New Evolutionary Method for Simultaneous Structural Strength and Dynamics Optimization

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Summary

In this paper, the authors present a new evolutionary structural optimization method based on FE modeling using identical cubic elements for optimizing strength and dynamics characteristics of structures. The method is developed from the previous ones([1]-[3]), and carries out the size and topological shape optimization to satify the strength against external force and inertia force of itself and to control the natural frequencies of the structure. The method gives us the lightest structure satisfying the requirement about the strength and dynamic characteristics. The outline of the method is presented first, and a basic case study about a bridge model is shown.

Introduction

Michell-type structure in 1904 may be one of very early achievements categorized as evolutionary structural optimization. Optimum layout problems such as location of voids in structures were studied in 1970s. Since 1980's, digital computers have enabled to develop various evolutionary structural optimization methods. Examples are cellular automata method, homogenization method and bi-directional evolutionary structural optimization method([4]-[7]). Most of the papers showed two-dimensional and three-dimensional examples whose optimization were started with initial structures fully filled with structural elements in design space([4]-[7]). Roughly mentioning, resultant structures are obtained by the removal of a number of unnecessary structural elements in initial structures although some of the methods are capable of attaching new elements to the place where old elements were removed in the iterative optimization process.

This paper presents a new evolutionary structural optimization method for obtaining light structures under considering double-disciplinary conditions about strength and dynamics. The previous version of the method were presented in such the paper([1]-[3]). The dynamics means control of naturalfrequencies. The optimization normally starts from an initial structural model with very simple and slim shape. The typical initial models are ones like wire-frame models. The method enable such initial models to grow up to sophisticated structures. The computational

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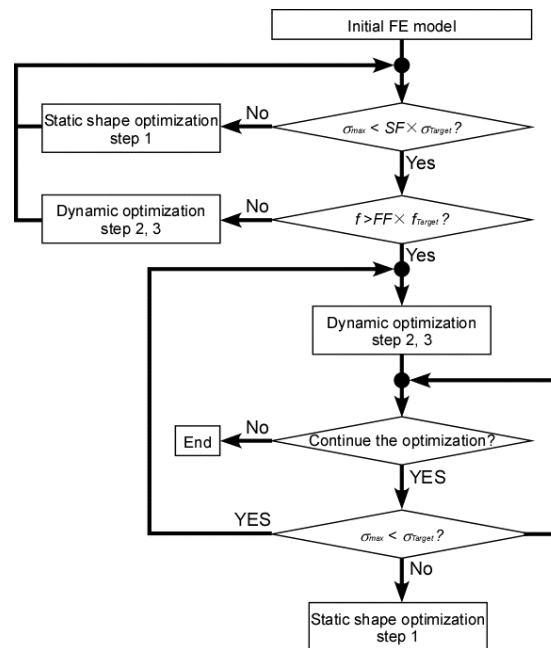
Figure 1: Block Diagram of the Present Optimization Method

load will be comparatively less than conventional ones because of the procedure strategy. In strength optimization, sophisticated structures mean the light structures having appropriate strength and rigidity against subjected external forces. Mises yield criterion is used to judge yielding condition for the case studies in this paper. Yielding place of structures are computed and reinforced by attaching some new finite elements onto the place. On the other hand, an appropriate number of finite elements are removed at the places having some degrees of margin till yielding. In dynamics optimization, sophisticated structures mean the light structures having its natural frequencies of interest as closely as possible to design target frequencies or having the natural frequencies of interest higher than required minimum frequencies. The present method is to optimize both the strength and the dynamics requirement simultaneously. The core of the algorithm of the method is based on sensitivity analysis. The strain energy is used as the sesitivity for the strength optimization, and Rayleigh quotient is used for the dynamics optimization. Note that good handling of the "mode-switching" problem is a key point to get the success of dynamic optimization. In the present method, the combination of the abovementioned two kinds of sensitivity functions and a mathematical device described in the following section work well to prevent the problem.

Outline of the Present Evolutionary Method

Figure 1 is the block diagram of the present evolutionary method. In the first
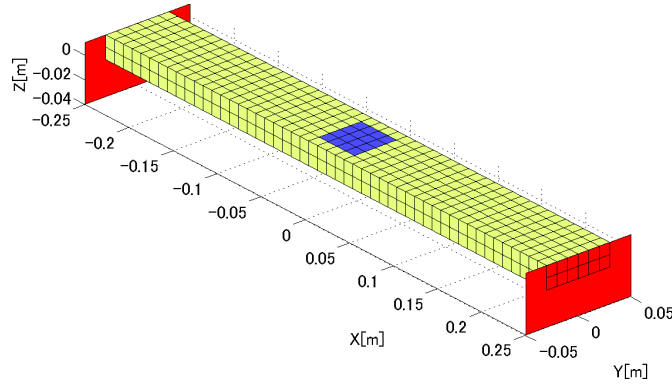
Figure 2: Initial Bridge Model to Be Optimized

some number of iterations, the method makes the initial structural model grow up mainly by newly attaching finite elements. Let us call this process as the growing-up process, which is the upper half part of the block diagram. The first requirement is to satisfy the strength. The stress of all finite elements are controlled to become under the yielding value. Once the strength is satisfied, the natural frequency of interest is controlled to become close to the design target frequency.

In the lower half part of the block diagram after the growing-up process, the grown-up structural model is optimized simultaneously with respect to the strength and the dynamics. In every iterative process, some number of new finite elements are attached at yielding parts and some number of elements are removed from the parts having some degrees of margin till yielding. In addition, according to comparing Rayleigh quotient of each finite element with that of the whole model, some new finite elements are attached near the elements whose Rayleigh quotients are larger than that of the whole model and some finite elements are removed whose Rayleigh quotients are relatively much smaller than that of the whole model. To realize the stability of the simultaneous optimization, we have employed the deviation value, Eq.1, for the comparision rather than the primitive way using the abovementioned physical value. Because the summation of evaluation values of strength and frequency having different units is nonsensical.

$$V_{i,normalized} = \frac{10(V_i - V_{mean})}{\sqrt{\frac{1}{n}\sum(V_i - V_{mean})^2}} + 50 \qquad (1)$$

where $V_{i,normalized}$ is the normalized value about finite element No.i in the form of deviation to be evaluated in the optimization method, V_i is the primitive value to be evaluated, and V_{mean} is the mean value of all finite elements composing the whole structural model. V_i is strain for strength and Rayleigh quotient for dynamics, respectively. Compared with the previous version of the algorithm [2], the present
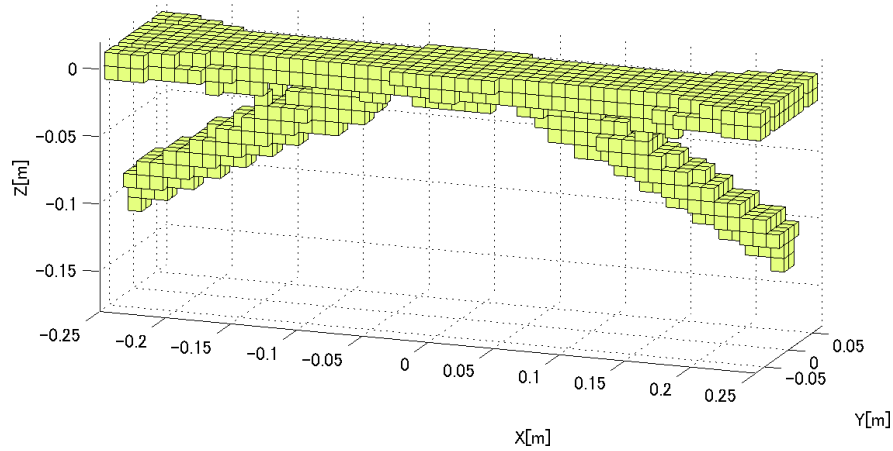
Figure 3: Optimization Result in the Case of Strength Against $20kN$ and the first Natural Frequency $= 1500Hz$

method improves the time efficiency and the stability. Equation (2) is the summation of different two kinds of values in this method.

$$V_{i,evaluated} = w_{strength}(V_{i,normalized})^{\beta}_{strength} + w_{dynamics}(V_{i,normalized})^{\beta}_{dynamics} \qquad (2)$$

where $w_{strength}$ and $w_{dynamics}$ are weighting values that are obtained by

$$w_{strength} = \left(\frac{\sigma_{max}}{\sigma_{target}}\right)^{\alpha} \qquad (3)$$

and

$$w_{dynamics} = \left(max\left(\frac{f_{a,target}}{f_a}, \frac{f_{b,target}}{f_b}\right)\right)^{\alpha} \qquad (4)$$

as an example for the case of two natural frequencies to be controlled. The subscripts a and b means the orders of the two natural frequencies. α and β are heuristic parameters to set in the equations. Acoording to our case studies so far, the integer values between 2 and 6 will be appropriate to be substituted into α and β in practice.

Basic Case Study of Bridge Model

The case study is the optimization of the initial structure of bridge model shown in Fig.2. Young's module, the material density, Poisson ratio and the yielding stress σ_{target} are assumed to be $70GPa$, $2700kg/m^3$, 0.33 and $45MPa$ for the structural model, respectively. The initial structural model does not have enough strength nor the first natural frequency enough high to be required for the optimization below. The design space of the evolutionary optimization is set in only the space under the
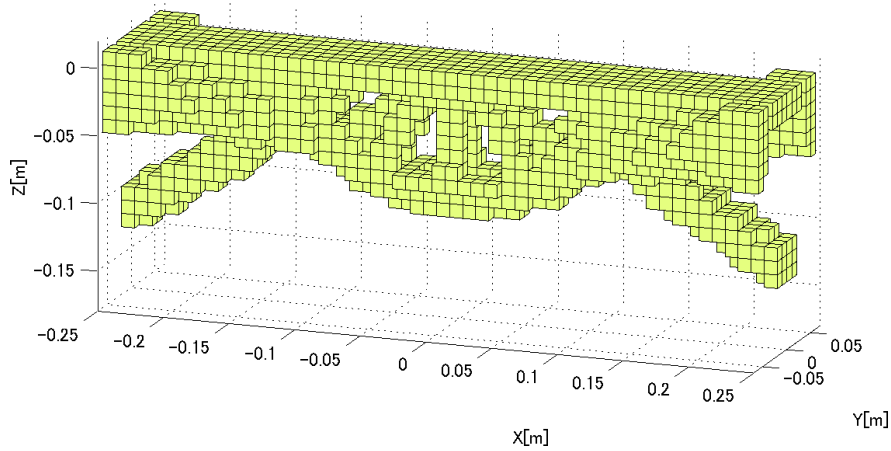
Figure 4: Optimization result in the Case of Strength Against 50*kN* and the First Natural Frequency = 1500*Hz*

girder of the initial bridge model for the structure to be able to grow. Subjected external force is applied on the squre area at the center of the girder. The optimization is carried out using a HP personal computer, xw4200/CT with CPU of 3.40GHz and the memory of 1GB.

Figure 3 is the schematic of the optimization result with $\alpha = 5$ and $\beta = 5$ for the requirement of the strength against 20*kN* and the first natural frequency to be shifted up to 1500*Hz*. The resultant model is composed of 1132 finite elements. Figure 4 is the schematic of the optimization result with $\alpha = 5$ and $\beta = 5$ for the requirement of the strength against 50*kN* and the first natural frequency to be shifted up to 1500*Hz*. The resultant model is composed of 1864 finite elements. Figure 5 is the schematic of the optimization result with $\alpha = 5$ and $\beta = 3$ for the requirement of the strength against 50*kN* and the first natural frequency to be shifted up to 2000*Hz*. The resultant model is composed of 2916 finite elements. According to more than 20 case studies about this model by changing requirements and heuristic parameters, it was found that the present method shortened the computational time about 10 % $\sim$ 20 % than the previous method [2].

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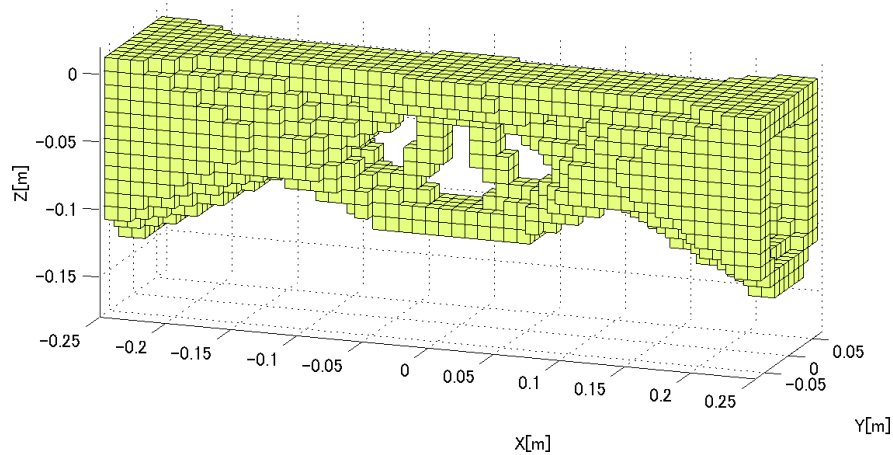
Figure 5: Optimization Result in the Case of Strength Against 50*kN* and the First Natural Frequency = 2000*Hz*

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