論文題名 Optimal Design Method for Seismic Upgrading of Existing Structures Using Buckling Restrained Braces

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The Japanese Specifications for Highway Bridges (JSHB) have been revised after the 1995 Hyogoken Nanbu Earthquake to require seismic design against major earthquakes, namely level 2 earthquakes. Moreover, seismic upgrading of weak existing structures became inevitable. Recently, there were many applications of employing Buckling Restrained Braces (BRB) to seismically upgrade structures. However, properties and installation places of BRBs in most applications have been determined by experience or trial-and-error since the available optimal design approaches of BRBs have some limitations on applicability to seismic upgrading of existing structures such as considering elastic frame structures only.

The main aim of this research is to propose a systematic and general optimum design method that considers the interaction between the nonlinear response of the BRBs and the main structure and is applicable to the seismic upgrading of many kinds of structures using BRB. The primary focus is on steel frame civil structures which can be either a separate structure such as piers of elevated highways, or a part of complex structures such as side piers of steel arch bridges. Design methods of seismic upgrading applications should determine the installation locations and properties of BRBs. In the proposed method, first, the BRB properties are optimized for assumed installation locations. Second, the sensitivity of optimal solution to input ground motion is confirmed in case of considering one design ground motion only in seismic performance verification using Nonlinear Response History Analysis (NRHA). In order to solve the problem of sensitivity, the applicability of an alternative of NRHA, i.e., pushover analysis, to structures equipped with BRBs is investigated. Third, both the BRB properties and installation locations in steel frame structures are optimized considering the interaction between them.

The dissertation is composed of 7 chapters.

Chapter 1 gives the background and objectives of the research together with a discussion of major previous works conducted in the related field.

Chapter 2 briefly explains the provisions of seismic performance verification against level 2 earthquakes according to JSHB. It also includes details about the structural assumptions and analytical models employed in this research.

In Chapter 3, BRB properties, i.e., cross sectional areas of core members or BRB areas, are optimized for assumed locations of installation. The optimization problem is formulated into a

Single objective Optimization Problem (SOP). Cost is the objective function to be minimized under the safety constraints. The constraints correspond to the ultimate strains in both BRBs and main members of the structure. Then, the adopted method for solving the SOP, i.e., Single Objective Genetic Algorithm (SOGA), is described. In order to improve the search performance, a simplified preliminary procedure is proposed. The procedure employs seismic design against level 1 earthquakes using seismic coefficient method. A numerical example of applying the proposed SOGA is provided and the results are discussed.

Chapter 4 includes formulation of BRB areas' optimization problem as a Multi objective Optimization Problem (MOP). In the formulation of MOP, not only cost but also damage are the objective functions to be minimized. The constraints and cost objective function are the same as those in SOP. Damage objective function is related to the maximum compressive strain in the upgraded structure induced by a level 2 earthquake input ground motion. Then, the employed method for solving MOP, i.e., Multi Objective Genetic Algorithm MOGA, is described. Finally, numerical evaluation is carried out and some MOGA parameters are tuned to improve the search performance. Moreover, validity and effectiveness of the preliminary procedure are numerically verified.

In Chapter 5, numerical investigations are conducted to verify the sensitivity of optimal BRB areas obtained by SOGA to input ground motions. To overcome drawback of sensitivity, applicability of the conventional pushover analysis with equal energy assumption as an alternative to NRHA to seismically upgraded structures is numerically examined. Although satisfactory results cannot be obtained, some of its reasons are clarified and the direction to solve them such as the application of advanced pushover procedure is suggested.

Chapter 6 proposes a method for optimizing both the BRB areas and installation locations in steel frame structures considering the interaction between them. The concept of the method is explained. The priority in this method is to minimize the number of BRBs regardless of their properties because it has more influence on the total cost. Therefore, in the proposed method, BRBs are added gradually until satisfying the constraints. First, the locations are determined to maximize the seismic performance. Second, BRB areas are optimized to minimize cost under the seismic performance constraints same as SOP in Chapter 3. In order to avoid the problem of sensitivity to input ground motion, NRHA is conducted using three design ground motions as recommended in JSHB. For each ground motion, the approximate response surface method is adopted and the average response is taken. Three frame structures are studied in the numerical evaluation of this chapter. The effectiveness of the proposed method is proved by comparing all possible solutions available for every number of added BRB in each studied model.

In Chapter 7, the main findings of each chapter are summarized and the points that need to be enhanced in future work are indicated.