A Study to Reduce the Inter-story Drifts of Steel Moment Frames Subjected to Seismic Load

Se Woon Choi\textsuperscript{1a} and Hyo Seon Park\textsuperscript{1}

\textit{Department of Architectural Engineering, Yonsei University, Korea}

Abstract

An optimal drift design model for the steel moment frames under the seismic load is presented. The objective function of the proposed drift design model is to minimize the differences of the inter-story drifts so that the inter-story drifts of the structure could be reduced. This model uses a constraint condition not to change the weight of the structure before and after the application of the presented method. This method resizes all or partial structural members consisting of the structure according to the values of displacement participation factors of the corresponding member. The efficiency of this algorithm is demonstrated by the application to a 3-story steel moment frame. It is concluded that the proposed method can determine the sectional properties of structural members to reduce the inter-story drifts of the structure without the iterative structural analysis.

Keywords: Resizing algorithm; Drift design; Inter-story drift; Steel moment frame.

\textsuperscript{a} Presenter: Email: watercloud@yonsei.ac.kr
1. INTRODUCTION

The earthquake is an uncommon natural phenomenon. However, if a strong earthquake occurs, there can be enormous damage. Because it could not only bring about the primary damages caused by such as building destruction, but also lead to secondary damages like the delay of restoration and infectious diseases caused by the destruction of public facilities such as hospitals and roads. For example, in the recent case of the Haiti earthquake (2010), the number of human death reached 3,000,000 and because the restoration was delayed due to destruction of major facilities like public offices and roads, and then as time went by, the damage was increased. Therefore an interest in the seismic design of the structures is increasing.

The seismic design in the several standards and codes allows the ductile behaviors of structures because of economics. In other words, it reduces the strength of an earthquake through response modification factor and ensures the ductile capacity through the detail of connections. For those reasons, the seismic design needs to evaluate and design the ductile capacity of structures through the nonlinear analysis. However, there are many difficulties in application to practical use, for the nonlinear analysis is complicated and time consuming. So now in practical use, the process of a seismic design based on the results of the linear analysis is generally chosen.

The moment resisting frame is the structural system consisting of beams and columns, that their joints are rigidly connected. It is one of the earthquake resisting building system which is used widely most in low/mid-rise buildings because of the advantages such as diversity of building design due to formative simplicity and high ductility (Bruneau et al., 1998). The inter-story drift constraint of system levels rather than strength of element levels works as a governing design factor in seismic design process of the moment resisting frame (Foutch and Yun, 2002; Liu, 2003). However, because the inter-story drifts are determined considering effects of all elements consisting of a structure, to control the inter-story drifts effectively is difficult. In the practical use, it is generally checked by the method of trial and error depending on engineer’s experiences. Due to this problem, many methods on the optimal drift design for the building have been proposed (Baker, 1990; Chan, 1992; Seo et al., 2008).

This study proposes the method that reduces the inter-story drifts of steel moment frames without the change of the total structural weight. This method reduces the inter-story drifts of it through resizing the all or partial elements consisting of it. The static linear analysis using equivalent static seismic load, considered widely in practical seismic design process, also is used to calculate the inter-story drifts of a building. The proposed method is applied to the 3-story example to verify the applicability and efficiency of the proposed method.

2. FORMULATIONS

The proposed method in this study uses the formulations such like Eq. (1) and (2) to reduce the inter-story drifts of a building. Because the building damage by an earthquake is closely associated with the inter-story drifts of a building developed by an earthquake, the technique of reducing the inter-story drifts of a building is important. It is widely known that the building deformed uniformly is less damaged than others (Xu et al., 2006). Eq. (1) means to minimize the difference of the inter-story drifts of the structure. The inter-story drifts of the structure are determined after calculating the displacement participation factor of each elements consisting of the structure using the unit load method. Eq. (2) means to maintain the total structural weight of the structure before and after the application of the proposed method. The proposed method is to resize the sectional area of elements based on the modification factor of the corresponding element. The modification factor of each element is calculated by Eq. (3), which is determined by taking a derivative of it after transforming Eq. (1) and (3) into the unconstrained
optimization problem using the Lagrange multiplier. Using the modification factors calculated by Eq. (3), the inter-story drifts can be reduced without the iterative calculation.

$$\sum_{j=1}^{m} \left| \Delta_{j,\text{interstory}} - \mu_{\text{mean interstory}} \right| \mu_{\text{mean interstory}}$$

Minimize

Subject to

$$\sum_{i=1}^{m} \rho_i A_i l_i = \sum_{i=1}^{m} \rho_i (\beta_i) A_i l_i$$

$$\beta_i = \sqrt{\frac{\left\{ \sum_{j=1}^{m} (\Delta_{j,\text{interstory}}) \right\}}{\mu_{\text{mean interstory}}} / \left\{ \sum_{i=1}^{m} \rho_i A_i l_i \right\} / \left\{ \sum_{i=1}^{m} \rho_i (\beta_i) A_i l_i \right\}$$

Where, $\Delta_{j,\text{interstory}}$ and $\mu_{\text{mean interstory}}$ indicate the inter-story drift of the $j$th story and the average inter-story drift of the structure, respectively. $\rho_i$, $A_i$, $l_i$, $\beta_i$ mean the density, sectional area, length, modification factor of the $i$th element, in turn. $m$ and $n$ are the number of story of the structure and the number of element consisting of the structure, respectively.

3. APPLICATIONS

The example used by Hasan et al. (2002), Gupta and Krawinkler (1999) is applied to demonstrate the applicability and efficiency of the proposed method. Figure 1 indicates the elevation of the example. It is assumed that this structure is located in Los Angeles, U.S.A. The soil class, Seismic Use Group and Seismic Design Category are assumed to be D (Stiff Soil), II and E, respectively. For more information of the design on the example, see Gupta and Krawinkler (1999). The equivalent static seismic load is used to calculate the inter-story drift of the structure.

The structural weight, base shear and period of the initial design are 413.42kN, 1645.62kN and 0.95sec, respectively. The max and average inter-story drift ratios of it are 1.70%, 1.48%. Meanwhile, those of the
design redesigned by the proposed method are 419.20kN, 1766.12kN and 0.91sec. The increasing amount is 1.40%. The structural weight of modified design unavoidably increased due to the discrete property of W-shape. The max and average inter-story drift ratios of it are 1.60%, 1.39%. It is confirmed that the inter-story drift of the structure is reduced.

4. CONCLUSIONS

It was proposed the optimal drift design model to reduce the inter-story drifts of steel moment frame subjected to seismic load using the resizing method. The method efficiently redesigns the elements of the structure based on the displacement participant factor of the corresponding element calculated by the unit load method without the iterative structural analysis and the change of the structural weight. The proposed method was applied to the 3-story example to verify the application and efficiency of the proposed method. The equivalent static seismic load was considered to calculate the inter-story drifts of the structure. The inter-story drifts of the initial design structure was compared with the one modified by the proposed method. The inter-story drift of the example was reduced by the proposed method. However, it needs to carry the further studies on the ductile behaviors of the design redesigned by this method using the non-linear analysis.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST)(No. 2010-0027246).

REFERENCES

[1] Bruneau, M., Uang C. M., and Whittaker, A. (1998). Ductile design of steel structures, McGraw-Hill, New York.
[2] Foutch, D. A., Yun, S. (2002). Modeling of steel moment frames for seismic loads, Journal of Construction Steel Research, 58, 529-564
[3] Liu, M. (2003). Development of Multiobjective Optimization Procedures for Seismic Design of Steel Moment Frame Structures, Ph.D. thesis, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL
[4] Baker, W. (1990). Sizing techniques for lateral systems in multi-storey steel buildings, Proc. 4th World Congress on Tall Buildings, Council on Tall Buildings and Urban Habitat, Hong Kong, 868-875.
[5] Chan, C.M. (1992). An optimality criteria algorithm for tall steel building design using commercial standard sections, Structural and Multidisciplinary Optimization, Vol. 5, No. 1-2, 26-29.
[6] Seo J. H., Song W. K., Kwon Y. H., Hong K., Park H. S. (2008). Drift design model for high-rise buildings based on resizing algorithm with a weight control factor, Struct. Design Tall Spec. Build. 17, 563-578
[7] Xu L., Gong Y., Grierson D. E. (2006). Seismic Design Optimization of Steel Building Frameworks, Journal of Structural Engineering, 132(2), 277-286.
[8] Hasan R., Xu L., Grierson D. E. (2002). Push-over Analysis for Performance-Based Seismic Design, Computers and Structures, 2483-2493
[9] Gupta A., Krawinkler H. (1999). Seismic Demands for Performance Evaluation of Steel Moment Resisting Frame Structures, The John A. Blume Earthquake Engineering Center, Report No. 132, Dept. of Civil Engineering, Stanford University, Stanford, California
[10] Federal Emergency Management Agency (1997). NEHRP guidelines for the seismic rehabilitation of buildings(FEMA Publication 273), Washington, DC