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Simulation of the nonlinear vibration of a string using the Cellular Automata based on the reflection rule

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Abstract

In this study, the nonlinear dynamic responses of a string are simulated using the Cellular Automata method based on the reflection rule. In the case of nonlinear systems, the velocity of wave propagation is not constant and depends on the amplitude. A new treatment of the dynamic time step is proposed for the Cellular Automata method considering the effect of the propagation velocity. As numerical examples, first, the dynamic responses of a string with linear characteristic are simulated using the Cellular Automata method. A typical resonance curve can be obtained. Second, the dynamic responses of a string with nonlinear characteristic are simulated using the proposed method. Some characteristic types of vibration can be obtained. It is concluded that the linear and nonlinear dynamic responses of a string may be obtained by simulation using the Cellular Automata method.

Keywords: Cellular automata; Reflection rule; Wave propagation; Nonlinear vibration; Higher harmonics

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1. Introduction

Recently, some machines or structures become lighter in spite of its severe operating condition. As their vibrations may be large, a nonlinear vibration analysis becomes important for precise analysis and design. A nonlinear 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 or the Harmonic Balance method [1]. Many studies have been found analyzing the nonlinear phenomena by these methods. These methods are very effective, though its procedures for computation are complex and fixing the order for 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 system.

A discrete computation method, such as the Cellular Automata (CA) method or the Lattice Gas Automata 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 wave propagation have been previously proposed [3,4]. There are some studies regarding wave propagation [6–9] based on the rule proposed in [3]. The rule is applied for the amplitude of vibration and the decay rate of amplitude, however, it is feasible to only the linear problem. Applying the CA method, the wave will propagate over a distance between cells in one time step, thus the propagation velocity must coincide real velocity estimated 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. One of the authors has been proposed a new CA method for nonlinear dynamic analysis [10] based on the rule in [3]. In that proposed method, the time step for simulation in the CA method is adjusted to real time by considering the effect of the propagation velocity. Both the linear and nonlinear dynamic responses of a string can be demonstrated using the proposed method. On the other hand, the rule proposed in [4] is based on the collision between cells, and the elastic collision between some cells is simulated. Due to the same reasons as mentioned above, this rule can be applied to only the linear problem.

In this study, the nonlinear dynamic responses of a string are simulated using the CA method based on the rule proposed in [4]. The rule in [4] is used for the transverse vibration and a new treatment of the dynamic time step will be proposed for