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Optimum Design of Structures for Earthquake Induced Loading by Genetic Algorithm Using Wavelet Transform

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Abstract. Optimum design of structures is achieved by genetic algorithm. The evolutionary algorithm is employed to design structures. The method improves the computing efficiency of the large-scale optimization problems and enhances the global convergence of the design process. The loads are considered as earthquake loads. A time history analysis is carried out for the dynamic analysis. To decrease the computational work, a wavelet transform is used by which the number of points in the earthquake record is reduced. A reverse wavelet transform is also employed to reconstruct the functions under consideration in the time domain. A number of space structures are designed for minimum weight and the results are compared with exact dynamic analysis.

AMS subject classifications: 65T50, 74F99
Key words: Genetic algorithm, discrete wavelet transform, reverse wavelet transform, dynamic analysis.

1 Introduction

Optimum design of structures is to select the design variables systematically such that the weight of the structure is minimized while all the design constraints are satisfied. The external loads can be static [1–3] or dynamic [4–6]. In the present study, the design variables are considered as the member cross-sectional areas, which are chosen from a set of available values (discrete variables). The design constraints are bounds on member stresses and joint displacements. The optimum design problem against earthquake loads is formulated as a mathematical nonlinear programming problem and the solution is obtained by genetic algorithm (GA). The GA method has the capability of finding the global optimal solution while a time history dynamic analysis is employed.

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The probabilistic nature of the standard GA makes the convergence of the method slow. This is due to the fact that the control probabilities for some of the GA operations such as crossover and mutation are chosen constant during the optimization process [7–9]. Another aspect of the GA technique is that the computational cost of the process is high. For problems with large number of degrees of freedom, the structural analysis is time consuming. This makes the optimal design process very inefficient, especially when a time history analysis is considered. To overcome this difficulty, a discrete wavelet transform (DWT) [10–12] is used to transfer the ground acceleration record of the specified earthquake into a function with very small number of points. Thus the time history dynamic analysis is carried out at a fewer points. Another reverse discrete wavelet transform (RWT) is employed to obtain the results of the dynamic analysis for the original earthquake accelerograph record. The numerical results of the dynamic analysis show that this approximation is a powerful technique and the required computational work can be reduced greatly. The error involved in this transformation is small.

In the paper, the details of the optimization approach with approximation concepts will be discussed and some numerical examples for optimum design of structures will be presented. The details of the DWT and RWT will also be outlined. The computational time is compared for the exact optimization method with those of the approximate results.

2 Design problem formulation

The most popular optimization problem in structural design is to minimize the weight. The structure is subjected to constraints imposed on the member stress and joint displacement. This is mathematically shown as:

$$\text{Find } X \text{ to minimize } F(X), \tag{2.1a}$$

$$\text{Subject to } g_j(X) \leq 0, \qquad j = 1, \cdots, m. \tag{2.1b}$$

In this formulation, $X^T = \{x_1, x_2, \cdots, x_n\}$ is the vector of design variables with n variables. In this study X is considered as the cross-sectional areas of the elements. The objective function $F(X)$ is normally taken as the structural weight. The m design constraints imposed on the design problem are shown as inequalities of the form $g_j(X) \leq 0$. To solve the above-mentioned constrained optimization problem by the GA method; first the problem must be converted into an unconstrained optimization problem. There are various methods and a simple method is achieved through exterior penalty function method as follows:

$$\phi(X) = F(X) + r_p \sum_{j=1}^{m} \{\max[0, g_j(X)]\}^2. \tag{2.2}$$

The scalar r_p is a multiplier and by changing this multiplier and minimizing $\phi(X)$, the minimum of $\phi(X)$, approaches minimum of $F(X)$. Genetic algorithm is based on