A wavelet-based approach for vibration analysis of framed structures

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In general, second-ordered differential equation of motion, governing the structures has been examined by several numerical methods, both in the linear or nonlinear behaviors. Mathematically, these numerical schemes are being categorized into the two main domains. Firstly, explicit procedures which do not require a factorization of the characteristics of the system in the step-by-step solution of the equation of vibration. Secondly, implicit schemes which require a set of simultaneous linear equations for the time instant solution for vibration analysis [1,2]. Accordingly, it has been inferred that implicit schemes are most effective for structural vibration analysis, in which the response is ascertained by a relatively small number of low frequency modes. In addition, it is reported that these procedures are more popular for the vibration analysis of structures using longer time steps [3–7]. As a result, the shortcomings of numerical approaches have been revealed when encountering broad-frequency content excitations. Explicit schemes are very efficient for all wave propagation problems. Consequently, in shaking or blast problems where a small-time step is needed to evaluate the response of large-scaled models, a practical and optimal algorithm has been implemented through the explicit procedure [2,8–10].

On the other hand, wavelet analysis has widely become the focus of interest among all researchers and engineers all over the world. Although wavelet analysis is well-known and frequently utilized in theory, the implementation of this powerful approach for practical applications has received little attention in the literature. Many mathematical research works have considered this methodology to examine not only ordinary or partial but also fractional differential equations [11–15]. All of them have proposed wavelet analysis to solve equations in a very limited time range. The reason for this is the perception that solution of time dependent equation has been restricted only in a unit time step [15–18]. Furthermore, there is no consideration of the frequency content of operators [11–16], although, as will be shown throughout this study it is the most important criteria to make results desirable or undesirable.

Fundamentally, in structural vibration analysis, engineers are more concerned on the evaluation of the efficiency of numerical approaches in the case of multi-degrees of freedom (MDOF) systems. Accordingly for approximation of the complex dynamic system, a high efficient algorithm of time integration which should be adaptive with frequency content of excitation is required [19]. Frequency-based filtering using wavelet filter banks has been reported in the literature but the numerical integration approach has not been developed yet [20].

In this study, a new explicit approach is proposed using the wavelet functions. Due to the inherent ability of wavelet functions, vibration analysis of structures is optimally satisfied. For this purpose, as in Section 3 of this paper the straightforward formulation is improved for single-degree of freedom systems (SDOF) based on the basis function of Haar and Chebyshev wavelet. Subsequently in Section 4, vibration equilibrium for the MDOF systems is developed accordingly. Furthermore, to examine stability and accuracy of response, in Sections 5 and 6 of this paper, the proposed approach is evaluated. Finally to confirm validity of results of this work, three applications are discussed in Section 7, which includes a harmonic excitation and a complex frequency-domain excitation governing a small-scaled structure, and an impact load on a large-scaled structural system.

Background of wavelet analysis

This section presents a brief background on wavelet analysis utilized in this paper emphasizing on the simplest and one of the complex types of basis functions. Basically, wavelets are classified into the two main categories. Explicit basis function of wavelet which has been shifted for all scaled functions is known as the two-dimensional (2D) wavelet. Developed basis function of wavelet which has been shifted in each new scale, based on the mother wavelet is known as the three-dimensional (3D) wavelet. Thus, a signal with diverse frequency components can be examined elaborately by 3D wavelets rather than 2D ones, where, scale, transition and time are defined as the three dimensions, respectively [15,16].

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