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Nonlinear dynamic analysis using one-dimensional subspaces

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Abstract

The finite element method changes the systems with unlimited degrees of freedom to a model with limited degrees of freedom (DOFs), which has a similar physical behavior. The one-dimensional generalized subspace (ODGS) method presents a proper solution to the analysis of nonlinear dynamic problems with Ritz-Wilson vectors. It could be used as a reduction method that transforms DOFs to a much more limited number in a new coordinate. In this paper the ODGS method has been used in combination with mode-acceleration technique, to analyze nonlinear dynamic problems. With emphasis on inside error component, a modification criterion using the mode-acceleration technique is suggested for updating the base vectors required in stiffness changes in nonlinear dynamic analysis. Numerical examples show the suitability of the proposed method in both economy and exactness.

Keywords: Nonlinear dynamic analysis, Numerical analysis, Ritz vector, Reduction method.

1. INTRODUCTION

Reduction of system analysis has been widely used for nonlinear dynamic problems. These equilibrium equations are introduced as a set of simultaneous equations. Taking damping effects into account yields that:

$$M_{n\times n}\ddot{U}_{n\times 1}(t)+C_{n\times n}\dot{U}_{n\times 1}(t)+K_{n\times n}U_{n\times 1}(t)=F_{n\times 1}(t) \tag{1}$$

which M, C and K are the matrixes of mass, damping and stiffness, respectively. F(t) is the external loading vector, U, $\dot{U}$ and $\ddot{U}$ are the vectors of displacement, velocity and acceleration, respectively. Transformation of equilibrium equation of system is used in order to apply reduction technique. The reduction technique decreases the number of equations from n to m, which results in higher analysis speed and saving time. The nodal displacement vector $U_{n\times 1}(t)$ of order n, is approximated by a linear combination of a set of linearly independent vectors $Y_{m\times 1}(t)$:

$$U_{n\times 1}(t)=\Psi_{n\times m}Y_{m\times 1}(t) \tag{2}$$

The transformation matrix Ψ has m columns composed of linearly independent vectors Ψ_i of order n. Substituting U, $\dot{U}$ and $\ddot{U}$ by the same transformation and pre-multiplying both sides of equation (1) by Ψ^T, it can be expressed in reduced form as:

$$M^*\ddot{Y}(t)+C^*\dot{Y}(t)+K^*Y(t)=F^*(t) \tag{3}$$

In which the reduced matrixes of mass, damping and stiffness are:

$$M^*=\Psi^T M\Psi, C^*=\Psi^T C\Psi, K^*=\Psi^T K\Psi \tag{4}$$

Selecting the proper base vector of Ψ provides a suitable guess and estimation of the system's response. Eigenvectors and Ritz-Wilson vectors are two main types of base vectors. In the eigenvectors method the reduced damping and the reduced stiffness matrixes of C^* and K^* are diagonal matrixes and the reduced mass matrix M^* is a unit diagonal matrix [1, 2]. In nonlinear states and when not taking the loading factor into account eigenvectors are particularly not the best choices due to high computational expenses in large systems [1, 3]. Since eigenvectors, which do not play a role in the analysis due to perpendicularity to the loading vector, are sometimes engaged in the analysis, or sometimes some modes of vibration are eliminated because of lying in the mode stop area, while they play a key role in the system's response due to similarity to the loading frequency [4, 5]. On the other hand, Ritz vectors are derived from spatial distribution of external loading and affected by the dominant frequency content of loading and as a result of this matter they are used in this paper. In this method all of the generated Ritz vectors are involved with the response and stimulated by the system, also the elimination of the vectors which have a similar frequency to the loading frequency is prevented. Unlike the eigenvector method in the Ritz method, the damping and stiffness