COMPDYN 2011
3rd ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis, V. Plevris (eds.)
Corfu, Greece, 25–28 May 2011

INFLUENTIAL PARAMETERS FOR THE DESIGN OF NONSTRUCTURAL COMPONENTS IN MULTI-STORY BUILDINGS

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Keywords: Secondary System, Floor Response Spectra, Nonstructural Component.

Abstract. *Damage to nonstructural components may conduce heavy financial losses and injuries; therefore, it is a necessity for these components to be carefully designed for seismic loads. Meanwhile, even the most recent editions of the corresponding codes and instructions are still based on some assumptions that impair their accuracy and degree of conservatism. In this paper, it is intended to highlight the influential effect of some of these assumptions and the other related parameters that affect the floor acceleration response in buildings. For this reason, this paper constitutes the nonlinear dynamic time-history analysis of seven code-designed multi-story regular steel moment-resisting frames which have been subjected to selected strong ground motions (SGMs) for each individual building. Floor acceleration response spectra (FARS) have been calculated for the building floors. The spectra have been computed for the case of the components having dynamic interaction with the primary structure or not, so that the influence of the dynamic interaction is spotlighted. Besides, the FARS have been specified for different component mass ratios so as to account for the effect of the component weight. Another factor which is neglected in most of the instructions and studies is damping. Different damping coefficients have been utilized to investigate the effect of this parameter. The frame beams have the freedom to bend; therefore, the buildings are not consisted of simple shear frames. The effects of all mentioned parameters have been quantitatively illustrated and the results have been compared with each other for various cases. It is found that the mass ratio of the component, the degree of damping in primary or secondary systems, and the interaction between the primary and the secondary structure are crucial factors to be considered in seismic design of nonstructural components (NSCs), which regarding them helps improve the precision of studies. Moreover, results indicate that in contrary to the assumptions of current seismic codes, not always does the fundamental vibration mode of the primary structure produce the highest floor acceleration responses. Also, it can be inferred that if such factors are included in seismic design codes, their level of conservatism can become more rational and proposed methods can get closer to reality.*

1 INTRODUCTION

During past earthquakes, damage to nonstructural components has always shown to constitute a wide portion of economic losses. Thus, in recent decades, the seismic behavior of NSCs has become an area of research interest. Compared to structural components, our knowledge of nonstructural systems is relatively limited and research works and available codes and guidelines in this field are, for the most part, based on past experience, engineering judgment, and intuition, rather than on experimental and analytical results.

There are many different factors which affect the design force of secondary systems in buildings. In this study, the influence of the secondary system mass ratio, secondary and primary system damping ratios, and the primary-secondary system interaction on floor acceleration demand has been investigated. In past studies, these parameters have either been neglected or their effects have not been spotlighted quantitatively using precise time-history analyses. This study; however, quantifies the crucial effects of these parameters via comprehensive numerical analyses.

2 STRUCTURAL MODELS AND SELECTED GROUND MOTIONS

In this paper, seven multi-story building frames have been utilized for the dynamic time-history analysis. The frames have been pulled out of seven code-designed building structures such that their dynamic behavior is the same as that of the buildings. The studied buildings comprise a group of 4-, 6-, 8-, 12-, 16-, 20-, and 25-story special steel moment-resisting frames which bear a single-degree-of-freedom linear secondary system on one of their floors for each analysis. The secondary systems have been attached to the bottom, middle, or top floor of each building (equivalent frame) every time. Figure 1 shows a schematic of the 6-story building typical floor plan and interior frame with nonstructural components attached at its floors. The other six studied buildings have similar floor plans with frames which have been designed for each individual building.

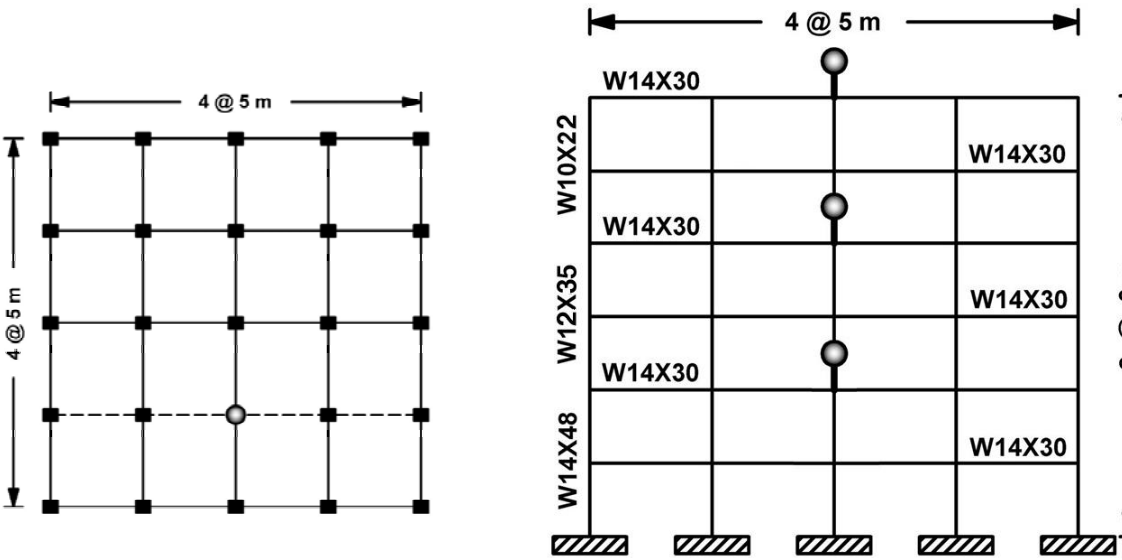

Figure 1: 6-story building typical floor plan (left) and interior frame (right) with nonstructural components attached to its lower, middle or top floor.

Since this study aims to gain an understanding of the behaviour of nonstructural components mounted on nonlinear buildings, the ground motions used in the analysis are selected based on their ability to stimulate the nonlinear behaviour of the buildings. Thus, for each building, the earthquake input for this study is defined in terms of eight strong ground motion (SGM) acceleration time histories recorded in different earthquake events and scaled to match the spectral ordinate at the fundamental period of the building. Table 1 shows the exclusively selected SGMs for the 6-story building from M6.5 scenario SGM data base proposed by Hatefi, Ashtiany and Ansari [4] using SGM selection method proposed by Ashtiany, Mousavi and Azarbakht [5].

No.	Earthquake	Year	Station	M	PGA (g)	Scale factor	V_{S30} (cm/sec)	Effective Duration (sec)
1	Qaen(S. Khorasan)	1979	Khezri	7.1	0.10	1.804	701	15.05
2	Qaen(S. Khorasan)	1979	Khezri	7.1	0.10	2.087	701	15.635
3	Eslamabad(Ardebil)	1997	Kariq	6	0.57	1.613	589	4.205
4	Avaj	2002	Kaboodar Ahang	6.5	0.16	2.909	613	18.06
5	Kajoor,Firooz ab-abd	2004	Moalem Kelayeh	6.3	0.29	1.668	490	10.625
6	Kocaeli	1999	Devlet Hastanesi	7.4	0.14	2.909	348	11.595
7	Duzce	1998	Bayındırlık ve İskan	7.1	0.81	0.835	294	8.57
8	Loma Prieta	1989	Hollister City Hall Annex	6.9	0.25	1.086	-	14.435

Table-1. Details of earthquake ground motions considered in this study for the 6-story building

3 INFLUENTIAL FACTORS TO AFFECT FLOOR ACCELERATION

In this section it is intended to spotlight some of the important and influential parameters that affect the floor acceleration values in buildings or other structures which are mostly neglected in code provisions or other studies. For this reason, the nonlinear acceleration floor response spectra (AFRS) have been calculated using the aforementioned structural models and ground motions for the bottom, middle, and top floors of the buildings. Since floor spectra can illustrate the frequency content of the responses, they have been taken advantage of in the study to show the effects of the secondary system mass ratio, the primary and the secondary system damping ratio, and the dynamic interaction between the primary and the secondary system. The spectra have been calculated for a range of secondary system periods from 0.01 to 5 seconds. These spectra have been obtained for every floor of the buildings but here, they are only shown for the 6-story building. The master values for the secondary system mass ratio, the primary system damping ratio and the secondary system damping ratio in this study have been chosen 0.01, 0.05 and 0.05, respectively, and all other cases are compared with these quantities. Besides, the master model in this study is the one in which the dynamic primary-secondary system interaction is considered.

3.1 Mass ratio

Secondary system mass ratio is defined as the ratio of the secondary system mass to the mass of the floor to which the NSC is attached. Here, the NSCs mass ratios have been selected to be equal to 0.005, 0.01, 0.02, or 0.05. For each analysis, a secondary system with one of the four different mass ratios has been added to one of the three different building floors (top, middle, or bottom) of each building to investigate how the secondary system mass ratio may affect the floor acceleration response. For each building, the AFRS have been obtained using the corresponding selected eight ground motions and the mean AFRS have been used as one may see in the following figures. Since it is not possible to show all of the figures, the mean AFRS for only the 6-story building are presented here at the bottom, middle, and top floor for different secondary system mass ratios in figures 2, 3, and 4, respectively. Also shown on the figures are the building modal periods in vertical dashed lines.

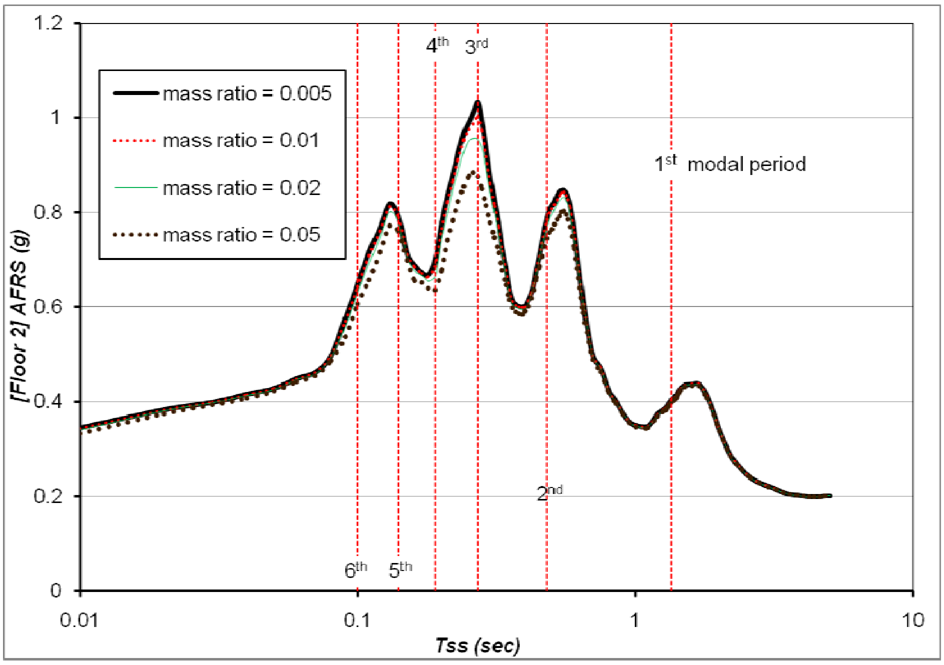

Figure 2: 6-story building mean AFRS at the 2nd (bottom) floor for different secondary system mass ratios.

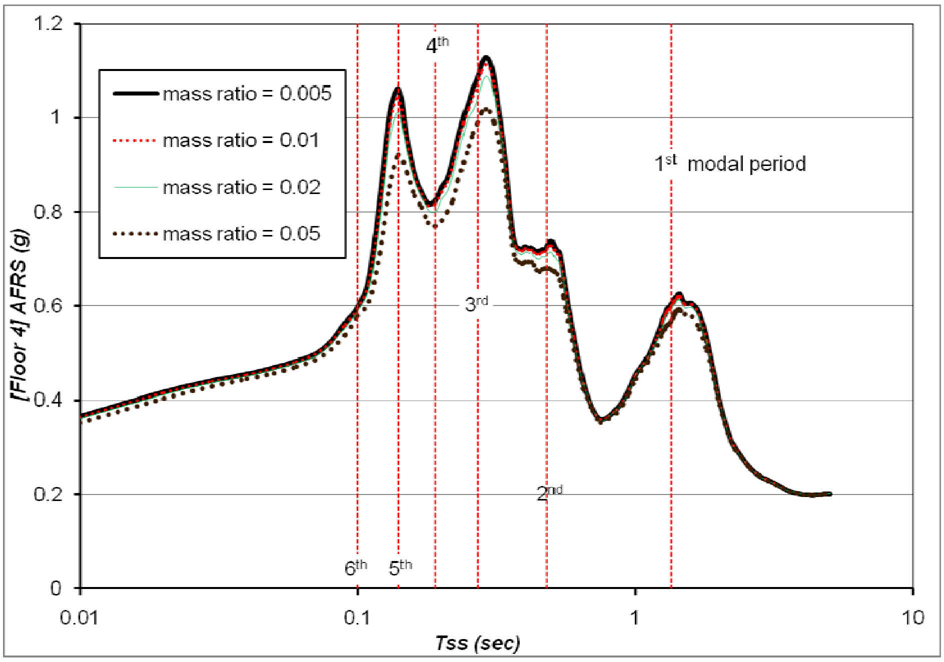

Figure 3: 6-story building mean AFRS at the 4th (middle) floor for different secondary system mass ratios.

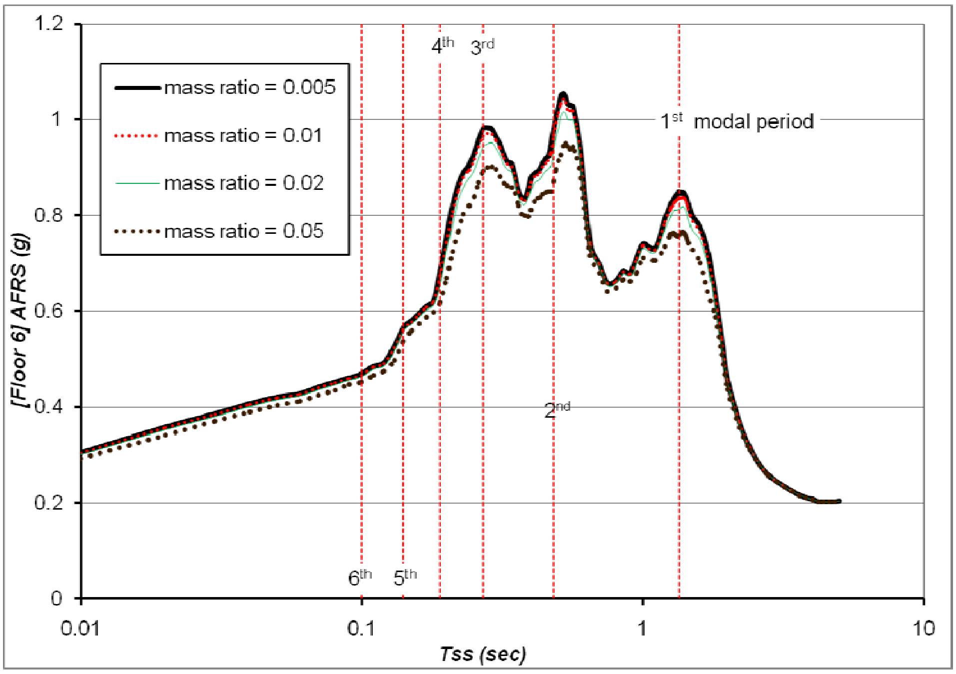

Figure 4: 6-story building mean AFRS at the 6th (top) floor for different secondary system mass ratios.

It may be realized from the figures that, in the six-story building, an increase in the mass ratio form 0.005 to 0.05 may decrease the AFRS values slightly in all of the three locations along the building height. For the other six buildings, similar mean AFRS have been obtained and such an overall decrease has been observed. To quantify the differences in the response spectra due to mass ratio changes and see how this parameter can generally affect the floor acceleration demand along the building height in all of the seven investigated buildings, the root mean square deviation (RMSD) of the AFRS has been calculated out of the mean AFRS values for the top, middle, and bottom stories. Figure 5 quantifies these effects, compared to the master mass ratio value in this study (i.e. 0.01), on the AFRS values.

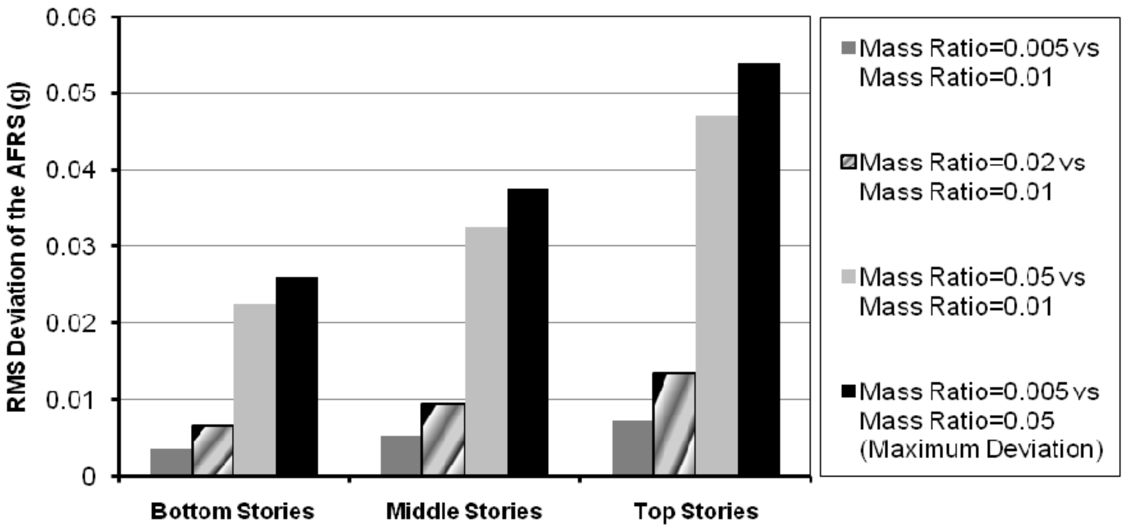

Figure 5: Root mean square deviation of the mean AFRS for different secondary system mass ratios.

As it may be seen in the figure, mass ratio has a relatively slight influence on floor acceleration response and the maximum deviation resulting from the two farthest mass ratio values, which are 0.005 and 0.05, reaches an average value of 0.04g. It may also be observed that going higher along the building height, the effect of mass ratio on floor acceleration demand increases.

3.2 Primary system damping ratio

Primary system damping ratio is another important factor whose effect has been investigated in this section. In this case, for each analysis, the secondary system is attached to one of the three different building locations (top, middle, or bottom floor) while the primary structure damping ratio equals one of three different values each time. The Primary system damping ratios which have been studied here are 0.02, 0.05, or 0.07. Note that, in this section, properties of the secondary system are those of the master model, i.e. a damping ratio of 0.05 and a mass ratio of 0.01. To investigate how the primary system damping ratio may affect the floor acceleration response, for each building, the AFRS have been obtained using the corresponding selected eight ground motions and the mean spectra have been used for the comparisons. Here, the mean AFRS are presented only for the 6-story building at the bottom, middle, and top floor for different primary system damping ratios as in figures 6, 7, and 8, respectively. The building modal periods have been also shown on the figures in vertical dashed lines.

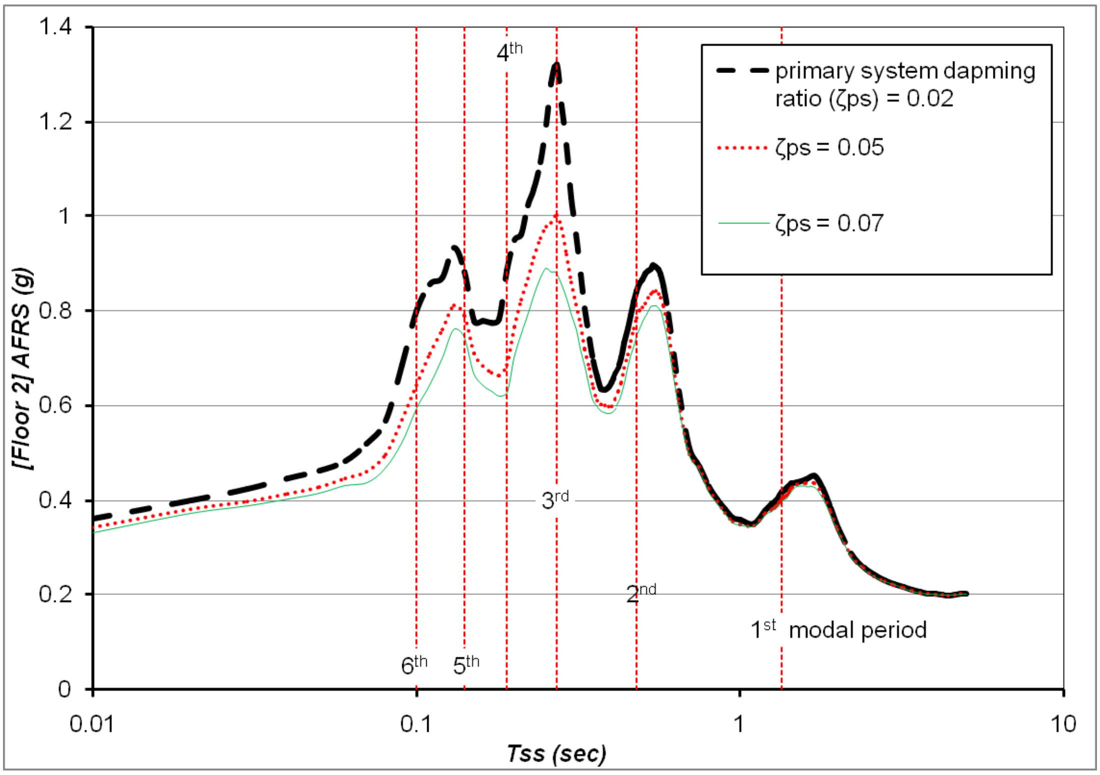

Figure 6: 6-story building mean AFRS at the 2nd (bottom) floor for different primary system damping ratios.

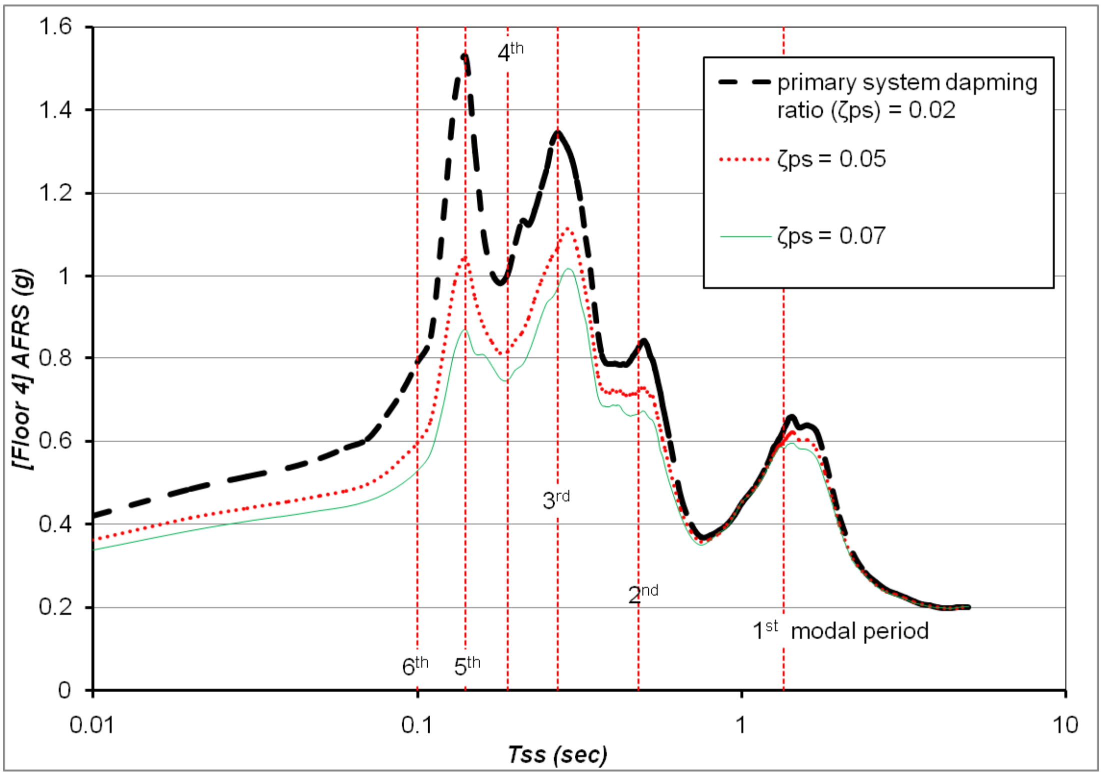

Figure 7: 6-story building mean AFRS at the 4th (middle) floor for different primary system damping ratios.

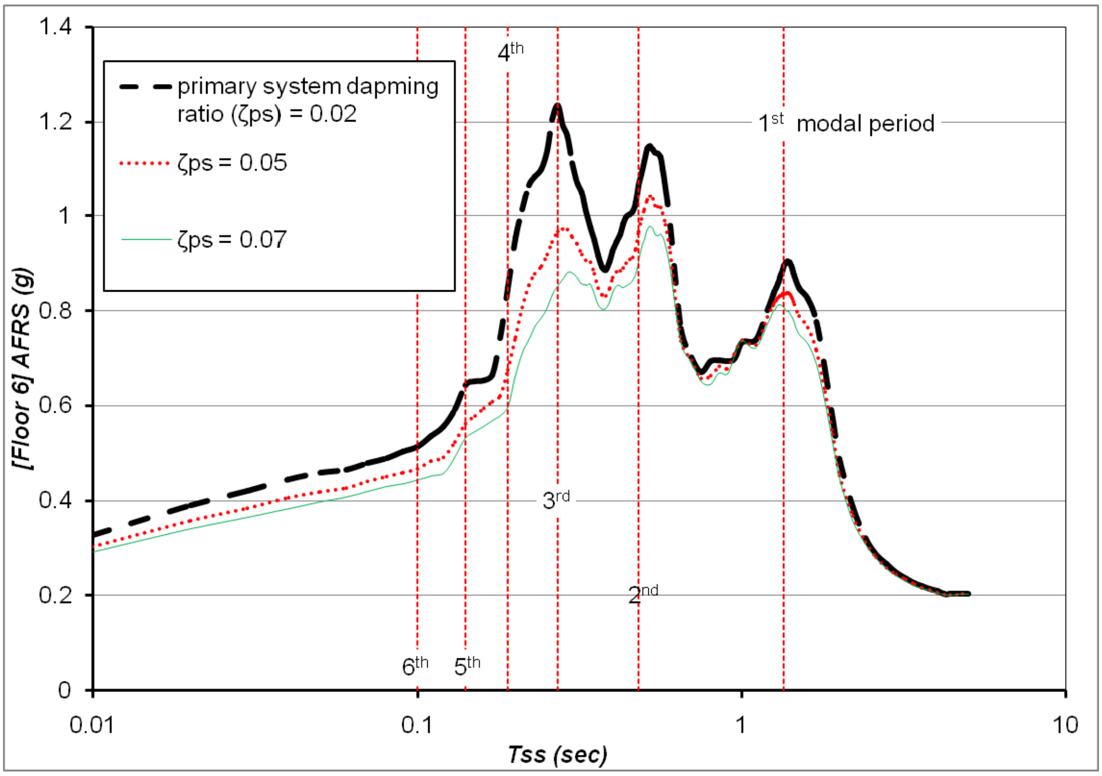

Figure 8: 6-story building mean AFRS at the 6th (top) floor for different primary system damping ratios.

One may realize from the figures that, in the six-story building, when the primary system damping ratio increases form 0.02 to 0.07 the AFRS values decrease. For the other six buildings, similar mean AFRS have been obtained and such an overall decrease has been observed.

Considering the respective curves for other buildings, this acceleration response attenuation becomes lower for the secondary systems with fundamental periods higher than 1 second. So, it seems that for such NSCs the primary system damping ratio has no influence on the responses. However, for other secondary systems, especially for those with a fundamental period close to one of the modal periods of the primary building, this effect is notable. To quantify the differences in the AFRS curves due to primary system damping ratio changes in all of the seven investigated buildings, the root mean square deviation (RMSD) of the AFRS has been calculated using the mean spectral values for the top, middle, and bottom stories. Figure 9 illustrates these effects, compared to the master primary system damping ratio value (i.e. 0.05).

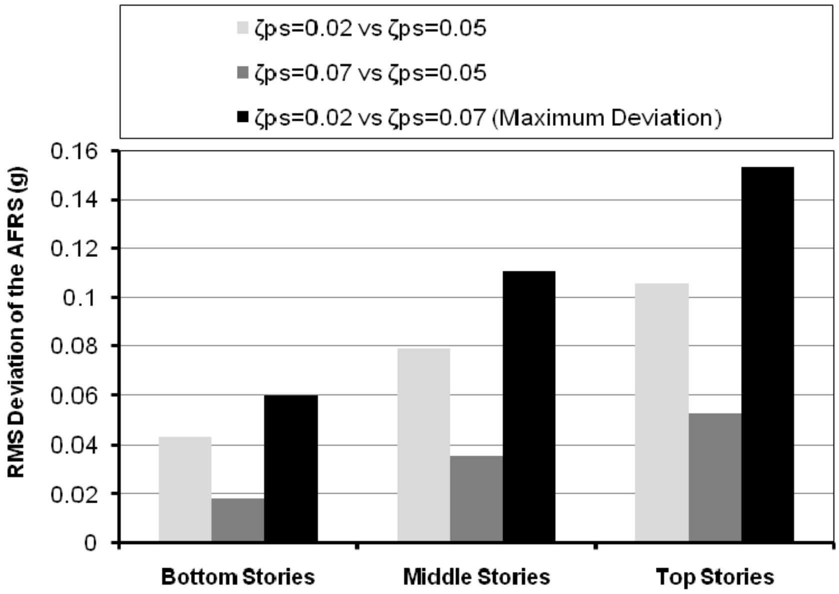

Figure 9: Root mean square deviation of the mean AFRS for different primary system damping ratios.

As seen in the figure above, the primary system damping ratio has a notable influence on floor acceleration response. The maximum deviation resulting from the two farthest damping ratios, which are 0.02 and 0.07, has an average value of 0.11g while this value in the top stories may reach an average of 0.15g. Again, it is observed that if the NSC is placed at higher locations along the building, the induced difference increases.

3.3 Secondary system damping ratio

In this section the effect of secondary system damping ratio has been investigated. Like the previous sections, NSCs with damping ratios of 0.05, 0.07, 0.10, or 0.20 are attached to one of the three different buildings floors. Other properties of the primary and secondary systems are those of the master model, i.e. a primary building damping ratio of 0.05 and a mass ratio of 0.01. The AFRS have been calculated using the corresponding selected eight ground motions for each building and the mean response spectra have been obtained. Again, only the 6-story building mean AFRS for different secondary system damping ratios are shown in figures 10, 11, and 12 with the building modal periods.

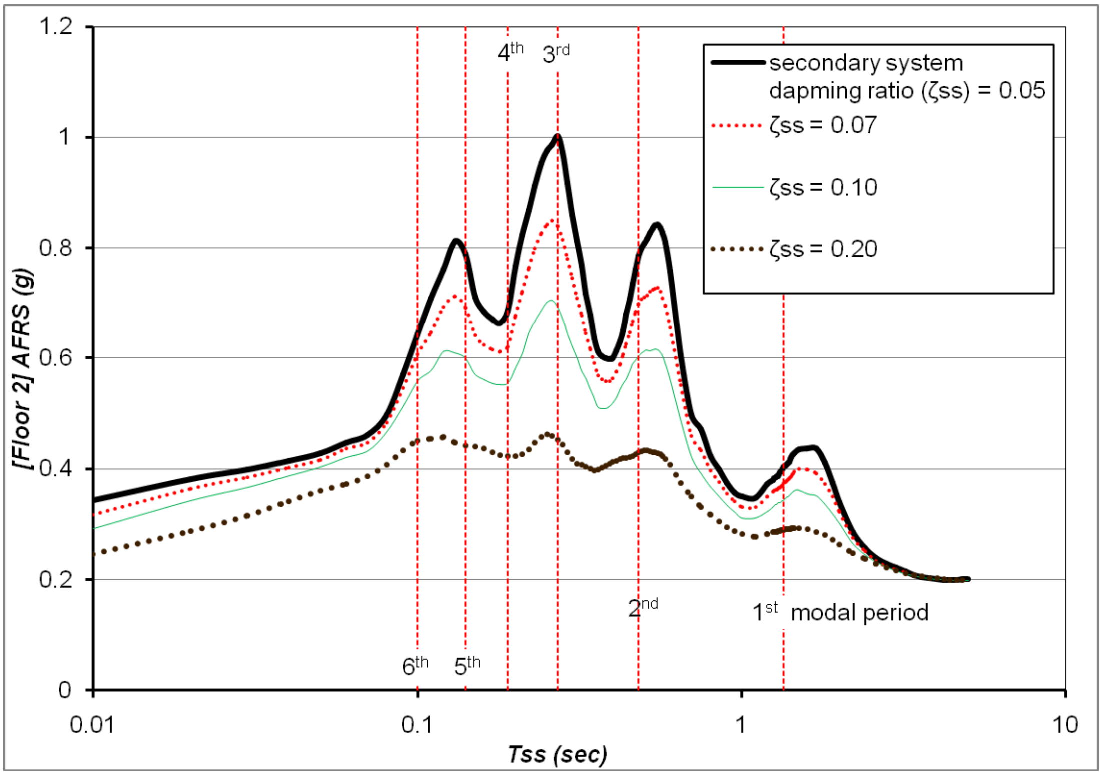

Figure 10: 6-story building mean AFRS at the 2nd (bottom) floor for different secondary system damping ratios.

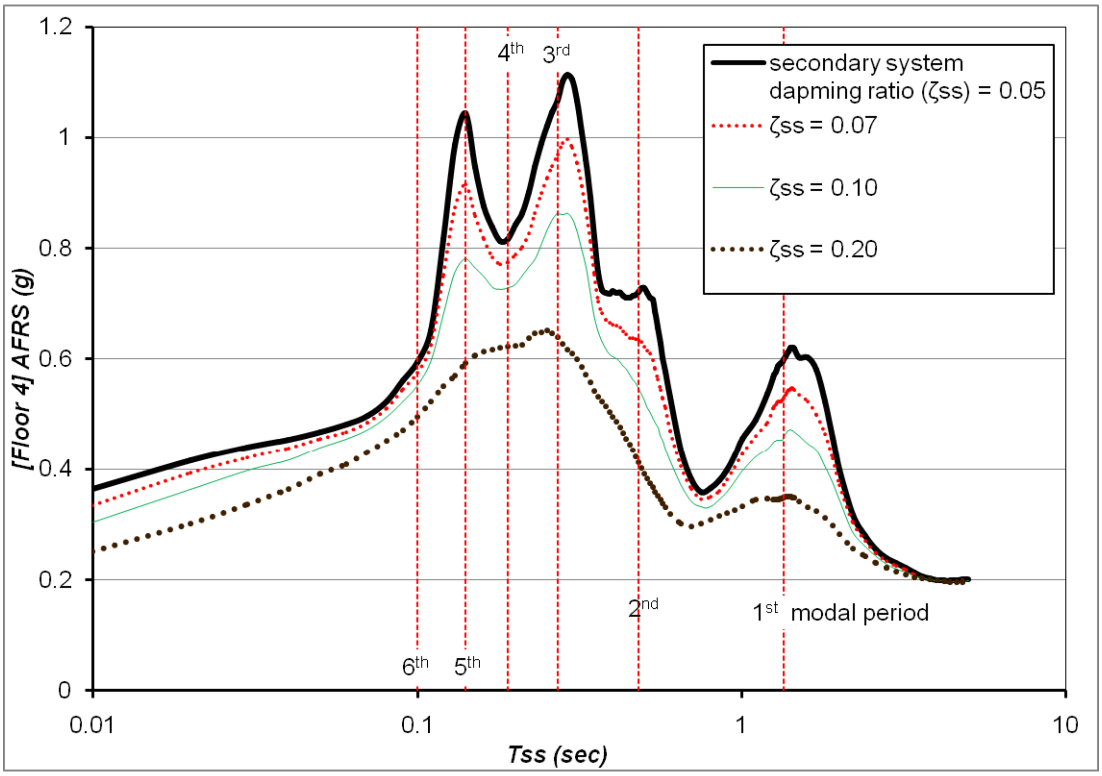

Figure 11: 6-story building mean AFRS at the 4th (middle) floor for different secondary system damping ratios.

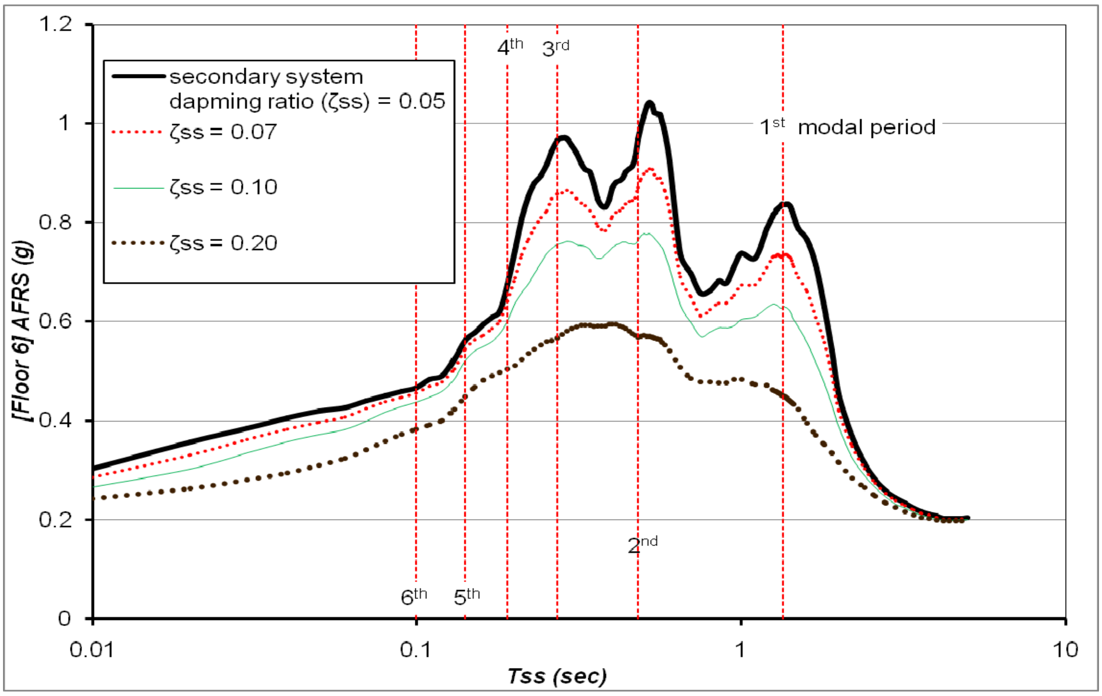

Figure 12: 6-story building mean AFRS at the 6th (top) floor for different secondary system damping ratios.

Figures 10 to 12 show that, in the six-story building, with an increase in the secondary system damping ratio form 0.05 to 0.20 the AFRS values in all of the three building height locations decrease. When the other buildings spectral values are taken into account, it may be inferred that the secondary system damping ratio is another factor which can affect the AFRS significantly. Also, one may notice that the spectral values are amplified when the secondary system is tuned with one of the building modal vibration periods. This amplification; however, lessens for more highly damped NSCs while the curves become smoother.

Figure 13 quantitatively illustrates the differences in the AFRS values caused by the secondary system damping ratio changes in all of the seven studied buildings. The RMSD of the mean AFRS has been calculated for the top, middle, and bottom stories and compared with the %5 master secondary system damping.

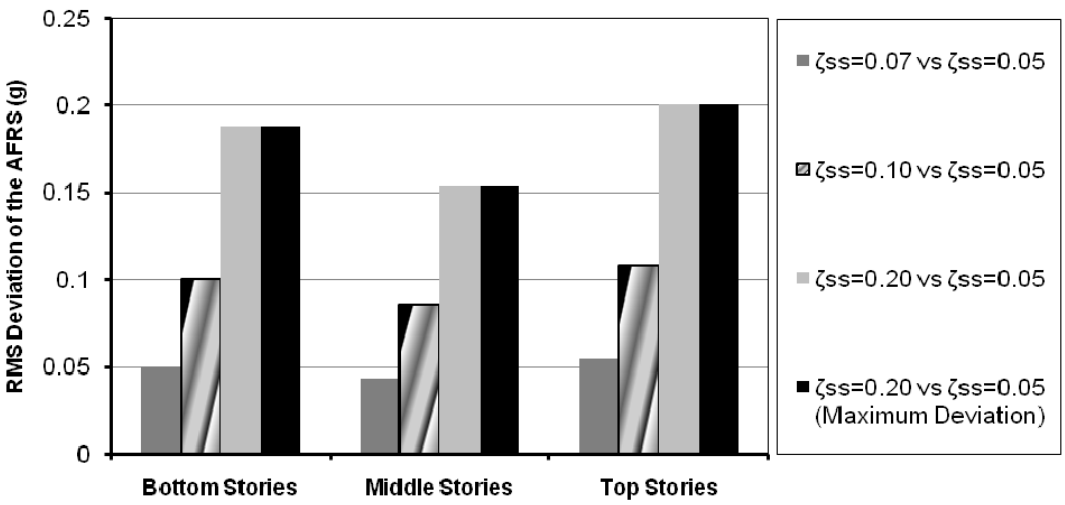

Figure 13: Root mean square deviation of the mean AFRS for different secondary system damping ratios.

Figure 13 shows that the secondary system damping ratio is another important parameter to affect the floor acceleration demand in buildings with an average induced deviation of 0.18g while comparing the %5 and %20 damped NSCs. The figure shows that the effect of secondary system damping ratio is almost the same along the building height and the component location seems to have no substantial influence on the responses.

3.4 Interaction

One of the most important factors which is, for the most part, neglected in different studies is the effect of the dynamic interaction between the primary and the secondary structures. In most of the studies the primary and the secondary systems are modeled and analyzed separately, i.e. at first the primary building response is calculated at the point of attachment of the NSC to the building and then this response is used as the input for the secondary system excitation. This way, the interaction is not taken into account.

In this section; however, it is intended to show how this interaction may affect the AFRS values. Thus, two groups of models have been developed: in the first group the interaction is neglected and the primary building has been separately modeled and its floor acceleration responses have been used as new inputs to calculate the secondary system responses; meanwhile, in the second group the effect of the interaction effect has been completely considered and in spite of the higher cost of the numerical analyses, the models have been set up such that the NSC is part of the whole model and the primary and secondary systems are in physical contact with each other (see Fig. 1 for example). Like the previous sections, three different building floor locations (top, middle, or bottom) of each building have been investigated and the mean AFRS have been obtained using the corresponding selected eight ground motions. The results for the 6-story building are as in figures 14 to 16. Other primary and secondary system properties are those of the master model.

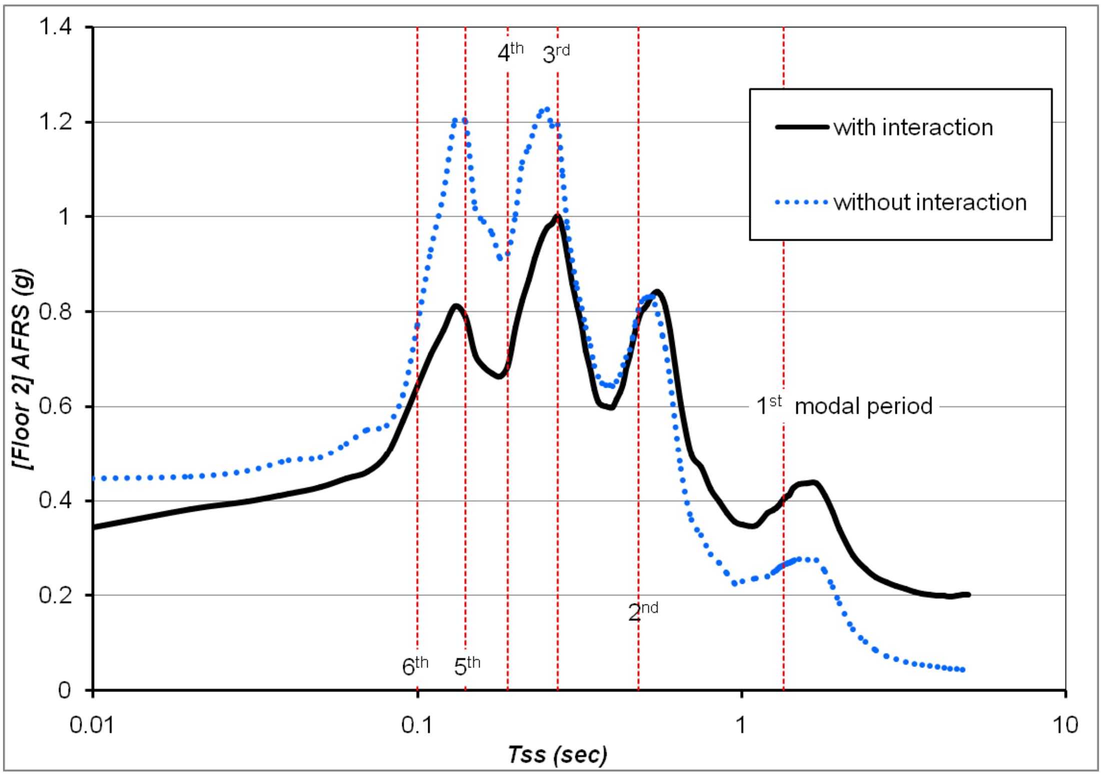

Figure 14: 6-story building mean AFRS at the 2nd (bottom) floor considering or without considering interaction.

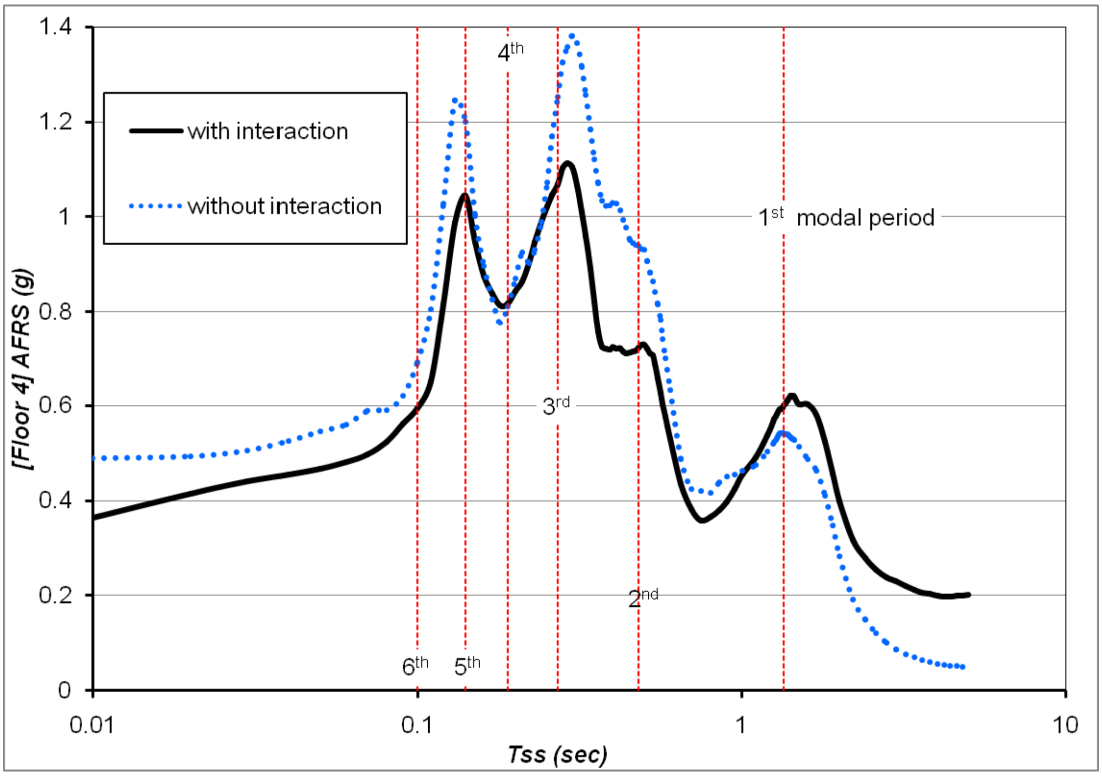

Figure 15: 6-story building mean AFRS at the 4th (middle) floor considering or without considering interaction.

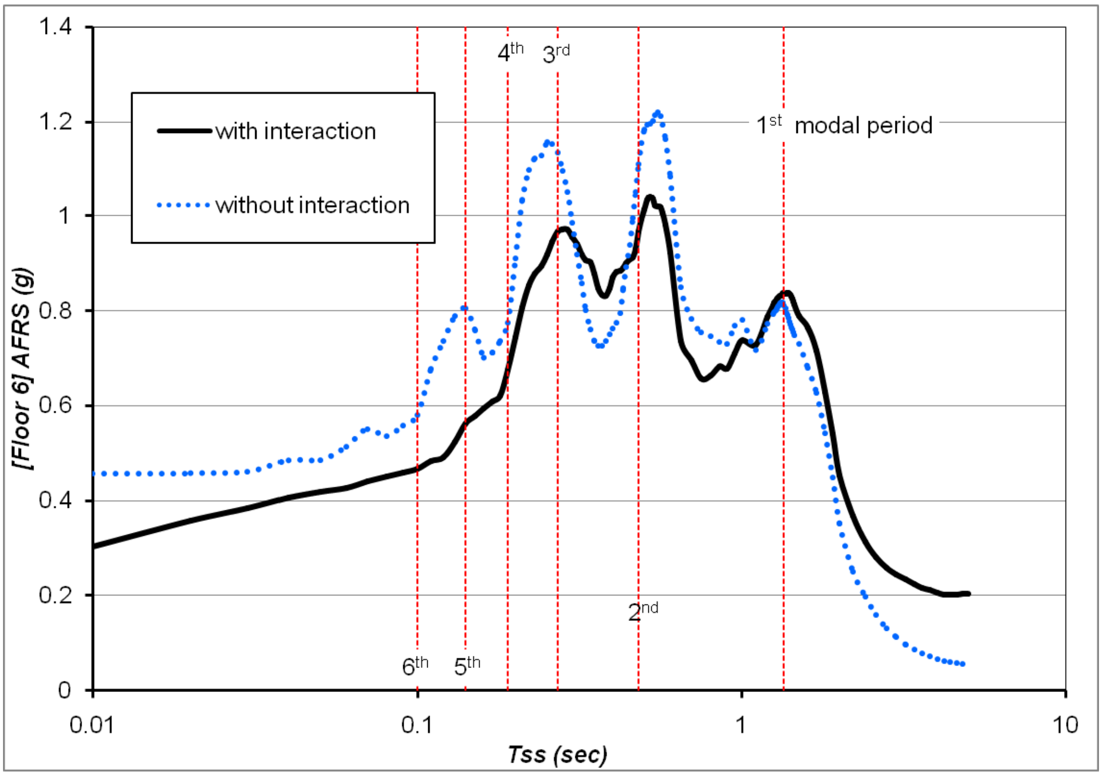

Figure 16: 6-story building mean AFRS at the 6th (top) floor considering or without considering interaction.

The recent figures and the similar figures obtained from the other six buildings show that considering the effect of primary-secondary system interaction to calculate floor acceleration demand in buildings has a very notable impact. As the figures indicate, for very flexible NSCs with higher fundamental periods, neglecting the interaction contributes to response underestimation. However, the response values can not be claimed to be higher or lower after consideration of the interaction, but, the induced difference or error is noteworthy and evident. In order to quantify this error in the response spectra and see how this parameter may generally affect the floor acceleration demand along the building height in all of the seven investigated buildings, the root mean square error (RMSE) of the AFRS has been calculated out of the mean AFRS values for the top, middle, and bottom stories as in figure 17.

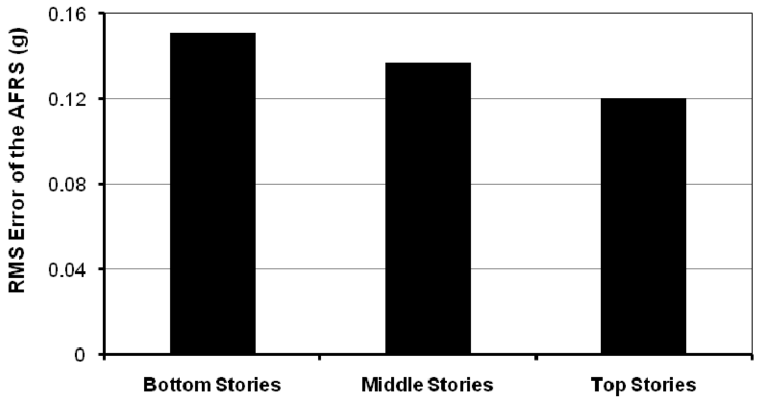

Figure 17: Root mean square error of the mean AFRS considering or without considering interaction.

Figure 17 also shows that at the upper building floors, the error caused by missing the interaction effect reduces. However, on the whole, these errors in the three studied portions are almost equal with an average value of 0.14g.

4 CONCLUSIONS

Based on this study, it is found that the mass ratio of the component, the degree of damping in primary or secondary systems, and the interaction between the primary and the secondary structures are crucial factors to be considered in seismic design of nonstructural components, which regarding them helps improve the precision of studies. Moreover, as it was illustrated in the proposed figures and results, in contrary to the assumptions of some current seismic codes (e.g. the Eurocode8 seismic provisions), not always does the fundamental vibration mode of the primary structure produce the highest floor acceleration responses. Also, it can be inferred that if such factors are included in seismic design codes, their level of conservatism can become more rational and proposed methods can get closer to reality.

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