Application of Genetic Algorithm to Optimization of Buckling Restrained Braces for Seismic Upgrading of Existing Structures

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1. Introduction

Recently, there were many applications of Buckling Restrained Braces (BRB) to rehabilitation of structures. However, systematic approach to obtain its optimal properties and installing places has not been established. In this work, a systematic methodology using Genetic Algorithm (GA) to determine the optimal properties of BRB for seismic upgrading of existing structures against severe ground motions is presented

2. General Description of the Optimization Methodology

2.1. Formulation of the Optimization Problem

a) *Design Variables* are cross sectional areas of BRBs' core members.

b) *Objective Function* is COST which considers only steel volume used in BRBs.

$$C(\mathbf{x}) = \sum_{i=1}^{B} V_i$$

where $C(\mathbf{x})$ is the cost index of the solution $\mathbf{x}$, V_i is the volume of core plate in i-th BRB, and B is the number of BRBs.

c) *Constraints* correspond to the minimum required safety of the structure. Because of the difference in modeling and behavior between BRBs and other structural members, two constraints are considered:

$$g_1(\mathbf{x}) = \max_{1 \le i \le B} \left(\frac{(\varepsilon_{abs.\max})_{B\,i} - \varepsilon_{u.B}}{\varepsilon_{y.B}} \right) \le 0$$

$$g_2(\mathbf{x}) = \max_{1 \le i \le M} \left(\frac{(\varepsilon_{abs.\max})_{i} - \varepsilon_{u.M}}{\varepsilon_{y.M}} \right) \le 0$$

where $(\varepsilon_{abs.\max})_{B.i}$ and $(\varepsilon_{abs.\max})_i$ are the maximum absolute strains in the i-th BRB and i-th upgraded structure's member, respectively. B and M are the number of BRBs and number of main structure's members, respectively. $\varepsilon_{u.B}$ and $\varepsilon_{u.M}$ are the assumed capacity or ultimate strain in BRBs and main structural members, respectively. $\varepsilon_{y.B}$ and $\varepsilon_{y.M}$ are the yield strain for BRB and main structural members, respectively.

2.2. The Applied Optimization Method

Genetic Algorithm GA is employed. The GA was coded and run in MATLAB environment. The MATLAB toolbox presented by Houck *et al.*[1] providing a set of GA operators for real-valued representation of individuals was implemented in the proposed methodology. Normalized Geometric Selection is adopted as Selection function with probability of selecting the best individual equals 0.08. The GA is terminated when reaching an assigned maximum number of iterations. Three functions are employed for Crossover (Arithmetic, Simple, and Heuristic Crossover). Four functions are employed for Mutation (Boundary, Uniform, Non Uniform, and Multi non Uniform Mutation). Reproduction operators are applied probabilistically. Details about the GA operators are described in Houck *et al.* [1].

GA cannot be applied directly to constrained optimization problems, hence fuzzy-logic penalty function method is applied, in which a penalty term R reduces the fitness of an infeasible solution, such penalty term is related to the violation of constraints. The procedure for evaluating fitness of a solution is illustrated in Figure 1.

2.3. Effective Pre-procedure

Additional pre-procedure based on seismic design using Seismic Coefficient Method for moderate ground motion (Level-I) is adopted before applying the GA in order to reduce the number of feasible solutions and improve the efficiency of search.

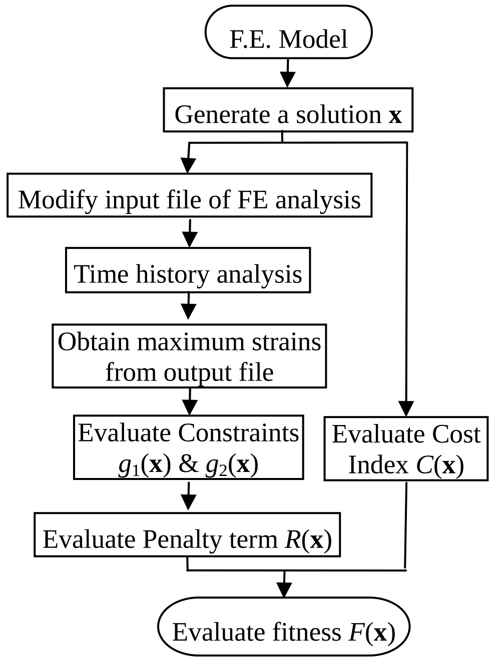

Figure 1. Flowchart of fitness evaluation for a solution

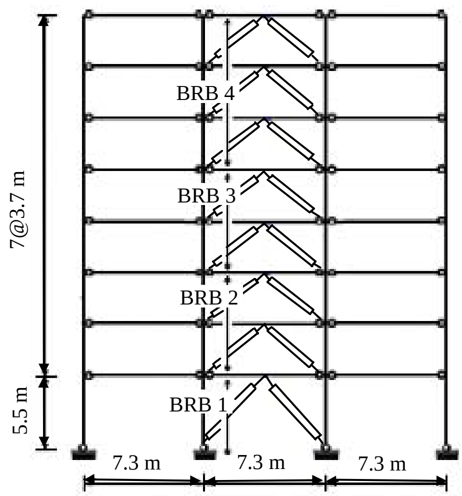

Figure 2. Studied model

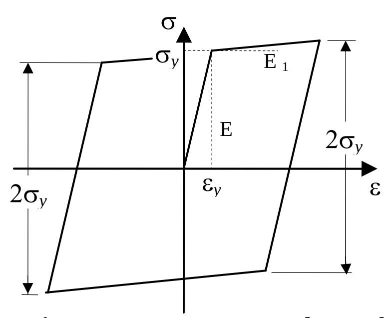

Figure 3. Stress-strain relationship

3. Numerical Evaluation

3.1. Studied Structure

The studied structure is a 2-D Frame with 8-storeys and 3-bays shown in Figure 2. It is modeled by nonlinear finite element analysis software (Y-fiber 3D). Beam element and truss element are used for frame members and BRBs, respectively. Only material nonlinearity is considered by fiber model. SM 490 and SM 400 are the material for frame members and BRBs, respectively. Kinetic hardening rule for all members is employed considering bi-linear stress-strain relationship as shown in Figure 3. Strain hardening stiffness (E_1) is considered as E/100 and E/60 for frame structures and BRBs, respectively. Such value for BRBs is adopted in other researches [2]. Four sections of BRB are used for seismic upgrading as shown in Figure 2. All sections have the same cross sectional shape shown in Figure 4, with fixed width of core plate, thus thicknesses of the core plates are the four design variables considered in the optimization problem.

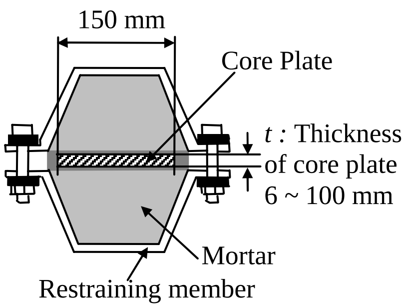

Figure 4. BRB Cross section

3.2. Outline of Analysis

Time history analysis is conducted using Newmark-β method with design input ground motion Level-II T211, which is scaled up by the factor of 2.5 to obtain severe damage in the structure without seismic upgrading. Maximum absolute strain in the structure reached the value of $7.91\varepsilon_y$ for that case. For evaluating the constraints, the considered ultimate strains for BRBs and other structural members are $20\varepsilon_{y.BRB}$ and $6\varepsilon_y$, respectively.

3.3. Results and Discussions

The GA was applied under the following conditions:

Np: population size = 1001 individuals, Maximum Number of generation = 100 iterations, Probability of each Mutation Operator = 4 %, and Probability of each Crossover Operator = 3 %.

The obtained optimal solution is $\mathbf{x}^*= \{91, 7, 6, 14\}$, with maximum fitness, minimum cost index, and no violation of constraints $[g_1(\mathbf{x}^*)$ & $g_2(\mathbf{x}^*)] <0$, i.e. $R(\mathbf{x}^*)=0$.

Fitness development of the *BEST* and *AVERAGE* individual in the population throughout generations is shown in Figure 5, and Figure 6. As we can see from Figure 5, the optimal solution could be attained after 25% of the maximum generation. In Figure 6, fitness of the *AVERAGE* individual was also increasing rapidly, which means that GA was effective in evolving the population generally to include fitter individuals. Moreover, the fluctuation of the *AVERAGE* individual after the rapid increase shows that new random individuals were continuously entering the population. Thus, the local optima could be avoided, and hence the obtained optimal solution can be considered with high credibility as the global optimal solution of the problem.

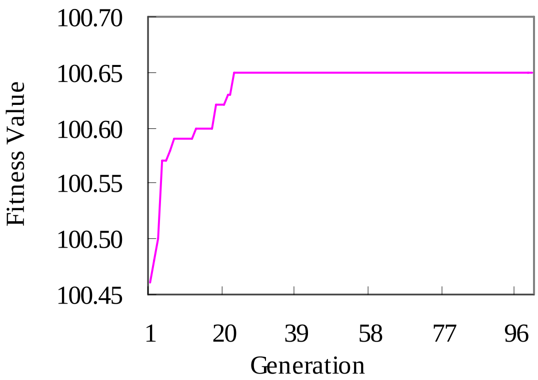

Figure 5. Fitness development of the *BEST* individual in the population

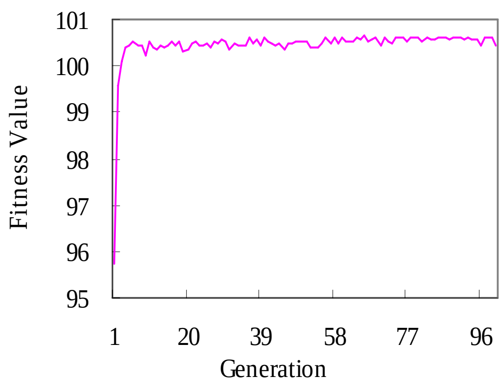

Figure 6. Fitness development of the *AVERAGE* individual in the population

4. Conclusions and Future Work

This work aimed to propose a systematic methodology to determine the optimal properties of BRB for seismic upgrading of existing structures. The main findings can be summarized as follows:

1) The proposed methodology was efficient in obtaining the optimal feasible solution of BRBs' cross sectional areas.

2) Values of GA parameters were suitable for achieving high performance of GA.

In future work, installing places of BRBs as well as other BRB properties need to be among the design variables to be optimized. Moreover, the proposed method will be applied to other kinds of structures such as steel arch bridges.

5. Acknowledgment

Authors would like to express personal appreciation for the valuable assistance given by Dr. Tetsuya Nonaka.

6. References

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