis on civil and aerospace structures. Barakat et al. [10] illustrated a general approach to the single objective reliability-based optimum design of prestressed concrete beams, in which several limit states including permissible tensile and compressive stresses at both initial and final stages, prestressing losses, ultimate shear strength, etc. were considered and the single objective function represented by the overall cost of the beams in terms of concrete, prestressing steel, mild steel, and form-work is minimized subject to eleven reliability constraints and four geometrical constraints. From above, reliability optimization has been a hot issue in the structural optimum field. But the references mentioned above mainly focused on the optimizations where the constraints were static reliabilities or all of the loads and responses involved were static random variables or random variables simply changing with time.

The external loads acting on the structures, however, are often random process excitations such as the wind, earthquakes, waves, explosions and shocks. So dynamic damage is the main

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