Influence of Ultimate Strain on the Optimal Properties of Buckling Restrained Braces for Seismic Upgrading of an Existing Structure

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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 previous work [1] by the authors, a systematic methodology to determine the optimal properties of BRB for seismic upgrading of existing structures against severe ground motions was presented. In this work, the influence of accepted ultimate strain in structure on the optimal solution obtained by this method is investigated.

2. General Description of the Optimization Methodology

Multi-objective genetic algorithm (MOGA) with a nondominated rank procedure is employed, in which cost and safety are considered as the objective functions of the optimization problem. Cross sectional areas of BRBs core plates are considered as the design variables of the problem.
Safety is represented by the safety index:

$$S(\mathbf{x}) = \max_{1 \le i \le M} (\varepsilon_{abs\,.\max})_i$$

where $(\varepsilon_{abs\,.\max})_i$ is the maximum absolute normalized strain in the main structure's member i (excluding BRBs) induced by design ground motion (Level-II specified in the Japanese design code for highway bridges), M is the number of main structure's members. Only the cost of the steel volume used in BRBs is included in the cost objective function. Constraints of ultimate strains in all members are considered using a fuzzy-logic penalty function method.
Additional pre-procedure based on seismic design using static analysis for moderate ground motion is adopted before applying the MOGA in order to narrow the feasible range and improve the efficiency of search.
As evolution continues, a population converges to its Pareto Optimal set which represents the frontier of trade-off between the objective functions and includes a huge set of optimal solutions. For a Pareto optimal solution, it is impossible to improve one objective value without penalizing the other. Since the size of Global Pareto set is huge, there is a need to filter this set into a short list in order to ease decision making process for picking the preferred optimal solution. Two filters, i.e. Smart Pareto filter and Minimum Distance filter, are used for this purpose.
The details of the method are presented in previous work[1] by the authors.

3. Numerical Evaluation

3.1. Studied Structure

The studied structure is a 2-D Frame with 8-storeys and 3-bays shown in Figure 1. 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 2. Strain hardening stiffness (E_1) is considered E/100 and E/60 for frame structures and BRBs, respectively. Such value for BRBs is adopted in other researches[2]. Four patterns of BRB are used for seismic upgrading as shown in Figure 1. All patterns have the same cross sectional shape shown in Figure 3, with fixed width of core plate, thus thicknesses of the core plates are the four design variables considered in the optimization problem.

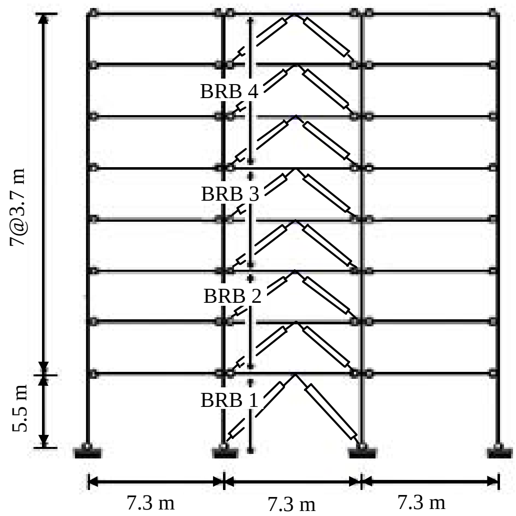

Figure 1. Studied model

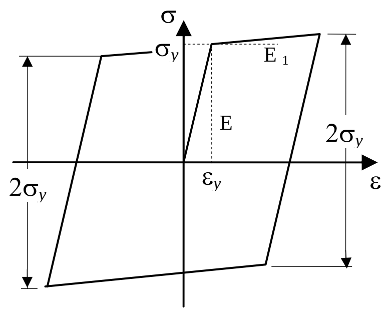

Figure 2. Stress-strain relationship

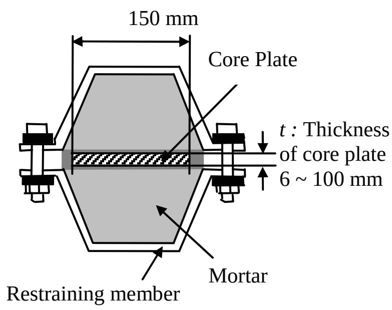

Figure 3. BRB Cross section

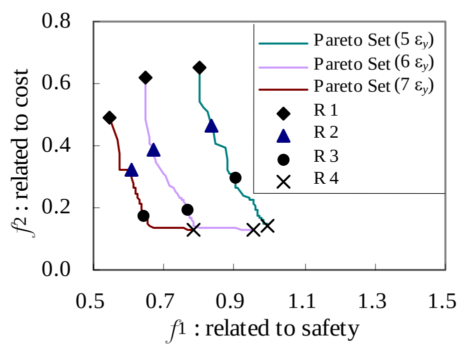

Figure 4. Pareto set and representative solutions for ε_u= 5 ε_y, 6 ε_y and 7 ε_y

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 7.91ε_y for that case.

The objective functions need to be normalized in order to make comparison possible. For this purpose, utopia value and maximum value for both objective functions should be determined. The utopia value for the safety objective function corresponds to a perfectly linear response of the structure during earthquake excitation. Maximum value corresponds to the ultimate strain (ε_u) that is accepted in the main structure before one structural member at least is over plasticized and failure happens. Ultimate strain also is one criterion for judging feasibility of a solution. The proposed method is applied in several cases of ultimate strain value ($\varepsilon_u = 2\varepsilon_y$, $3\varepsilon_y$, $4\varepsilon_y$, $5\varepsilon_y$, $6\varepsilon_y$ and $7\varepsilon_y$).

3.3. Results and Discussions

For $\varepsilon_u = 2\varepsilon_y$, $3\varepsilon_y$ and $4\varepsilon_y$, all obtained solutions are unfeasible, which means that the maximum strain induced in the studied problem is higher than $4\varepsilon_y$ regardless of the seismic upgrading solution. On the other hand, for $\varepsilon_u = 5\varepsilon_y$, $6\varepsilon_y$ and $7\varepsilon_y$, the feasible optimal sets of solutions are obtained. Pareto sets and representative solutions for these ε_u-values are shown in Figure 4. Four representative solutions corresponding to four evenly distributed points from the obtained Pareto sets (see Figure 4) are compared in Figure 5 to clarify the influence of ultimate strain on the optimal solution. The representative optimal solutions scatter according to ultimate strain values. Such scattering can be explained by the random nature of search using GA. Another way to explain it is the influence of ultimate strain on the difference in magnitude between the normalized objective values of feasible and unfeasible solutions. For example, when the assigned ultimate strain is unrealistically small, most of the solutions will be unfeasible and comparison among the extremely large penalized objective values becomes difficult. Thus search would cluster around local optimum solutions and become inefficient in reaching global optimum solutions.

4. Conclusions and Future Work

This work aimed to check the influence of ultimate strain on the optimal solutions obtained by a previously proposed method for determining the optimum seismic upgrading design using BRB. The main findings are as follows:

1) Employing BRB in seismic upgrading of structures can improve the seismic performance and reduce the residual displacements due to severe earthquakes.
2) The optimal solutions obtained by the proposed method might be influenced by the ultimate strain in structural members.

In future work, the influence of other factors on the optimal solutions needs to be examined in order to improve the stability and reliability of the proposed method, in addition to applying the method to seismic upgrading of other kinds of structures.

5. Acknowledgment

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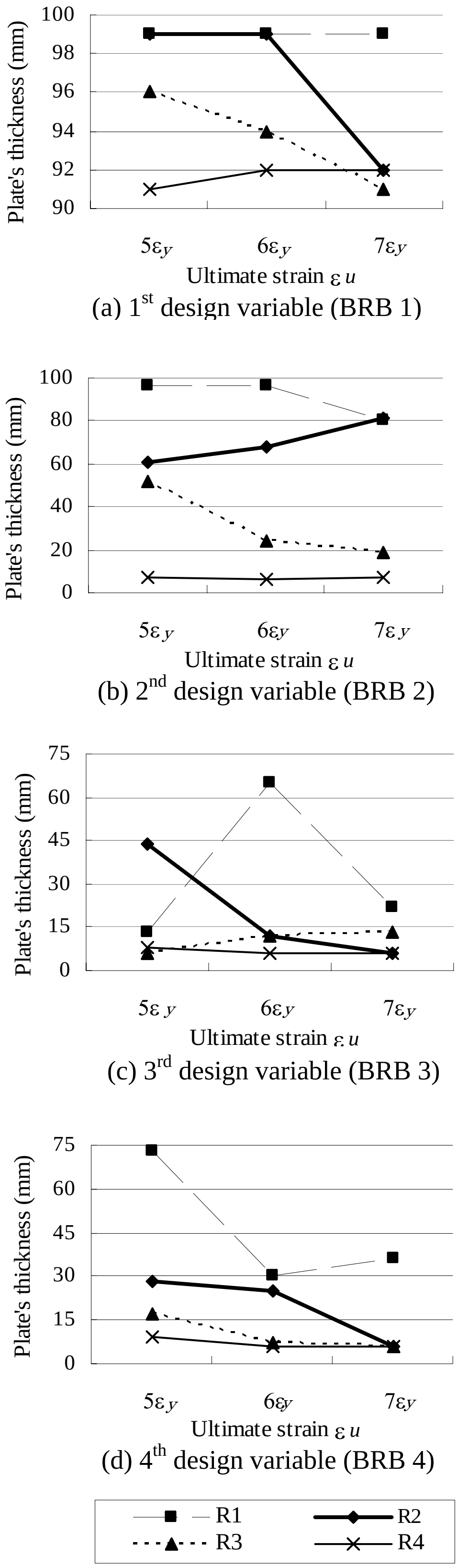

Figure 5. Comparison of the four representative solutions for several values of ultimate strain

6. References

1) FARHAT F., NAKAMURA S., TAKAHASHI K.: A Multi-Objective Genetic Algorithm for Optimizing Seismic Upgrading of structures using Buckling Restrained Braces, Proceedings of the 4th International Symposium on Steel Structures ISSS'06, Vol. 3, pp.869-880, 2006.11.

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