An Optimization Method of Buckling Restrained Braces for Seismic Upgrading of Existing Structures Using Genetic Algorithm and Pushover Analysis

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1. Introduction

In previous work, a systematic methodology to determine the optimal cross sectional areas of Buckling Restrained Braces, BRB, for seismic upgrading of existing structures against level 2 ground motions was proposed (Farhat et al. [1)]). However, sensitivity of seismic performance which is verified by time history analysis to input ground motion is the weak point of the previously proposed method. In this work, sensitivity is verified by considering nine representative input ground motions corresponding to three ground types and the optimal solution for the studied frame structure is compared for each ground type. Finally, as a solution for the problem of sensitivity, a pushover analysis-based seismic performance verification method is proposed instead of time history analysis.

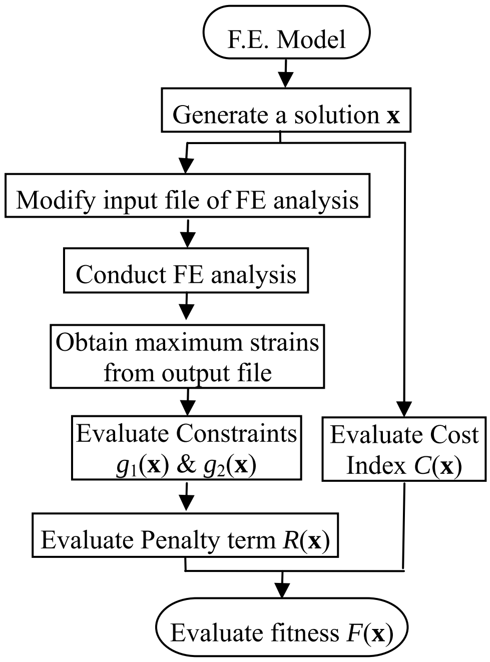

Figure 1. Flowchart of fitness evaluation for a solution

2. Background of the Previously Proposed 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:

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

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

where $(\varepsilon_{abs.\max})_{B.i}$ and $(\varepsilon_{.\max})_i$ are the maximum absolute strains in the i-th BRB and maximum compressive strain in 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. Maximum strains are obtained by conducting time history analysis.

2.2. The Applied Optimization Method

Genetic Algorithm, GA, is adopted to solve the optimization problem in MATLAB environment. The "Genetic Algorithm and Direct Search Toolbox 2" [2)] is employed. Flowchart of fitness evaluation is shown in Figure 1.

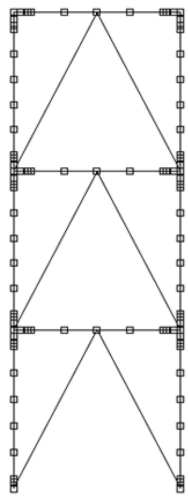

Figure 2. Studied model

3. Verification of Sensitivity to Design Ground Motion

3.1. Outline of Analysis

The studied structure is tri-deck steel bridge piers of frame type, see Figure 2. Three pairs of BRB are installed into the structure for seismic upgrading; BRB 1, BRB 2, and BRB 3 refer to the pair of BRBs in the first, second, and third floor, respectively. BRB member employed by Chen et al [3)], whose cross section is illustrated in Fig. 3, is assigned for all BRBs. Frame members and BRBs are modeled as Timoshenko beams and truss element, respectively, with nonlinear Finite Element analysis software MSC. MARC[3)]. 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. Strain

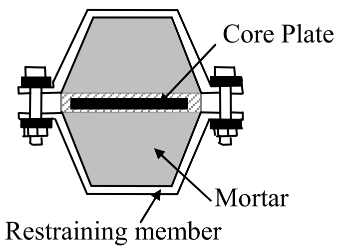

Figure 3. BRB Cross section

hardening stiffness is considered as E/100 and E/60 for frame structures and BRBs, respectively, where, E is Young's modulus for steel. Time history analysis is conducted using Newmark-β method with nine design input ground motions level 2, type 2 proposed by the Japanese Specifications for Highway Bridges[4].

3. 2. Optimization Results

The optimization algorithm was run for the nine ground motions. Local buckling of each member should be considered when determining the value of ultimate strain which might exceed the yield strain without failure. For instance, maximum compressive strain reached 3.5 ε_y in the same structure in Chen et al [3]. In this work, one value of $\varepsilon_{u.M}$ for all members is taken as 3ε_y for ground type 1 and 2. However, for ground type 3, no feasible solution could be obtained when considering the previous value, thus, $\varepsilon_{u.M}$ is assigned as 6ε_y. Results for the nine cases are shown in Table 1. It is obvious that optimal solution is sensitive to input ground motion. Moreover, the differences are also in the damaged segments and failure mechanism for each ground motion.

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Table 1. Optimal solutions for each ground motion

Ground Type	Ground motion	Scale	BRB1(m^2)	BRB2(m^2)	BRB3 (m^2)	ε.max / ε y
1	T211	1	0.030	0.020	0.010	1.68
	T212	1	0.020	0.020	0.035	2.98
	T213	1	0.020	0.025	0.010	2.54
2	T221	0.5	0.0275	0.0275	0.0250	0.997
	T222	0.5	0.0050	0.0050	0.0050	4.25
	T223	0.5	0.0325	0.0325	0.0250	5.11
3	T231	1	0.056	0.049	0.007	5.87
	T232	1	0.049	0.035	0.007	4.73
	T233	1	0.035	0.049	0.007	5.05

4. Employing Pushover Analysis Instead of Time History Analysis

Many simplified design methods for estimating nonlinear response of structures can be found in the literature. For example, the applicability of equal energy assumption was verified to many kinds of structures (Cetinkaya et al. [5] and Nagata et al.[6]). Differences among correction function formulas are negligible; therefore, it is supposed that such functions can be applicable to seismically upgraded structures with BRBs. The energy of linear system requires estimating the peak response from the relevant response spectrum and by considering three modes in the modal superposition method. By conducting pushover analysis, the energy of nonlinear system can be calculated from the pushover curve which represents the relation between horizontal displacement of the roof point and the applied base shear force. After estimating the nonlinear response of the structure, strains in BRBs and critical locations are obtained to evaluate the constraints of optimization problem.

5. Conclusions and Future Work

In this research, sensitivity of BRB optimum design in seismically upgraded structures to input ground motions is verified. The main findings can be summarized as follows:

- Optimal cross sectional areas of BRB and damaged parts of the structure are highly sensitive to input ground motion.
- It is necessary to consider more than one ground motion. However, such consideration will be extremely time consuming when employing time history analysis.

Pushover analysis-based seismic performance verification method is proposed instead of time history analysis. The applicability of equal energy assumption to seismically upgraded structures with BRBs needs to be investigated in future work. Pushover analysis can solve the problem of time consumption as well as ground motion sensitivity.

6. References

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