16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 1025

Registration Code: S-N1464682517

THE EFFECT OF STORY MASS DISTRIBUTION ALONG THE HEIGHT OF MULTI-STORY MID-RISE BUILDINGS ON THE SEISMIC INPUT ENERGY

M. Minavand[1], M. Hosseini[2]

[1] *Ph.D. Student, Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran, Email: Minavand@safaiau.ac.ir*

[2] *Associate Professor, Structural Eng. Research Centre, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran, Email: hosseini@iiees.ac.ir*

Abstract

One of the effective factors on the amount of input energy of a multi-story building is the mass distribution along the height of building. In the present paper this issue has been discussed with regard to steel building with moment resisting frames. For this purpose three states of mass distributions, including uniform, ascending and descending along the building's height, were considered in regular buildings, having symmetrical plans and elevations. Three sets of buildings, including 6-, 9-, and 12-story ones were considered. The amount of total mass was assumed to be the same in all buildings of each set, implying the same total available architectural space in each set. In ascending and descending state the changes were applied by adding or removing one bay at either direction and at each side every two, three, and four stories, respectively in 6-, 9-, and 12-story buildings, so that in all cases the symmetry of the building was kept. The considered buildings in each state were designed first based on a conventional seismic design code (AISC LRFD method), and it was tried that the required sections of structural elements are selected in such a way that the amount of over-strength remains minimal. Then, three series of accelerograms corresponding to low-, mid-, and high-frequency were selected for time history analysis (THA). In each series the records were scaled according to the Iranian code for seismic resistant design of buildings (Standard No 2800 v4). Linear THA were performed for all buildings using the selected records, and the input energy was obtained in each case. Results show that uniform mass distribution along the building's height does not necessarily results in the minimal input energy, and for various frequency contents of earthquakes, different mass distribution should be investigated to achieve the minimal input energy.

Keywords: Input energy; Mass Distribution; Frequency content; Time history analysis.

1. Introduction

Seismic damage in a building is directly related to the amount of earthquake input energy. Therefore, identifying the factors which can affect the amount of input energy and the extent of their effects is of great importance for seismic damage control. One of these effective factors in case of multi-story buildings is the mass distribution along the height of building. It is clear that mass of the building and its distribution throughout its body is highly influential in the frequencies and modal shapes of the building structure, and therefore, affects the seismic response features, including the amount of input energy. However, most of multi-story buildings have uniform distribution of mass along their height, mostly for regularity and simplicity of the building structure, which is recommended by seismic design codes.

Non-uniform distribution of story mass along the building's height, and its effect on the seismic response of the building, has been taken into consideration by some researchers since late 90s. Al-Ali and Krawinkler (1998) performed a study on the seismic behavior of building structures with vertical irregularities [1]. In that study the effects of vertical irregularities in the distributions of mass, stiffness, and strength were considered separately and in combinations. The results of that research revealed that the seismic response of building structures is more sensitive to stiffness irregularities than to mass irregularities of similar magnitudes. Strength irregularities have much larger effects on the seismic response than mass or stiffness irregularities of similar magnitudes. Even small changes in story shear strengths may lead to a significant change in seismic demands.

Sadashiva and colleagues (2008) considered regular shear-type building structures of 3, 9, 15 and 20 story subjected to the 20 SAC Los Angeles 10 in 50 earthquake records [6]. In that study a probabilistic definition of the change in structural response due to different levels of vertical mass irregularity was provided which may be used as a design tool. They reported that vertical mass irregularity has the most effect on peak inter-story drift when the eccentric mass is placed either on the very top, or very bottom few story.

Hosseini and Kourehli (2009) conducted a study on using earthquake input energy as a target function for optimizing the seismic design of building systems with various mass distribution along building's height [2]. They showed that the mass distribution can have a significant effect on the amount of earthquake input energy.

Sarkar and colleagues (2010) proposed a new method of quantifying irregularity in stepped building frames, accounting for dynamic characteristics (mass and stiffness) [4]. Their proposed 'regularity index' provides a basis for assessing the degree of irregularities in a stepped building frame.

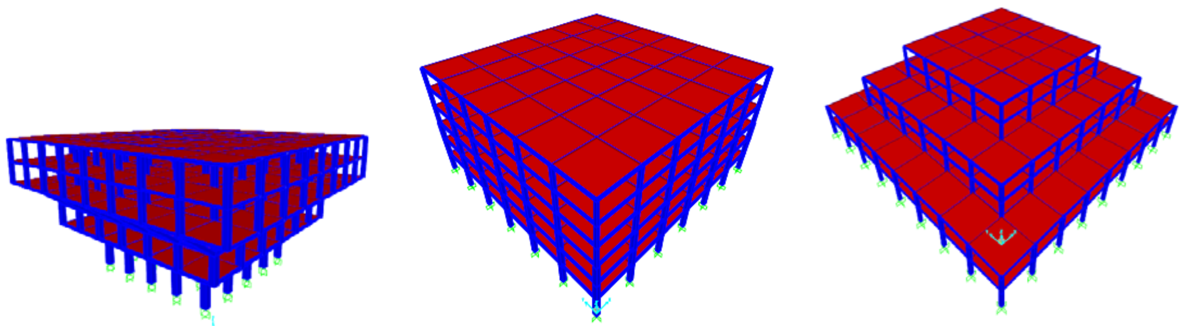
Pudjisuryadi and colleagues (2011) conducted a study on the seismic performance of structure with vertical set-back designed using partial capacity design, in which 10-story building having set-back at their fifth story were considered [5]. They recommended that special attention should be paid to the structural detailing at the place of set-back.

Varadharajan and colleagues (2014) examined the behavior of irregular buildings subjected to seismic excitation [6]. In that study, seismic response of the building frames with setback irregularity was determined. To achieve this purpose, building frames with different geometrical configurations of setbacks were modeled and analyzed using nonlinear dynamic analysis. They proposed simple equations to estimate the seismic response parameters such as maximum roof displacement, maximum interstory drift ratio, maximum plastic hinge rotation and collapse risk parameters.

In this paper the issue of mass distribution effect on the seismic performance of the building has been investigated in steel building with moment resisting frames. For this purpose three states of mass distributions, including uniform, ascending and descending along the building's height, were considered in regular buildings, having symmetrical plans and elevations. Three sets of buildings, including 6-, 9-, and 12-story ones were considered. The amount of total mass was assumed to be the same in all buildings of each set, implying the same total available architectural space in each set. In ascending and descending state the changes were applied by adding or removing one bay at either direction and at each side every two, three, and four stories, respectively in 6-, 9-, and 12-story buildings, so that in all cases the symmetry of the building was kept. The considered buildings in each state were designed first based on a conventional seismic design code (AISC LRFD method) [7], and it was tried that the required sections of structural elements are selected in such a way that the amount of over-strength remains minimal. Then, three series of accelerograms corresponding to low-, mid-, and high-frequency were selected for time history analysis (THA). In each series the records were scaled according to the Iranian code for seismic resistant design of buildings (Standard No 2800 v4) [8]. Linear THA were performed for all buildings using the selected records, and the input energy was obtained in each case. Details of the study are presented in the following sections of the paper.

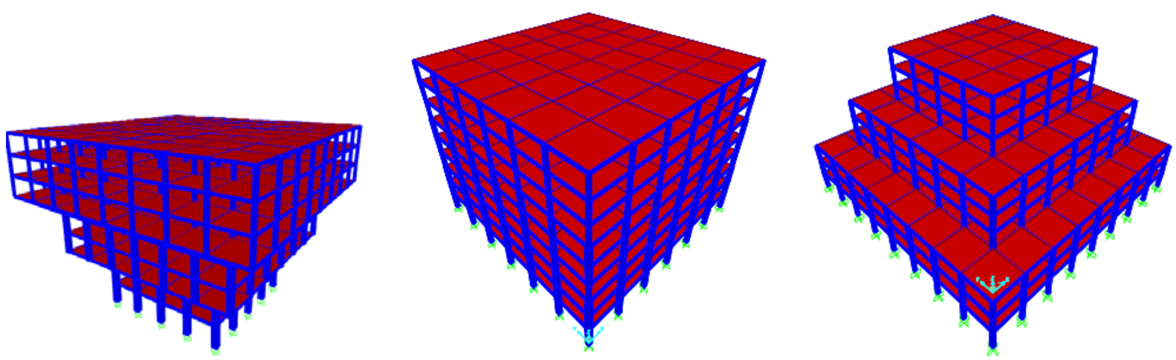
2. Considered Buildings with Various Mass Distributions along the Height

In order to study the effect of different mass distributions in the problem, three different mass distributions were considered in the structures namely ascending, uniform and descending in the height. To investigate the effect of the structure height, low-, medium-, and relatively high-rise buildings, including three sets of steel buildings with 6, 9 and 12 stories were considered, and three kinds of mass distributions were assumed in each set, as shown in figures 1 to 3.



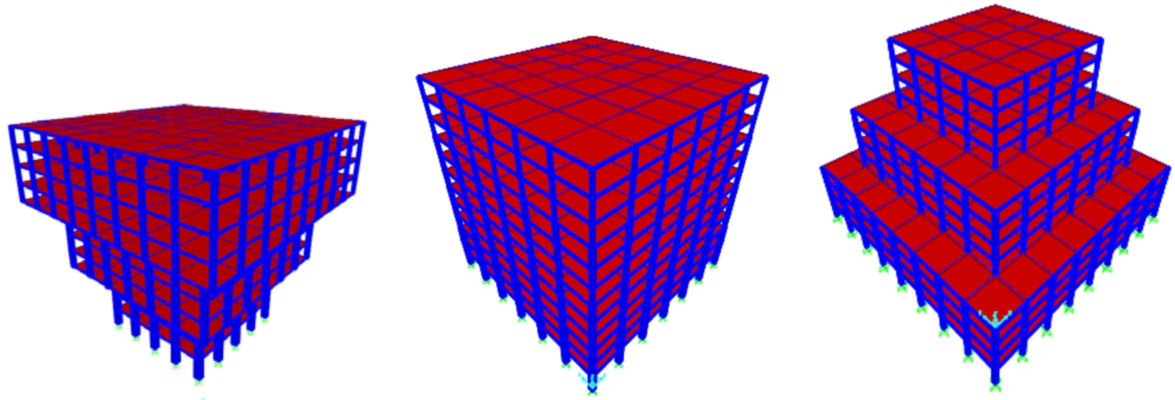
Ascending Uniform Descending

Fig. 1- Three states of mass distribution in height of the 6-story structure



Ascending Uniform Descending

Fig. 2- Three states of mass distribution in height of the 9-story structure



Ascending Uniform Descending

Fig. 3- Three states of mass distribution in height of the 12-story structure

The total mass of the buildings were the same in each case, implying the same total available architectural space in each set. The building's structures were all of moment resisting frame type, and it was assumed that the infill walls are separated from the structural members so that they cannot contribute in carrying the lateral loads. All frames spans were 5.5 meter, and all column sections were steel HSS and all beam sections were I shape. In order to design structural members, a spectral analysis was performed. In the design process it was tried to keep the amount of over-strength as small as possible. This means that the stress ratios of members were tried to be between 0.9 and 1.0. Tables 1 to 3 present the fundamental periods of the designed buildings with the three considered states of mass distribution, obtained based on the computer models of the buildings.

Table 1- Fundamental periods of 6-story buildings in three states of mass distribution

Mass distribution in height	T_1(sec)
Descending	0.92
Uniform	1.09
Ascending	1.20

Table 2- Fundamental periods of 9-story buildings in three states of mass distribution

Mass distribution in height	T_1(sec)
Descending	1.24
Uniform	1.45
Ascending	1.90

Table 3- Fundamental periods of 12-story buildings in three states of mass distribution

Mass distribution in height	T_1(sec)
Descending	1.35
Uniform	1.68
Ascending	2.34

It is seen in Tables 1 to 3 that the fundamental periods of the buildings are not only dependent on their height, but also in the state of mass distribution. In order to investigate the effect of mass distribution along the buildings' height on their seismic performance a series of time history analysis (THA) were conducted by using a set of selected earthquake records as described in the next section.

3. Ground Motions Selection and Time History Analyses of the Buildings

The first step for conducting time history analyses (THA) is selection of appropriate earthquake records. For this purpose, in this study three sets of earthquake records were selected, including low-, moderate- and high-frequency content from PEER ground motion data base. High-frequency records contained dominant period lesser than 0.5 sec (T<0.5), moderate-frequency records contained dominant period between 0.5 to 1.0 sec (0.5<T<1.0) and low-frequency records contained dominant period more than 1.0 sec (T>1.0). On this basis, nine earthquake records were selected, three ones for each frequency range. The characteristics of selected earthquake records are shown in Table 4 to 6 for each case of frequency contents.

Table 4- Characteristics of the selected low-frequency earthquake records

Event	**RSN**	**Station**	**Magnitude**	**PGA(g)**
Chi-Chi_ Taiwan	1411	TAP005	7.62	0.129
Chi-Chi_ Taiwan	1542	TCU117	7.62	0.123
Cheutsu	5103	IBRH07	6.80	0.059

Table 5- Characteristics of the selected mid-frequency earthquake records

Event	RSN	Station	Magnitude	PGA(g)
Kobe_ Japan	1110	Morigawachi	6.90	0.214
Loma Prieta	776	Hollister - South & Pine	6.93	0.370
Taiwan SMART1(40)	508	SMART1 M07	6.32	0.255

Table 6- Characteristics of the selected high-frequency earthquake records

Event	RSN	Station	Magnitude	PGA(g)
Cape Mendocino	830	Shelter Cove Airport	7.01	0.228
Irpinia_Italy-01	288	Brienza	6.90	0.219
Northridge-01	1023	Lake Hughes #9	6.69	0.216

Acceleration spectra of the selected earthquake accelerograms were developed by using Seimosignal software. Figures 4 to 6 shows the acceleration spectra for the three sets of selected earthquakes.

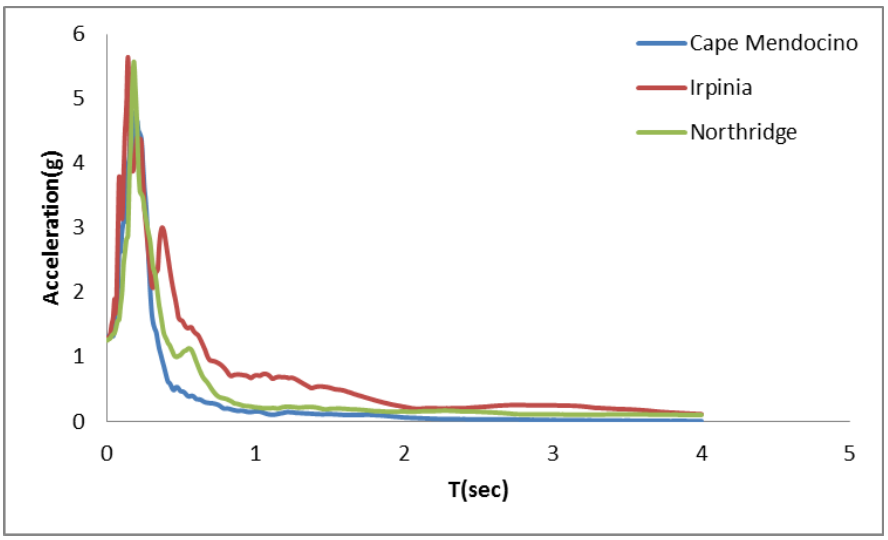


Fig. 4- Acceleration spectra of the high-frequency records

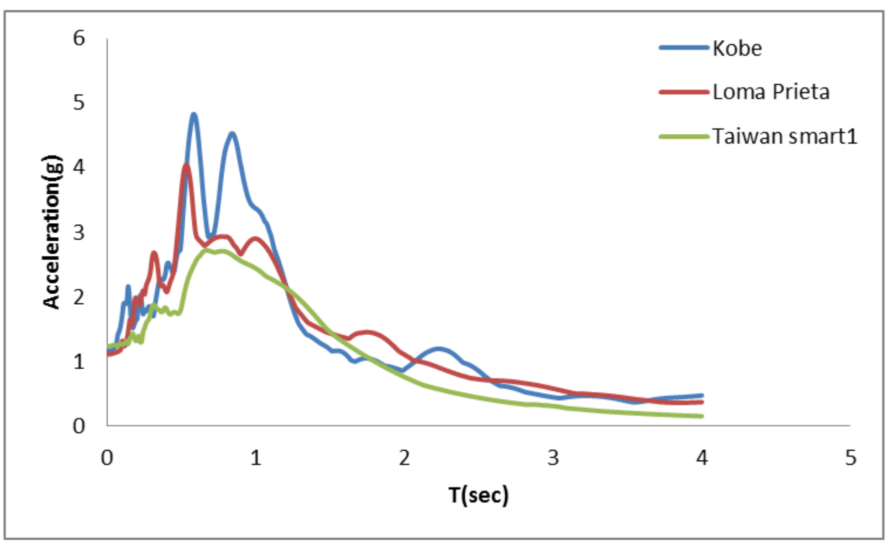


Fig. 5- Acceleration spectra of the mid-frequency records

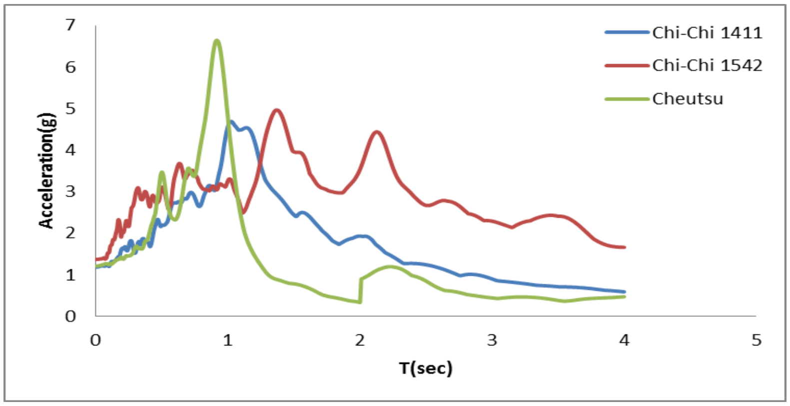


Fig. 6- Acceleration spectra of the low-frequency records

The selected records were scaled according to the Iranian code for seismic resistant design of buildings (Standard No 2800) [8] which require that in the range of 0.2T to 1.5T the SRSS response spectrum of records should be above the target response spectrum of the code. By using the scaled records the THA were conducted and the amounts of input energy were obtained in each case. As an example, the input energy variations in the 12-story building with uniform mass distribution subjected to Chi-Chi1411 earthquake record is shown in Figure 7.

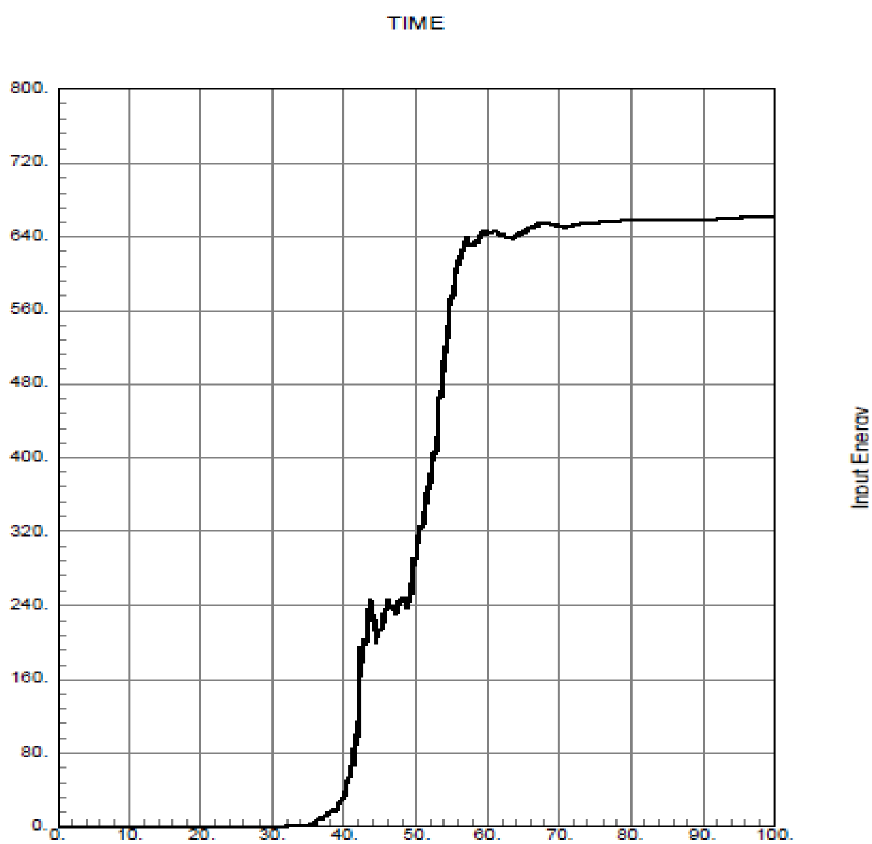


Fig. 7- Input energy variation for the 12-story building with uniform mass distribution subjected to Chi-Chi1411 earthquake record

The total amounts of the input energy to each building (at the end instant of each earthquake) for all of the considered buildings with different states of mass distribution, subjected to all scaled accelerograms are shown in Figures 8 to 10.

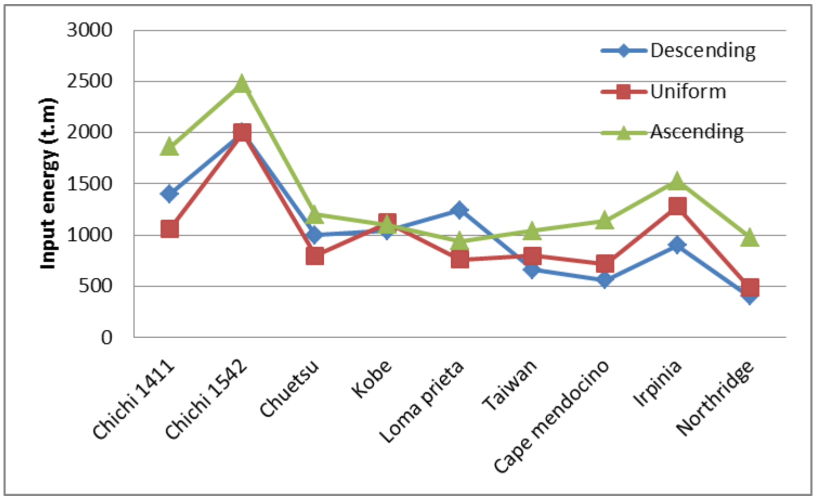


Fig. 8- The total input energy to the 6-story buildings with different states of mass distributions

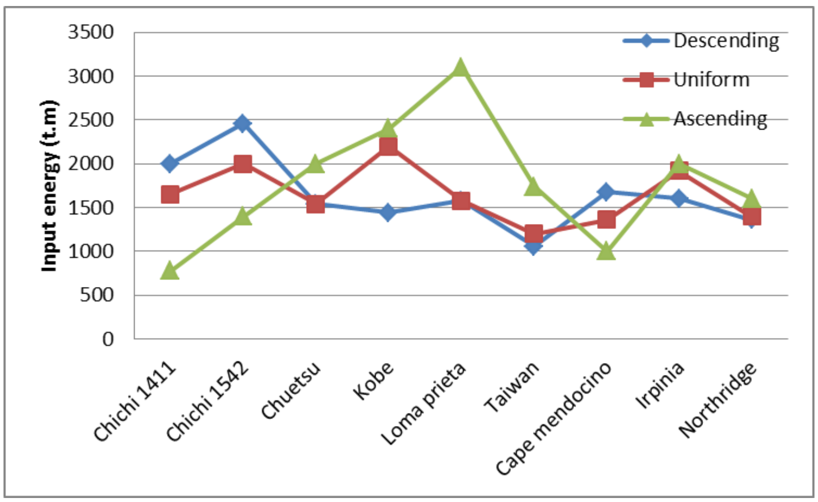


Fig. 9- The total input energy to the 9-story buildings with different states of mass distributions

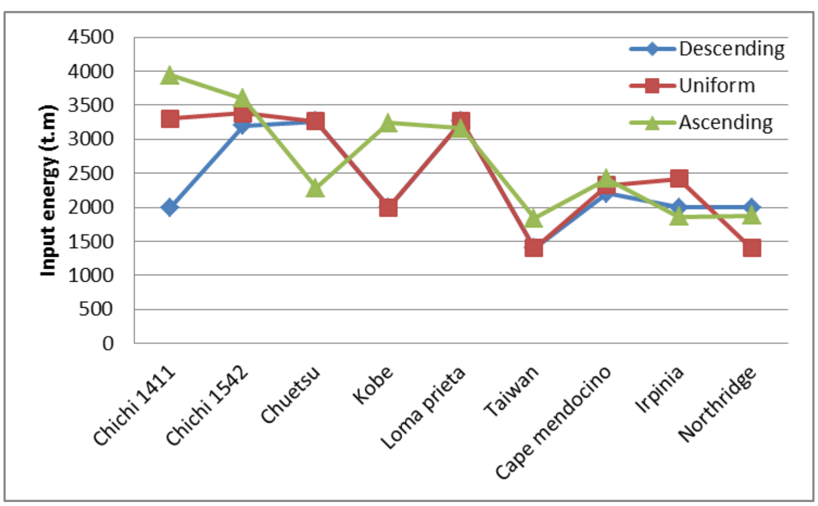


Fig. 10- The total input energy to the 12-story buildings with different states of mass distributions

It is seen in Figures 8 to 10 that the amount of total energy is quite dependent on the mass distribution states. For further investigation, the values of the maximum base shear forces of the considered buildings with different states of mass distributions, subjected to the selected earthquakes were calculated. Results are presented in Figures 11 to 13.

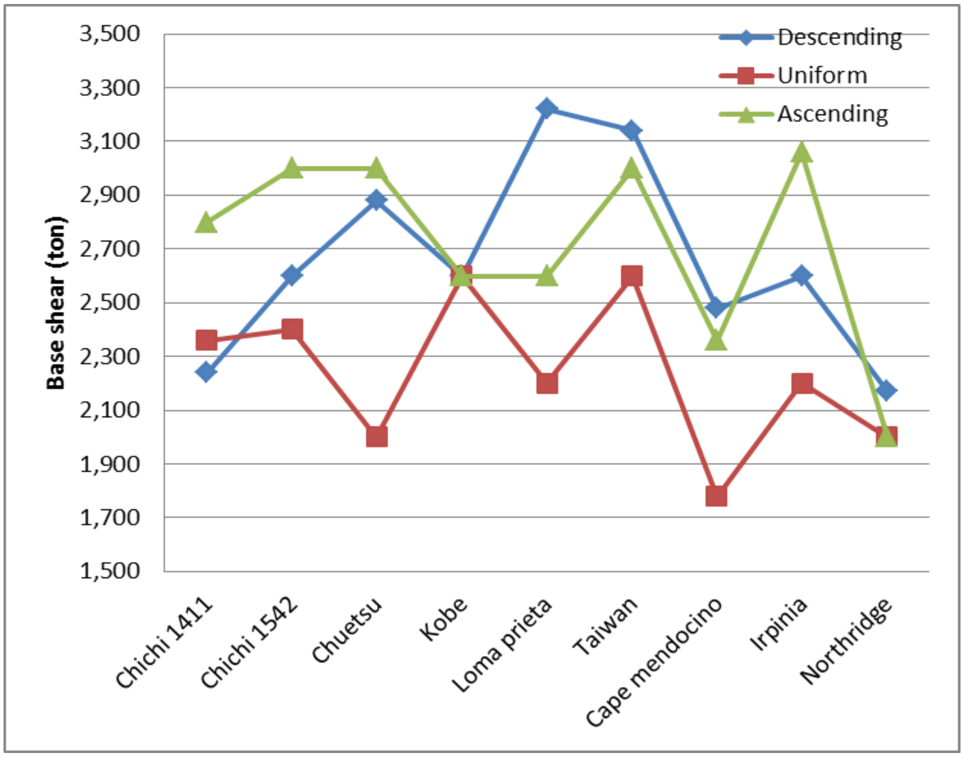


Fig. 11- Maximum base shear (ton) in the 6-story buildings with different states of mass distributions subjected to the selected earthquakes

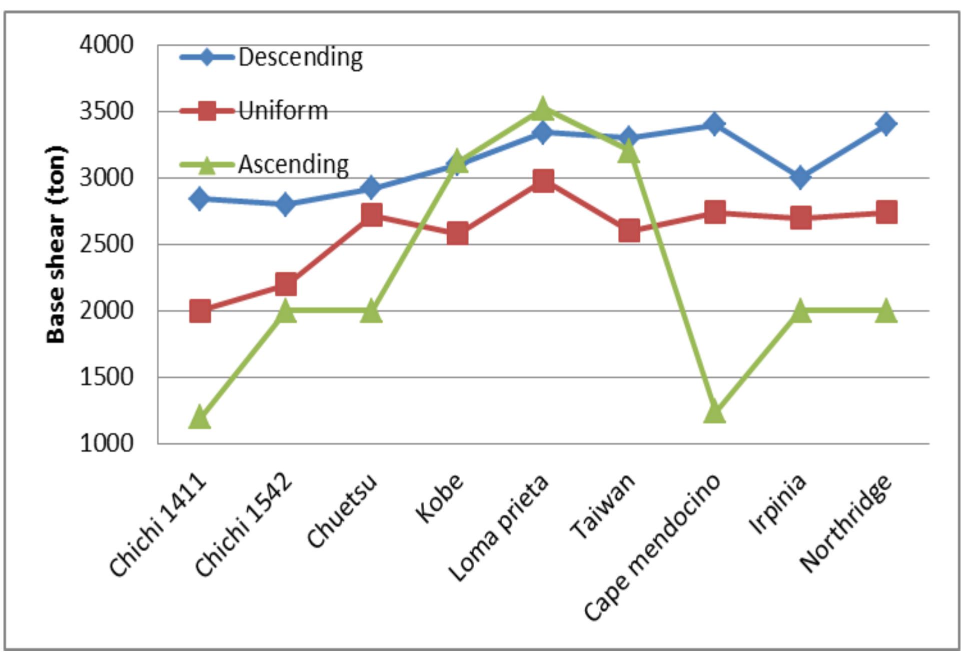


Fig. 12- Maximum base shear (ton) in the 9-story buildings with different states of mass distributions subjected to the selected earthquakes

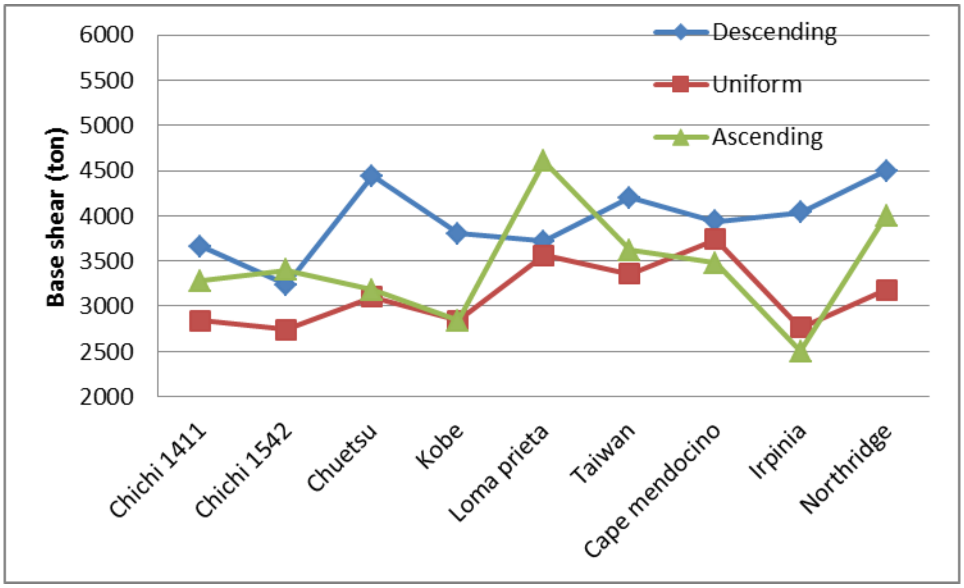


Fig. 13- Maximum base shear (ton) in the 12-story buildings with different states of mass distributions subjected to the selected earthquakes

It is seen in Figures 11 to 13 that the amount of maximum base shear force is also quite dependent on the state of mass distribution along the buildings' height.

4. Conclusions

Based on the numerical results obtained from the design of buildings with various states of mass distribution along the building's height, and also the THA conducted by using earthquakes with various frequency content, it can be concluded that:

- The fundamental periods of the buildings are not only dependent on their height, but also in the state of mass distribution.
- The uniform mass distributions which is the most common state used by structural engineers and architects in conventional buildings, does not necessarily results in the minimal input energy or base shear.
- For some earthquakes the ascending distribution of mass, and for some other earthquakes the descending distribution, results in the minimum seismic responses.

Finally, it should be noted that this study was limited to steel buildings with moment resisting frame structure, and linear behavior of the system. To get more general conclusions it is necessary to study other types of load bearing structural systems, including concrete buildings with shear walls.

5. References

[1] Al-Ali, A. A., & Krawinkler, H. (1998): Effects of vertical irregularities on seismic behavior of building structures. John A. Blume Earthquake Engineering Center.

[2] Sadashiva, V. K., MacRae, G. A., Deam, B. L., & Maunoury, C (2008): Vertical Mass Irregularity Effects on the Seismic Performance of Shear Buildings. 2008 NZSEE conference, New Zealand.

[3] Hosseini M, Mirzaei R, Kourehli S S (2009): A study on using earthquake input energy as a target function for optimizing the seismic design of building systems. Third International Conference on Modeling, Simulation and Applied Optimization, Sharjah, U.A.E.

[4] Sarkar, P., Prasad, A. M., & Menon, D. (2010): Vertical geometric irregularity in stepped building frames. Engineering Structures, 32(8), 2175-2182.

[5] Pudjisuryadi, P., Lumantarna, B., Teddy, S., & Wijoyo, H. (2011, Sep.): Seismic Performance Of Structure With Vertical Set-Back Designed Using Partial Capacity Design, Proceedings of the 3rd International Conference on EACEF (European Asian Civil Engineering Forum), Universitas Atma JayaYogyakarta, Indonesia.

[6] Varadharajan, S., Sehgal, V. K., & Saini, B. (2014): Seismic behavior of multistory RC building frames with vertical setback irregularity. The Structural Design of Tall and Special Buildings, 23(18), 1345-1380.

[7] ANSI, A. AISC 360-10 (2010): Specification for structural steel buildings. American Institute of Steel Construction. Inc.: Chicago, IL.

[8] BHRC (2005): Iranian code of practice for seismic resistant design of buildings (Standard No. 2800), Building and Housing Research Center (BHRC), Tehran, Iran.