

Simulation of the nonlinear vibration of a string using the cellular automation method

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Received 17 May 2004; received in revised form 8 June 2004; accepted 11 June 2004

Available online 26 August 2004

Abstract

In this study, the nonlinear dynamic responses of a string were simulated using the cellular automaton (CA) method. The local rules were set for the amplitude of vibration and the decay rate of amplitude. In the case of nonlinear systems, the velocity of wave propagation is not constant and depends on the amplitude. Thus, a new treatment of the time step was proposed, i.e., the time step in the CA method is adjusted to real time by considering the effect of the propagation velocity. As numerical examples, first, the dynamic responses of a string with linear characteristic were simulated and a typical resonance curve could be obtained. Secondly the dynamic responses of a string with nonlinear characteristic were simulated. Some characteristic types of vibration could be obtained. It was concluded that the linear and nonlinear dynamic responses of a string could be simulated using the CA method.

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Keywords: Cellular automaton; Local rules; Wave propagation; Nonlinear vibration; Higher harmonics

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1. Introduction

Recently, some machines or structures have been made lighter in spite of its severe operating condition. Their vibrations may be large, thus a nonlinear vibration analysis becomes important for precise analysis and design. An analysis of the dynamics of a multi-degree-of-freedom system or continuous system can be carried out, for instance, using the method of multiple scales [1], by which the nonlinear modal equations derived by the Galerkin's method are analyzed to obtain dynamic responses. Many studies have been performed which use the method of multiple scales. This method is very effective, though its procedures for computation are complex and the order estimation of a solution is not easy. One of the other methods for nonlinear dynamic analysis is the numerical integration of a nonlinear differential equation, however, this requires much computation time in the case of a multi-degree-of-freedom systems.

A discrete computation method, such as the cellular automaton (CA) method or the lattice gas automaton method, have been recently introduced to analyze some problems in the engineering field [2]. In the CA method, the analytical domain is divided into finite state variables called 'cells'. The state of each cell is updated according to local rules at every discrete time step. That is, the state of a cell at a given time step depends only on its previous state and that of the neighbor cells. The states of all cells are updated synchronously. Because of such computational characteristics, analysis can be performed for only a desired portion of the total space. A local rule is designed in such a way that the results will satisfy the requirements. These methods, for instance, have been applied to sound wave propagation [3,4] and the fluid dynamics problem [5].

The dynamic analysis of a string is one of the problems regarding wave propagation. Local rules for this problem have been previously proposed [3]. The rules based on the one proposed in [3] are used in the other studies regarding wave propagation [6–9]. They are set for the amplitude of vibration and the decay rate of amplitude, however, they can be applied to only the linear problem in a homogeneous media. Applying the CA method, the wave will propagate over a distance between cells in one time step, thus the propagation velocity must coincide with the one from the material properties of the media. For the nonlinear dynamic analysis of a string, the tension may depend on its amplitude of vibration, thus the propagation velocity is not constant. The local rules for a linear problem must be modified for a nonlinear one.

In this study, the nonlinear dynamic responses of a string are simulated using the CA method. A new treatment of the time step will be proposed for nonlinear dynamic analysis. In the proposed method, the time step seen in the CA method is adjusted to real time by considering the effect of the propagation velocity, though the basic idea is the same as that for the linear analysis [3]. As a numerical example, first, the dynamic response of a string having linear characteristics is calculated using the CA method. Secondly the forced response of a string having nonlinear characteristics is calculated. The nonlinear term related to the tension of the string is calculated using the dynamic response at the past time of one time step. The results are examined from the viewpoint of their physical meaning.

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