Technical Note

Rational Suggestions for Vertical Component Requirement in 2800 Iranian Standard for Near-Fault Areas

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ABSTRACT

The validity of ASCE7-05 standard guidelines for considering the effects of vertical component of earthquake on the response of moment resistant steel buildings for use in Iranian code were re-evaluated. Three steel buildings and 9 near-fault recorded earthquake motions were considered. It was shown that both ASCE and 2800 standards overestimate the displacement of buildings and the vertical component of earthquake has no significant effect on the maximum displacement of stories. It has also been observed that using the ASCE equation for considering the vertical component of earthquake in far-fault areas can lead to an overestimation of axial force of columns, but in near-fault areas it can lead to a rather good estimation of axial force of columns. In light of this research, it can be found that loading patterns of Iranian code (with or without considering ASCE equation) can overestimate moment of columns and using the ASCE equation in Iranian code for near- fault analyses is recommended.

Keywords:
Vertical component;
Steel buildings;
Nonlinear analysis;
Time-history analysis;
Push-over analysis

1. Introduction

In some recent earthquakes such as Northridge (1994), Kobe (1995) and Bam (2003), it has been observed that the recorded vertical component acceleration of earthquake was equal to, or even greater than the horizontal ones. The influence of this component of earthquake on the overall seismic responses of steel structures has been a considerable interest to the professions for a long time.

Most of the analytical research have been focused on studies of reinforced concrete bridges [1] and frames [2], but some studies have also been related to steel structures [3-4]. In nearly all of these studies, researchers considered that the effects of vertical component of earthquake in near-fault areas is very extensive in both compression and tension, and can lead to serious uplift problems. Most of the researchers believe that the effects vertical component of earthquake has on the axial load of columns, acting as the members of moment frames and bridge piers, is very high [3-4]. Some of them claimed that this effect is about 30% of the horizontal case alone. Other researchers claimed that the effect of vertical component in higher stories of structures is stronger than lower stories [4].

Several design codes have tried to address the issue in many different, and hopefully, conservative ways. Despite this, many steel structures that were designed by those codes, suffered a considerable amount of damage during the Northridge (1994), Kobe (1995), and Bam (2003) earthquake. Severe cracks are developed in many structures during these earthquakes. Researchers mostly attribute these damages to the effects of welding and materials, and to design related causes.

The ratio of the peak ground acceleration of vertical component (*PGAV*) to the maximum horizontal one (*PGAH*), denoted hereafter as *G* can be used to study the influence of the vertical component on the overall seismic response behavior of structures. For normal earthquakes, based on Newmark's studies, this ratio is expected to be 2/3 [6]. In Table (1), different proposed vertical to horizontal ratios, based on maximum ground acceleration are shown. Therefore, it is important to reconsider the adequacy of the design provisions outlined in the model building codes of the vertical component of earthquakes.

Table 1. Vertical-to-horizontal acceleration ratios proposed by researchers.

References	V/H
Newmark [6]	2/3
Kawashima et al [7]	1/5
Ambrasays and Simpson [8]	1.75
Elnashai [9]	1.00
Mohammadioun and Mohammadioun [10]	0.75

In design codes, the effects of vertical component is considered generally (such as *ASCE7*-05) [11] or is considered limitedly (such as Iranian code) [5]. Obviously, if the vertical component is much stronger than what is usually considered normal, then the simplified code approaches may underestimate the seismic load, and the structures will not perform as intended.

This study specifically addresses two seismic design guidelines for buildings: The American Society of Civil Engineers (*ASCE*) Minimum Design Loads for Buildings and Other Structures [11], and the Iranian Code of Practice for Seismic Resistant Design of Buildings [5]. The design requirements in other codes are expected to be similar.

In the 2005th edition of *ASCE* standard a new requirement was defined to consider the combined effects of the horizontal and vertical components on the structural responses. *ASCE* suggests combining the effect of gravity loads and seismic forces with the factored load combinations as presented in the form of load combinations 5 and 7 in section 2-3-2, and the effect of seismic loads. "E", in these load combinations shall be defined as $E = E_V \pm E_h$ in order to consider the effects of both the horizontal (E_h) and vertical (E_V) components of an earthquake (section 12-4-2). But the vertical seismic load effect, E_V shall be determined according to the Eq. (12.4-4) of section 12.4.2.2 as $E_V = 0.2S_{DS}D$, where S_{DS} is the design spectral response acceleration parameter in short periods and D is the effects of dead loads [11]. The $0.2S_{DS}$ factor on the dead load is not intended to represent the total vertical response. The concurrent maximum response of vertical acceleration and horizontal accelerations, direct and orthogonal, is unlikely, and therefore, the direct addition of responses was not considered appropriate. But in the Iranian Code, the effects of vertical component of earthquake is limited to only horizontally cantilever beams, beams with considerable concentrated forces and beams with span larger than 15 meters [5].

In this paper the authors have tried to investigate whether the *ASCE* standard requirements for vertical component of earthquake in the Iranian Code is appropriate or not. To approach this aim, a time domain nonlinear finite element program for evaluation of the seismic responses of the buildings were used realistically by simultaneously applying the horizontal and vertical components of an earthquakes strong ground motions.

2. The Description of Buildings and Earthquakes

Three steel buildings representing different characteristics were considered in this study: a five-story, a seven-story and a ten-story building. They represent short, intermediate and rather tall buildings, respectively. The story height for these buildings is a constant of 3.0*m*, and the length of each bay is 5.0*m*. All three buildings are assumed to have rigid connections. These buildings were designed not to collapse when subjected to all 9 earthquake time histories. This will help to compare results, as will be further elaborated later. Buildings were assumed to be located in Tehran (Iran). These three buildings with different dynamic characteristics were subjected to 9 strong ground motions identified in Table (2).

3. Results and Observations

In order to analytically evaluate the effect of the vertical component of the seismic responses of the

Table 2. Strong motion earthquakes.

Earthquake	Station	PGA_H		PGA_V	(PGA_V/PGA_H)
		L	T		
Manjil	Abbar	0.41g	0.34g	0.32g	0.78,0.91
Avaj	Avaj	0.48g	0.51g	0.31g	0.65,0.6
Bam	Bam	0.77g	0.6g	1.1g	1.43,1.8
Silakhor	Chalan Choolan	0.43g	0.42g	0.55g	1.28,1.3
Tabas	Tabas	0.84g	0.85g	0.69g	0.82,0.82
Northridge (1)	Sepulveda	0.75g	0.93g	0.47g	0.63,0.51
Northridge (2)	Arleta	0.34g	0.31g	0.55g	1.62,1.75
Northridge (3)	Sylmar	0.6g	0.84g	0.54g	0.9,0.65
Northridge (4)	Tarzana	1.8g	0.99g	1.05g	0.58,1.06

frames, the following cases are considered:

- **Case 1-** Buildings were excited by horizontal components using nonlinear time history analyses (*NLTHA*) denoted as 2*D*;
- **Case 2-** Buildings were jointly excited by horizontal components of earthquake and vertical one by *NLTHA* denoted as 3*D*;
- **Case 3-** Buildings were analyzed under Iranian code load pattern by a full load push-over analysis, (hereafter denoted as Iran);
- **Case 4-** Buildings were analyzed by Iranian load pattern plus *ASCE* equation, suggested for vertical component of earthquake by a full load push-over analysis (hereafter denoted as *ASCE*).

The nonlinear response of the buildings was estimated for 5% of the critical damping ξ. All of these buildings were also subjected to static applications of the dead load as suggested in *ASCE* standard, and the corresponding responses are evaluated. For comparison purposes, the differentiate term were defined as:

$$E = \frac{Codes\ Specified\ Loads - Analytical\ Results}{Analytical\ Results} \quad (1)$$

A positive difference in Eq. (1) implies that the results of Code Specified Loads analysis are larger than the results of *NLTHAs* and a negative error in Eq. (1) implies that the results of Code Specified Loads analysis are smaller than the results of *NLTHAs*.

3.1. Maximum Story Displacements

As it can be seen in Figures (1) and (2):

1. Effects of vertical component of earthquake on the displacement of all buildings are quite negligible.
2. Displacements of Buildings under codes specified loadings overestimate the displacement of buildings. Only in the seven-story building, these patterns of loadings underestimate the displacement of building under loading of Bam record.
3. Using the *ASCE* equation suggested that considering the vertical component of earthquake has no effect on the maximum displacement of buildings.
4. By increasing the number of stories, maximum displacement overestimation was increased. In the ten-story building a large difference between the results of nonlinear dynamic analyses and code suggested that the obtained results are revealed.

3.2. Axial Force of Columns

Axial forces in corner, interior and exterior columns were studied. They are presented in Figures (3) and

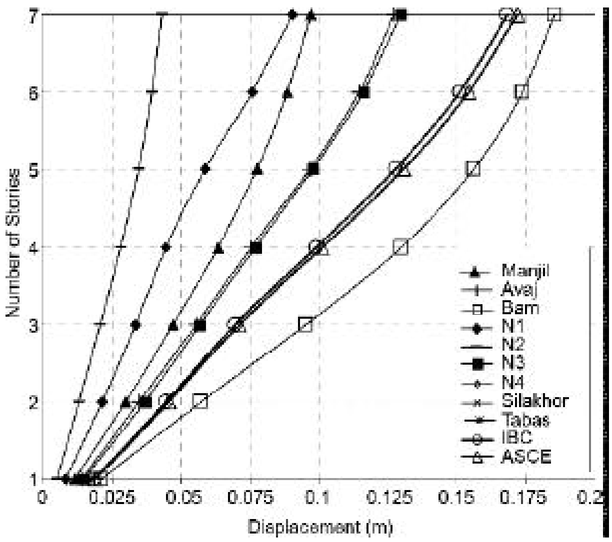

Figure 1. Maximum Story displacements in 10-story building.

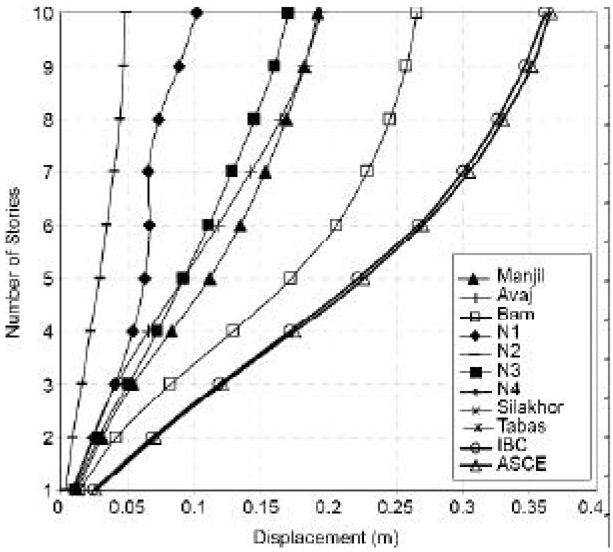

Figure 2. Maximum Story displacements in 7-story building.

(4). It can be revealed that only the 1st story of the 5-story building column force results were mentioned. In these figures, column labels are as follows:

1) Interior Columns: 6, 7, 10, 11
2) Corner Columns: 1, 4, 13, 16
3) Exterior Columns: 2, 3, 5, 8, 9, 12, 14, 15.

Axial force of columns for this project were compared and plotted in four categories:

1. Comparison of results obtained from 2*D* analysis by Iranian code analysis.
2. Comparison of results obtained from 2*D* analysis by *ASCE* analysis.
3. Comparison of results obtained from 3*D* analysis by Iranian code analysis.
4. Comparison of results obtained from 3*D* analysis by *ASCE* analysis.

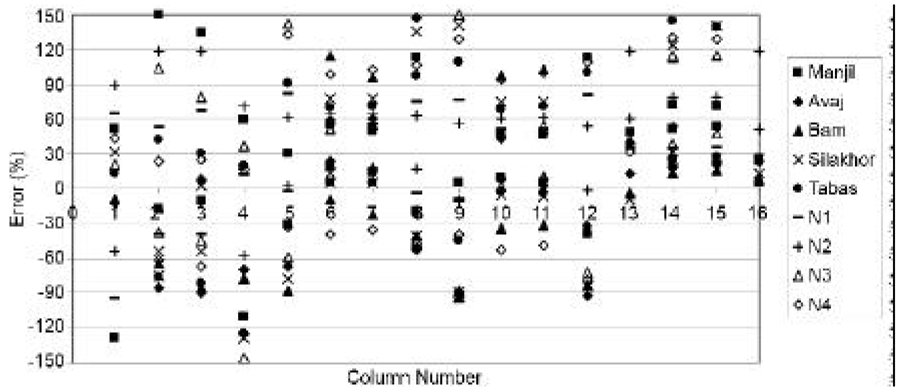

Figure 3. Comparison of axial forces obtained from 3D analysis by Iranian code analysis.

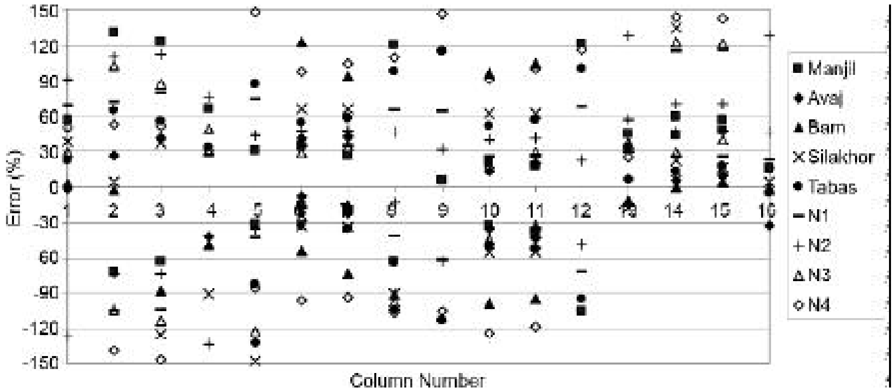

Figure 4. Comparison of axial forces obtained from 3D analysis by ASCE analysis.

All four cases of analysis were mentioned before in "Results and Observations" section.

This project shows that by considering the *ASCE*, equation axial forces of columns can be overestimated.

In comparison with 2-D analysis it can be found that:

1. In interior columns the Iranian code can estimate axial forces accurately.
2. In corner columns this code can estimate axial force of columns carefully.
3. In interior columns this code underestimates axial force of columns.

By adding *ASCE* equation to the Iranian code, it can be seen that:

4. This equation can overestimate axial forces of interior columns.
5. Using this equation can estimate axial force of columns carefully in corner columns.
6. Using this equation can lead to overestimation of axial force of columns in interior columns.

Generally, it can be said that using the *ASCE* equation for considering the vertical component of earthquake in far-fault areas can lead to a large overestimation of axial force of columns, and so using this equation in far-fault areas was not recommended.

In comparison with 3-D analysis from Figure (3), it can be found that:

1. In interior and corner columns, the Iranian code can not estimate axial forces accurately. In both categories of columns, this code underestimates axial forces of columns.
2. But in interior columns, the Iranian code in majority of those columns, underestimates axial force of columns.

By adding *ASCE* equation to the Iranian code, from Figure (4), it can be seen that:

3. This equation can overestimate axial force of interior and corner columns.
4. A majority of interior columns using this equation can lead to overestimation of axial force of columns. But in some columns, using this equation, underestimates axial force of columns. This underestimation is very small and can be neglected.

Generally it can be said that using the *ASCE* equation for considering the vertical component of earthquake in near-fault areas can lead to a rather good estimation of axial force of columns, and so using this equation in near-fault areas was recommended.

3.3. Moments of Columns

Moments of columns in corner, interior and exterior columns are presented in Figures (5) and (6). Due to the lack of space, only the 5-story building column moment results were mentioned. In these figures, the column labels and case analysis are presented as stated in previous sections.

It can be found that loading patterns of the Iranian code (with or without considering *ASCE* equation) can overestimate moment of columns. This overestimation in all three categories of columns (interior, exterior and corner columns) are nearly identical and when the effects of axial force and produce moment to design a column are combined, it can have a considerable effect.

4. Conclusions

In this research, several important observations were made. Both standards overestimate the displacement of buildings. It was shown that the vertical component of earthquake has no significant effect on the maximum displacement of stories.

The *ASCE* requirement in near-fault areas predicts the vertical effect of buildings with a rather good approximation. But in far-fault areas a large overestimation of vertical effect (about 35%) can be observed. Generally, it can be concluded that using the *ASCE* equation for considering the vertical component of earthquake in near-fault areas can lead to a rather good estimation of axial force of columns. Therefore, the use of this equation in near-fault areas in Iranian standard is recommended.

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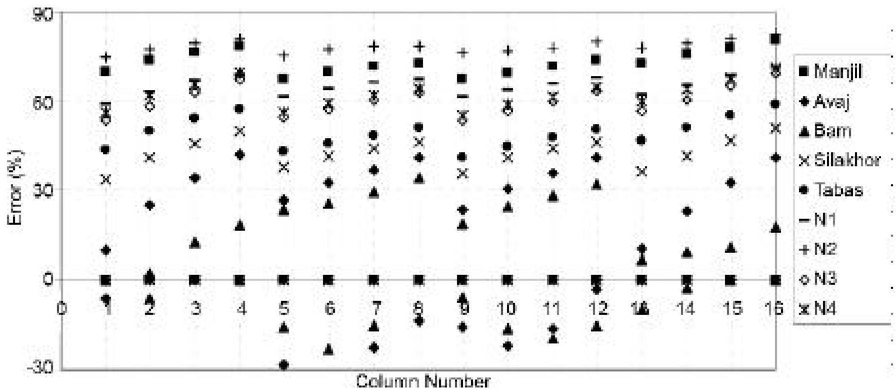

Figure 5. Comparison of moment of columns obtained from Case 2 by Case 3 of analysis.

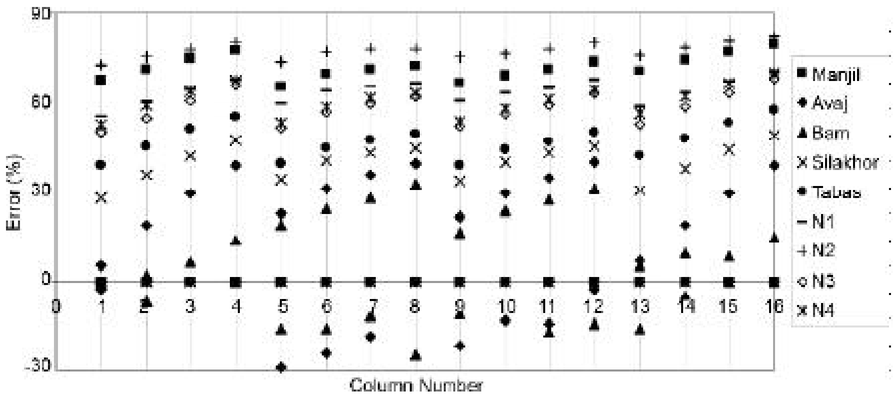

Figure 6. Comparison of moment of columns obtained from Case 2 by Case 4 of analysis.

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