Evaluation of the adequacy of the response spectrum analysis for the seismic analysis of moment-resisting and concentrically-braced buildings according to the seismic design codes

Ahmadreza Fatahi [1], Mehdi Poursha[2*]

[1] Master of Science in Earthquake Engineering, Faculty of Civil Engineering, Sahand University of Technology, Tabriz, Iran

[2] Associate Professor, Faculty of Civil Engineering, Sahand University of Technology, Tabriz, Iran

ABSTRACT

According to the seismic design codes, the response spectrum analysis (RSA) method can be used for the seismic analysis of tall buildings since it can consider the effect of higher modes. In addition, the nonlinear time history analysis is the most accurate method of evaluating the seismic responses of structures. Consequently, the present study investigates the accuracy of the RSA method by comparing the seismic responses computed by the RSA with the nonlinear time history analysis. To this end, six 3D structures with 4-, 10- and 20-story heights are investigated in this paper. The lateral load resisting systems of the structures include special steel moment-resisting frames (MRFs) and concentrically braced frames (CBFs). To conduct the nonlinear time history analyses, four sets of ground motion records including three groups of near-fault records with different characteristics and one set of far-fault records are used. The near-fault ground motion sets include forward directivity, fling step and no pulse characteristics. All sets comprise seven seismic ground motion records. The results indicate that the seismic responses obtained by the RSA, are mostly underestimated and non-conservative in comparison with those from the nonlinear time history analysis. In general, the more the height of the structure, the larger the error in the seismic responses derived from the RSA. Also, the largest error in the RSA relative to the rigorous time history analysis occurs in the case of the near-fault ground motions with fling-step effect.

KEYWORDS

Response spectrum analysis, Nonlinear time-history analysis, Near-fault ground motions, Far-fault ground motions, Moment-resisting frame, Concentrically-braced frame

Introduction

In the seismic codes such as ASCE7-16, three methods including the equivalent static analysis, response spectrum analysis and time history analysis are used for the seismic analysis of structures. In the static analysis method, which is the simplest method of analysis, the structure is designed to withstand the lateral static loads determined by the codes. The results of previous research investigations have revealed the weaknesses and limitations of this method.

The nonlinear time-history analysis method, which is the most accurate method of the seismic evaluation of structures, is time-consuming. On the other hand, the response spectrum analysis (RSA) method is a simplified method that can be used in accordance with the seismic design codes. In the RSA, after determining the periods and modes shapes of the structure, the modal responses

*Corresponding Author: Email: Poursha@sut.ac.ur

ACCEPTED MANUSCRIPT

derived from the response spectrum of the used ground motion records are combined using an appropriate combination scheme such as SRSS or CQC. This method has gained a great attraction in practice in the seismic design of structures. To the authors' knowledge, no study has been done to compare the accuracy of this method under the effect of ground motion records with different characteristics. Therefore, the purpose of this paper is to compare the accuracy of the RSA under near-fault ground motions with Forward Directivity (FD), Fling-Step (FS) and No Pulse (No P.) characteristics as well as far-fault ground motion records.

Methodology

To study the accuracy of the RSA under near-fault and far-fault ground motions, the nonlinear response history analysis (NL-RHA) is carried out as a benchmark method. Since the RSA is a linear analysis, the results obtained from the RSA should be modified by using the displacement amplification factor, C_d, and over-strength factor, Ω, to compare the RSA results with those of the NL-RHA. Therefore, the story shear derived from the RSA is multiplied by the over-strength factor and the floor displacements and the story drifts are multiplied by the displacement amplification factor. In this research, three special moment-resisting frame (MRF) buildings and three special concentrically braced frame (CBF) buildings with the heights of 4, 10 and 20 stories were designed in accordance with the ASCE7-16 [1] and AISC 360 [2]. All the linear and nonlinear analyses were performed by using the SAP2000 software[3]. Four different ground motion groups including the near-fault ground motions with Forward Directivity (FD), Fling-Step (FS) and No Pulse (No P.) characteristics and far-fault ground motion records were used in the NL-RHAs. The nonlinear behavior of the beams, columns and braces were modeled with plastic joints according to ASCE / SEI 41-13[4].

Discussion and Results

The story shears resulting from the RSA and NL-RHA for the 20-story CBF and MRF buildings subjected to four different sets of ground motion records are displayed in Figures 1 and 2, respectively. With the increase in the height of the structures, the difference between the story shears obtained from the RSA and NL-RHA for each group of the ground motion records increases due to the effect of higher modes. For instance, the error in the RSA for the 4-story MRF and CBF buildings amounts to 14% and 13%, respectively, while for the 20-story MRF and CBF buildings, it reaches 18% and 23%, respectively. The lowest error in the RSA for the story shear occurs for the near-fault No P. ground motion records and the largest error takes place for the ground motion records with fling step and far-fault ground motions.

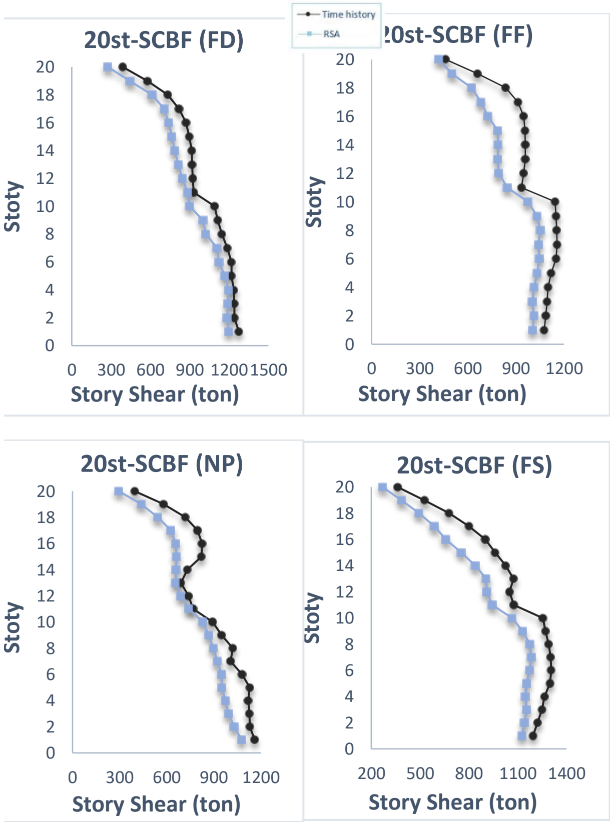

Figure 1. Story shears obtained from the RSA and NL-RHA for the 20-story CBF building subjected to four different sets of ground motion records.

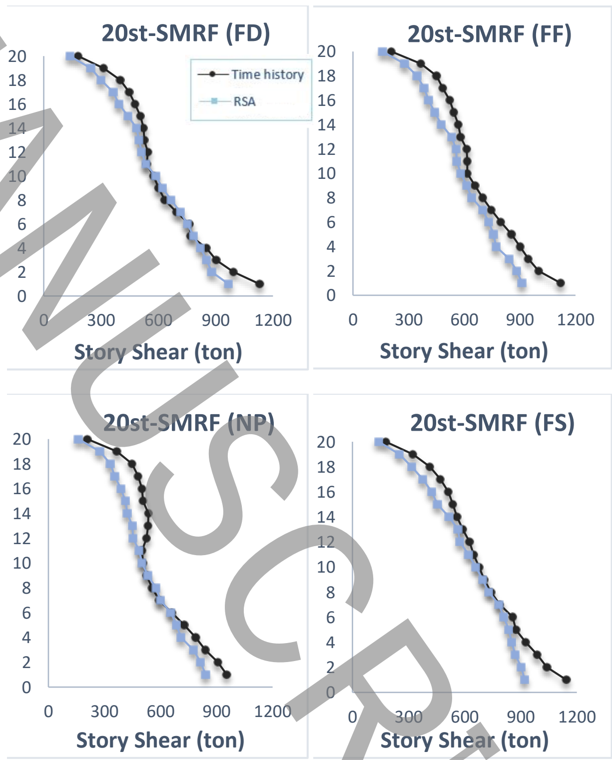

Figure 2. Story shears obtained from the RSA and NL-RHA for the 20-story MRF building subjected to four different sets of ground motion records.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

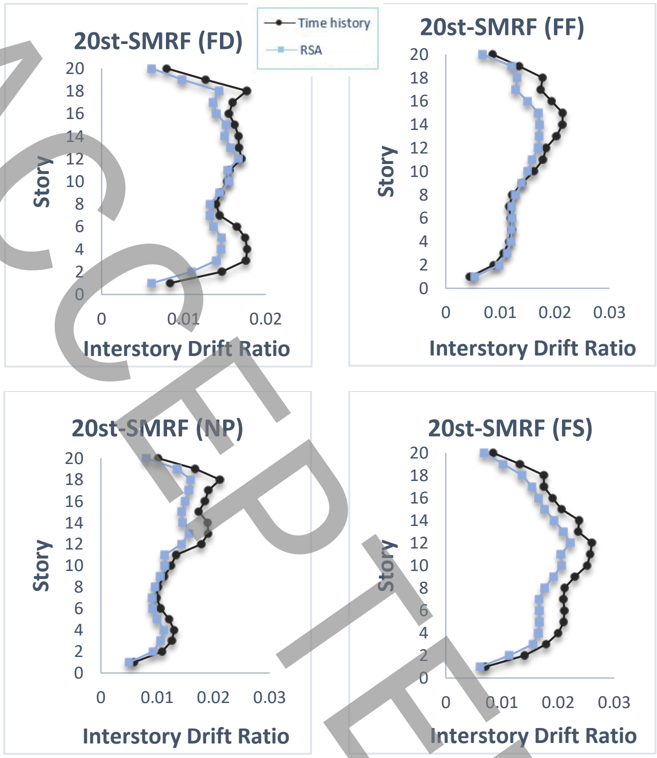

Figure 3. Story drifts obtained from the RSA and NL-RHA for the 20-story MRF building subjected to four different sets of ground motion records.

For instance, the story drifts obtained from the RSA and NL-RHA for the 20-story MRF building subjected to four different sets of ground motion records are shown in Figure 3. For all structures except the 4-story CBF structure, the largest error in the RSA for the floor displacements takes place in the case of the near-fault ground motion records with fling step and it amounts to 27%. In all of the structures under consideration, the smallest error in the RSA for the story drifts occurs for the near-fault No P. ground motion records and the largest error is produced in the case of the near-fault ground motion records with fling step and far-fault ground motions.

It should be noted that similar results were obtained for floor displacements in the case of all buildings and they are not shown herein for brevity.

Conclusions

In general, it can be concluded that the RSA underestimates the seismic responses in comparison with the NL-RHA and is non-conservative. The amount of underestimation may amount to more than 20% in some cases. Therefore, the codes such as ASCE7-16 and Standard 2800 [5]which consider the RSA as a reliable analysis method, need a revision in this respect.

It is noted that this conclusion has been derived for moment-resisting frame (MRF) buildings and concentrically braced frame (CBF) ones. To generalize this outcome, other lateral load resisting systems should be examined.

References

[1] ASCE/SEI 7-16, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, 2016.
[2] ANSI/AISC 360-16, Specification for structural steel buildings, 2016.
[3] Computers and Structures Incorporated (CSI), SAP 2000 NL, Berkeley, CA, U.S.A., 2018.
[4] ASCE/SEI 41-13, Seismic evaluation and retrofit of existing buildings, American Society of Civil Engineers, 2013.
[5] INBC. 2800, Standard No. 2800: Iranian Code of Practice for Seismic Resistant Design of Buildings. Iranian national building code, Tehran, Iran;, (2014).