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Serviceability Optimization using Hybrid NSGA-II and Resizing Technique

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***Abstract*—Vibration caused by wind can be a factor in reducing residential performance for building users. Although serviceability problems such as residential performance are not significantly related to a building's structural safety, wind-caused vibration is a detail that architects should consider, as it is related to the quality of residential performance. Such vibration can be reduced by adjusting the vibration acceleration in the top floor. Therefore, we aimed to implement an optimal design where residential performance is heightened by reducing vibration acceleration and optimizing building weights. NSGA-II was used as the optimal design technique, although NSGA-II has the shortcoming that the time required for structural analysis increases as the design variable and computational quantities increase. To overcome such problems, a resizing technique was used in the algorithm.**

***Keywords*—Optimization, NSGA-II, Resizing technique, Wind-induced acceleration**

I. Introduction

As long and thin high-rise buildings have become more common, it is important to satisfy the requirements for serviceability of this building structure. Displacement control techniques are usually researched to enhance the serviceability of buildings. Even when buildings have been designed to be safe, problems in serviceability such as noise and vibration could arise. In high-rise buildings, even though constraint conditions for lateral displacement are satisfied through drift control., vibration caused by wind can reduce residential performance for building users. Hence, it is necessary to control drift and components while enhancing the serviceability of the building. However, to implement a stiffness design that satisfies the above conditions, sensitivity analysis of building elements or repetitive structural analysis is required. These methods have the shortcoming that the time required for analysis of computational quantities become prolonged. In addition, designs to simply enhance serviceability can increase the components of the structure and enhance serviceability. Therefore, this research aimed to enhance serviceability by reducing the vibration acceleration caused by wind while satisfying the constraint conditions for lateral displacement of high-rise buildings. A multipurpose optimal design technique, NSGA-II, was used to satisfy the two purpose of optimizing structural components and enhancing serviceability.

In multipurpose design, however, there are a large number of design variables to consider and a large computational quantity. In this case, the time required to complete structural analysis and identify the optimal solution is prolonged. When this time is prolonged, the site application of architects in the field is reduced; this is the shortcoming of optimal design technique. This research used a resizing technique. This research used a resizing technique on NSGA-II, a multipurpose optimal design technique, to enhance the convergence speed. A resizing technique is a method that uses laws of energy to perform stiffness designs for building by adjusting the sectional capacity. This method applies a unit load on the node to be adjusted. Using the subsequent displacement participation factor of structural elements, the sectional capacity of the element is adjusted. This method maintains the total components of the structure while adjusting the area property of structural elements to suggest the optimal sectional capacity for each element. This research aims to enhance convergence in obtaining the optimal solution by using a resizing technique in NSGA-II

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II. Wind-Induced Acceleration

Wind-induced horizontal vibration of a building may result in unpleasant effects, such as motion sickness, for users of the building, thus reducing residential performance. Residential performance is evaluated based on the vibration acceleration that occurs in the top floor of a building.

Induced acceleration of a building is generally maintained below a certain maximum value to secure serviceability in the event of vibration occurring from external forces, such as wind load. Therefore, using the primary natural frequency from structural analysis, the maximum acceleration factor will be set and minimized as an objective function to enhance serviceability. The ASCE 7-02 standards were used to examine the evaluation standards for and permissible level of wind-induced acceleration in high-rise buildings.[5]

A. *Evaluation Standards for Wind-induced Acceleration*

In the ASCE 7-02 standards, the maximum accelration coefficient and maximum acceleration are calculated as formula (1) and formula(2), using building height, width, damping ratio, wind speed, and primary natural frequency of the building.

$$g_s = (2\ln(n_1 T))^{1/2} + 0.5772 / (2\ln(n_1 T))^{1/2} . \quad (1)$$

$$\sigma_{a,\max} = g_a \sigma_a . \quad (2)$$

g_s : maximum acceleration coefficient

n_1 : primary natural frequency

$\sigma_{a,\max}$: mean square root acceleration

g_a : maximum acceleration at top floor

T : 3600 seconds

III. Formulation

The objectives of this algorithm are the total components of the structure and wind-induced acceleration of the top floor. Wind-induced acceleration is shown in formula (1). The other objective function, total components of the structure, is shown in formula (3)

$$\text{minimize W} = \sum A_i L_i \rho_i . \quad (3)$$

The A_i, L_i, and ρ_i are the cross-sectional area, length, and unit density of each element. The objective function is the total sum of the values obtained by multiplying the cross-sectional area, length, and unit density of each element.

An optimal design technique, such as NSGA-II, is an unconstrained optimization technique. Therefore, constraint conditions are set to change into the constrained optimization technique.

$$F = W[1 + C]. \quad (4)$$

F is a fitness function. W and C are the total components of the structure and the constraint violation function of formula (3). The constraint conditions in this research are the allowable floor displacement and allowable stress for each element. Allowable floor displacement and allowable stress are AISC-LRFD, and allowable floor displacement is h/400. The elasticity coefficient of the structure E is 204000MPa.

$$C = \sum_{i=1}^{N_e} C_i^{\sigma} + \sum_{i=1}^{N_n} C_i^{d} . \quad (5)$$

Formula (5) expresses a penalty method. Ne and Nn in formula (5) are the number of elements in the algorithm-applied model and the number of nodes.

A. *Resizing Technique*

Resizing techniques, which are based on energy theory, can adjust the stiffness of a building by distributing the element components without the need for complicated structural or sensitivity analysis. Such a technique can also adjust the primary natural frequency of a building. Hence, a resizing technique was used on NSGA-II, the optimal design technique, to determine the effect of enhancing convergence of the optimal design technique as well as adjusting the primary natural frequency cycle through component distribution of the structure. The constitutive equation for displacement participation factors is presented in the following formula (6).[1][2]

$$\delta = \sum_{i=1}^{M} \left\{ \int_0^1 \frac{N_i^L N_i^U}{E_i A_i} dx + \int_0^1 \frac{M_i^L M_i^U}{E_i I_i} dx + a \int_0^1 \frac{V_i^L V_i^U}{G_i A_i} dx + \int_0^1 \frac{T_i^L T_i^U}{G_i I_{pi}} dx \right\} . \quad (4)$$

In formula (6), A_i, E_i, I_i, and I_{pi} are the cross-sectional area of each element, elasticity coefficient, area moment of inertia, and polar area moment of inertia. N, M, V, and T stand for axial force, moment, shear force, and torsion, respectively. L and U stand for the force applied to the element and the force applied to the element when a unit load is applied to the structure.

IV. Algorithm

NSGA-II was used as the optimal design technique to enhance serviceability by reducing wind-induced acceleration. NSGA-II is a method that discovers the optimal solution through the evolution processes of selection, crossover, and mutation. In this research, a resizing technique to allow stiffness design was introduced to NSGA-II. The order of the algorithm is as follows.[6]

Step1) Generate N number of initial entities

Step2) Generate the parent generation

Step3) Generate the child generation

Step4) Apply the resizing technique

Step5) Divide into satisfying and unsatisfying groups according to the constraint conditions

Step6) Generate a new group

Step7) Repeat Steps 2 through 6 to generate the optimal entity group

The algorithm moves through the process of Step 1 to Step 6 to obtain the optimal solution. When the optimal solution is not obtained from the process of Step 1 to Step 6, the process is repeated.

V. Example

This research applied the NSGA-II using a resizing technique to a 25-story steel frame model. Fig. 1 presents the grouping of elements, while the load and element size of the example model are shown in Fig. 2. [3][4]

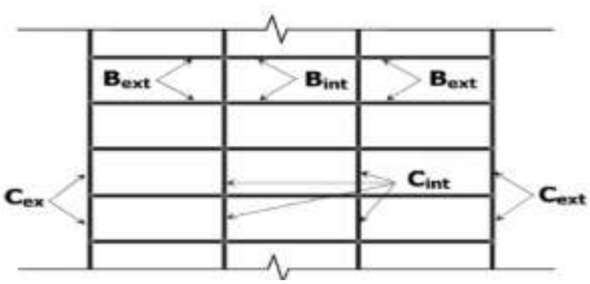

Figure 1. Grouping

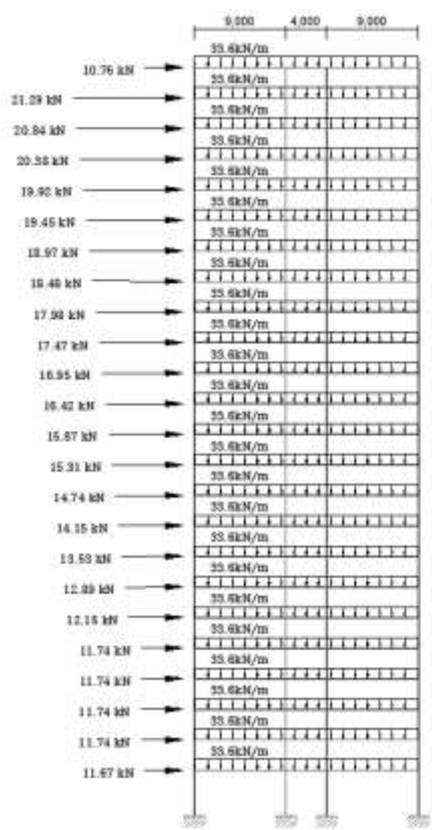

Figure 2. Example model

VI. Conclusion

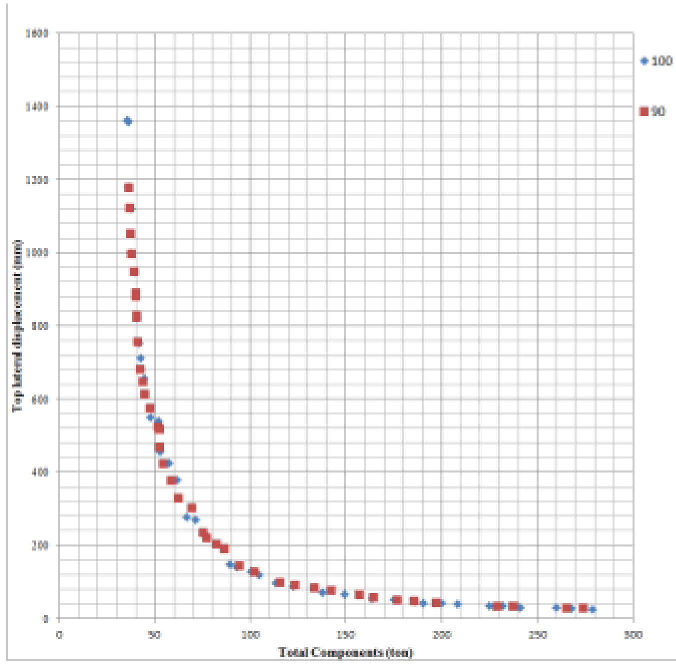

Figure 3. Analysis using only NSGA-II

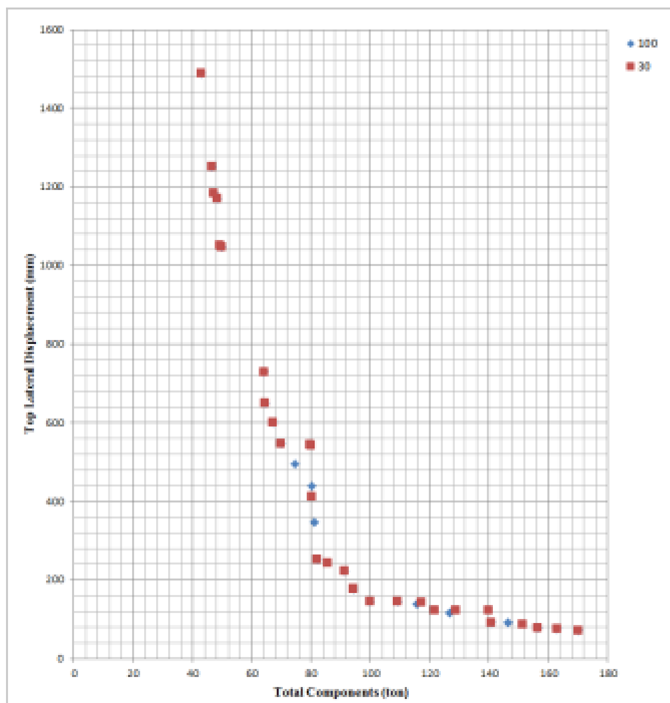

Figure 4. Analysis using NSGA-II and Resizing Technique

This research aims to enhance convergence in obtaining the optimal solution by using a resizing technique in NSGA-II. So applied the NSGA-II using a resizing technique to a 25-story steel frame model. As a result, optimal solution was found to reduce the time required shown figure 3 and figure 4.

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