# EFFECT OF TIME INTERVAL BETWEEN PEAK HORIZONTAL AND VERTICAL RESPONSE OF SEISMIC COMPONENTS ON THE BEHAVIOR OF RC BUILDINGS

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## ABSTRACT

Reinforced concrete buildings are generally subjected to three-dimensional earthquake ground motion. Recent studies, supported with increasing numbers of near-fault records, indicate that the ratio of peak vertical-to-horizontal ground acceleration can exceed the usual. With the considerable increase in near-fault strong ground motion records, and field evidence from earthquakes in two last decades, the considering importance of vertical ground motion has increased. Hence, in this study, a total of 7 records were selected to cover a range of frequency content, duration and amplitude. The specified arrival time was achieved by shifting the horizontal record along the time axis and original recorded V/H ratios were maintained throughout the arrival time study. The effect of arrival time interval on the period of vibration, ductility demand, and internal forces in structural members was studied by comparing against results from the case of the coincident vertical and horizontal peaks. The results show that the horizontal period is more elongated when the time interval is small. It can observe from results that mean ductility demand of the late arriving pulse motions is higher compared to the mean demand of the early arriving pulse motions. The results show that the contribution of vertical ground motion to the axial force variation tends to be reduced as time interval increases. Shear capacity of critical columns tends to decrease due to vertical ground motion. Changes in arrival time interval have no clear correlation with moments of critical columns and lateral displacement. The arrival time interval has a rather important effect on the shear capacity.

## INTRODUCTION

Earthquake as destroying phenomenon in most parts of the world threats buildings safety and lives of dwellers. By occurring near fault ground motion such as Northridge (USA), Kobe (Japan), Chi-Chi (Taiwan) that made a lot ruins lead to identifying the vertical components of earthquake and theory of researchers who believed in the past that a horizontal component of acceleration is always more than the vertical component of acceleration; therefore, it denies the most losses inserted on structures while earthquake is related to horizontal component of earthquake. Two known earthquakes of Parkfield (1966) and Pacoima Sanfernando (1971) are the big ones in California province and resource of research in identifying the nature of movement and heavy shakes near the center of earthquake. After these two earthquakes, the expression of fault was stated by Somerville et al. (1997).

Near fault ground motions such as Northridge USA, Kobe Japan, Chi-Chi Taiwan, occurring recently, have had many damages. We can refer to pulse-like movement with long- period at the beginning of record, fault rapture, acceleration and earth velocity being high, exerting hit to earth about earthquake near fault. The vertical component of acceleration is one of near filed earthquake characteristics. By increasing the distance from the center of earthquake, the vertical acceleration reduces high more than horizontal acceleration. Therefore, near filed his component is more than far field. From past ground motion records, it has been observed that peak vertical and horizontal pulse may arrive at a coincident time of a time-history. However, the effect of such simultaneous arrival of pulses on seismic response of RC buildings has not been investigated in detail. A few studies conducted so far have considered the arrival time of vertical and horizontal pulses and they come concluded that this coincidence influence the response of structures and cause high levels of distress in structural members. For this reason, it is important to study the relationship between the timing of peak response in the horizontal and vertical components of ground motion. Therefore, in this paper, the effect of time intervals between the arrival of vertical and horizontal peaks of given earthquake records are studied on the RC buildings.

## LITERATURE REVIEW

Many studies have beendone on vertical component of earthquake, and vertical component and its effects have been explored by many aspects. Di Sarno et al. (2011) worked on RC column evaluation exposed to vertical and horizontal movements registered in L'Aquila earthquake 2009. In this study, structural responses of RC members, exposed to horizontal and vertical movements of earth, have been explored. Results from inelastic dynamic analysis showed that changes in axial loads under combined movement of horizontal and vertical in pressure are considerable. In multi-story framed buildings, the response of central columns is influenced reversely from combined movements of vertical and horizontal movements. Shear forces are influenced by vertical movements. Such effects are function of previous loading in these columns. The reduction in stiffness and decline in resistance of RC members reduces by axial loads increase. More than that, it reduces by more axial loads; therefore, seismic shear demand reduces. It can be concluded that seismic designing and RC frame structure evaluation should consists both vertical and horizontal movements. Longinow and Rabinson (2005) in their paper under the title of earthquake forced movement on building frames by modeling high and low-rise structures of 4, 12, 24 and their analysis under Elcentero earthquake horizontal and vertical components concluded that shear force increases earthhquake vertical component, flexural beams, and column axial force; therefore, vertical component of earthquake  should be considered in building designing. Sadeghvaziri and Foutch (2001) also stated that vertical vibration leads to instability of columns. Palaskas (1996) after the earthquake of Northbridge in northwest of Los Angeles in 1944 explored the vertical components of earthquake on floors parking and concluded that earthquake lateral force inserted to these buildings were less than lateral force designed based on procedure UBC published in 1991, hence the reason of building damage was vertical component. In another research done by Kikuchi et al. (2000) about RC flexural frame with 5 floors, it was concluded that earth vertical movements solely structure columns haven't arrived to yielding, while the horizontal movement with lower PGA less than vertical movement, column arrived to yield. They found that earth slope has significant effect on building damages for vertical and horizontal movement combination that vertical movement wouldn't have significant effect on structures damage.

## CHARACTERISRICS OF SELECTED BUILDINGS AND CROUND MOTIONS

The selected C buildings in this research are 4, 7, 10, and 13 stories. Models have moment framed system with frame of 4-bays in length of 6m along X and length of 6 along Y and height of floors 3.2 m. The plan of models is shown in Figure 1.

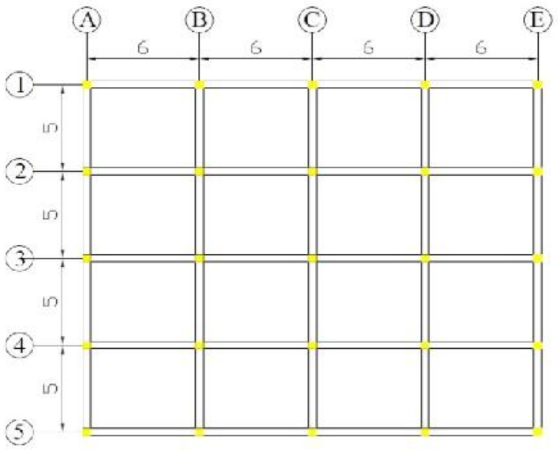


Figure 1. The plan of selected buildings

The study by Collier and Elnashai (2001) indicates that horizontal and vertical ground motion peaks can be coincident when source distance is less than 5 km. Within 25 km from the source, the arrival time interval for most records is less than 5 sec. In this study, a total of 7 records were selected to cover a range of frequency content, duration and amplitude. These records come from earthquakes having a magnitude ($M_W$) range of 6.2 to 7.3, and were recorded at closest fault distance of 0.0 to 7 km. Information pertinent to the ground motion data sets, including station, components of earthquake and peak ground acceleration (PGA) of vertical and horizontal components are presented in Tables 1.

Table 1. Near-fault ground motion database

| | Earthquake | Year | Station | Distance (km) | $M_w$ | PGA-$H_{max}$ (g) | PGA-$H_{min}$ (g) | PGA-$V_{ert}$ (g) |
|---|---|---|---|---|---|---|---|---|
| 1 | Gazli (USSR) | 1976 | Karakyr | 5.46 | 7.1 | 0.718 | 0.608 | 1.264 |
| 2 | Imperial Valley | 1979 | Bonds Corner | 2.68 | 6.4 | 0.755 | 0.588 | 0.425 |
| 3 | Loma Prieta | 1984 | Coyote Lake Dam | 0.30 | 6.2 | 1.298 | 0.711 | 0.388 |
| 4 | Kocaeli | 1992 | Erzincan | 4.38 | 6.8 | 0.515 | 0.496 | 0.248 |
| 5 | Landers | 1992 | Lucerne | 2.19 | 7.3 | 0.785 | 0.721 | 0.818 |
| 6 | Northridge | 1994 | Rinaldi Rec Stn | 6.50 | 6.7 | 0.838 | 0.472 | 0.852 |
| 7 | Kobe (Japan) | 1995 | KJMA | 0.96 | 6.9 | 0.821 | 0.599 | 0.343 |

## RESULTS OF ANALYSIS

In this paper, the vertical component of earthquake on column axial force, structural displacement and shear force were explored. Based on 2800 standard (2005), if 7 accelerograms or more are used, we can consider the average of them to control displacement changes and internal forces and so on. Therefore, as 7 accelerograms are used, in general comparison, the average of them has been used.

The most important case that vertical component of earthquake has significant effect is building's columns. In the previous researches, in near fault ground motions, the vertical component in comparison to the horizontal one is significant and failure happens in columns. Therefore, in this section, we explore the corner, internal and external axial forces of columns of the first floor of the building to see what effect vertical force has on volume axial force. The axial force of each column in vertical and horizontal components is compared with each other.

In figure 2, axial force of internal, corner, and external columns of 4, 7, 10, and 13 stories under the vertical and horizontal components are shown for 7 records of earthquakes. As it is seen in figure, the vertical component has the most effect on internal columns.

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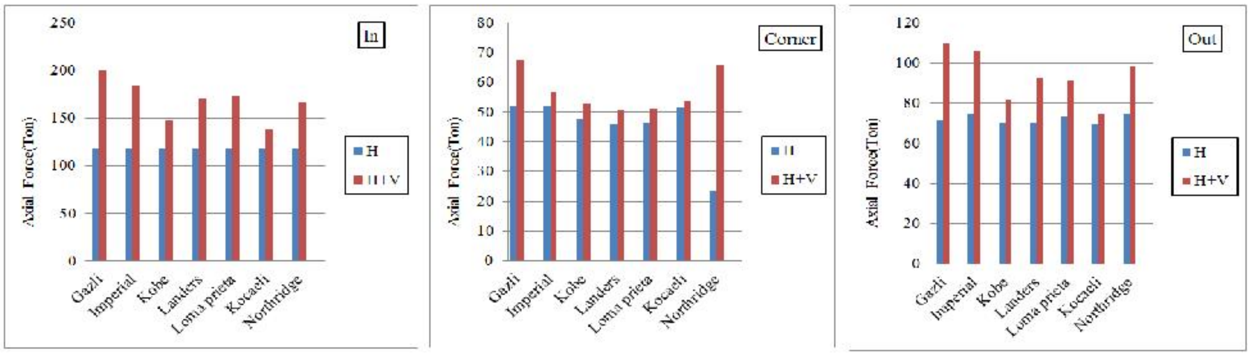
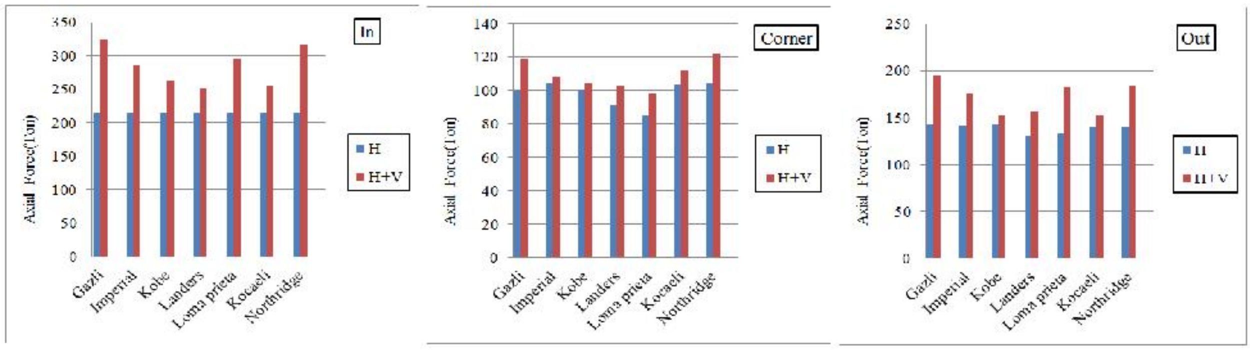
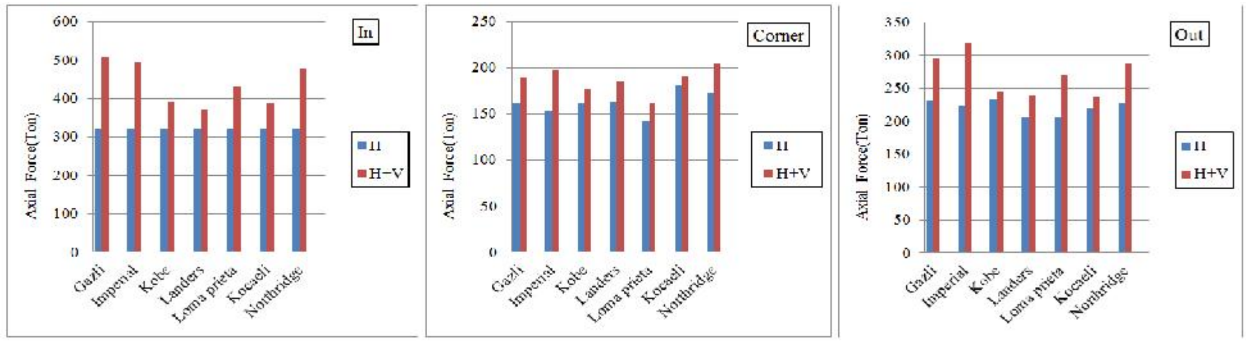
As it is seen in Figure 3, the average axial force of internal, corner, and external columns based on 2800 Code, internal columns in all models are more influenced by vertical components than two corners and external columns. Actually, it can be claimed that the vertical component has the least effect on the corner columns than the other ones.



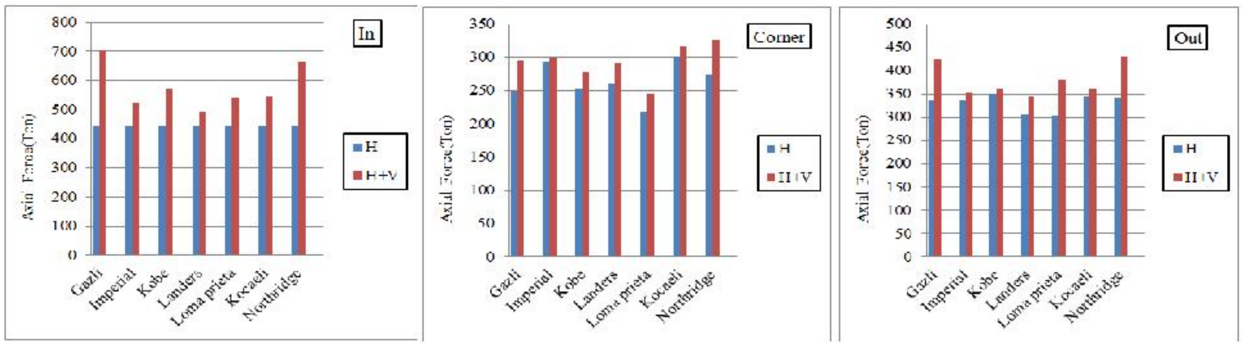

(a)




(b)

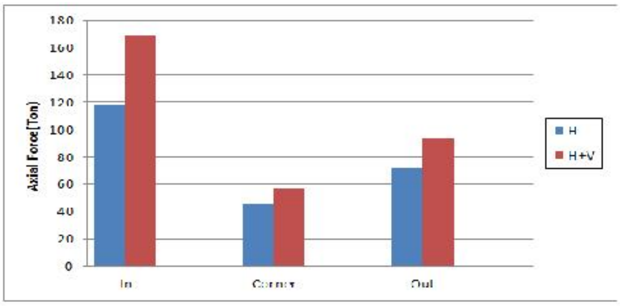



(c)

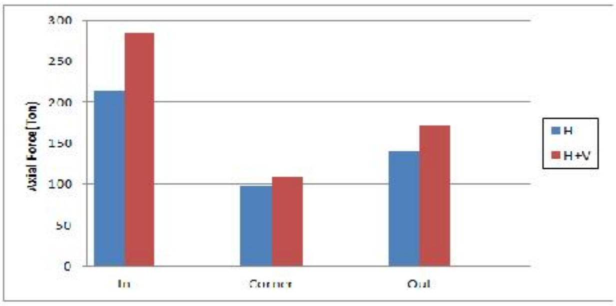



(d)

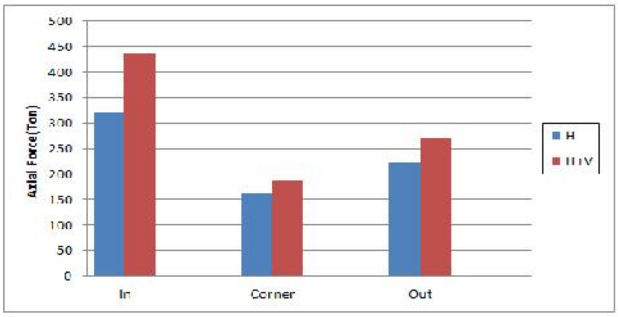
Figure 2. The maximum axial force of internal, corner, and external columns in various earthquakes models: a) 4-Story, b) 7- Story, c) 10- Story, and d) 13- Story



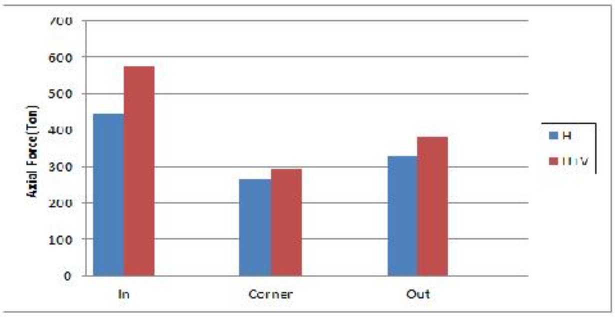

(a) 4-Story




(b) 7-Story




(c) 10-Story




(d) 13-Story

Figure 3. Average axial force of internal, corner, and external columns of models: a) 4-Story, b) 7- Story, c) 10- Story, and d) 13- Story

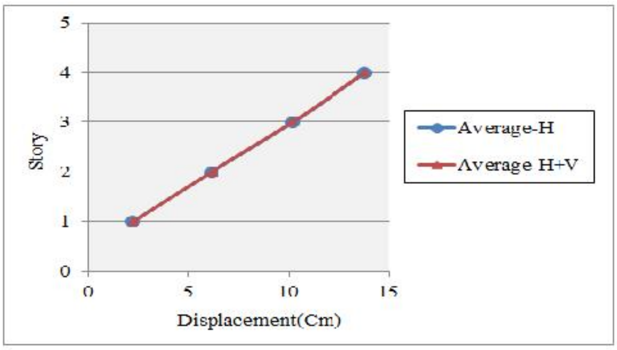
Table 2- Comparison of the axial force of buildings columns

| Story | Column | H (Ton) | H+V (Ton) | H+V to H (%) |
|---|---|---|---|---|
| 4-Story | In | 117.8 | 168.6 | 143.1 |
| | Out | 72 | 93.5 | 129.9 |
| | Corner | 45.7 | 56.9 | 124.7 |
| 7-Story | In | 214.3 | 287.4 | 132.7 |
| | Out | 139.2 | 171.5 | 123.2 |
| | Corner | 98.2 | 109.3 | 111.3 |
| 10-Story | In | 321.3 | 436.5 | 135.9 |
| | Out | 220.9 | 270.8 | 122.6 |
| | Corner | 161.8 | 186.2 | 115.1 |
| 13-Story | In | 443 | 576.7 | 130.2 |
| | Out | 331.4 | 379.5 | 114.5 |
| | Corner | 263.9 | 292.9 | 111 |

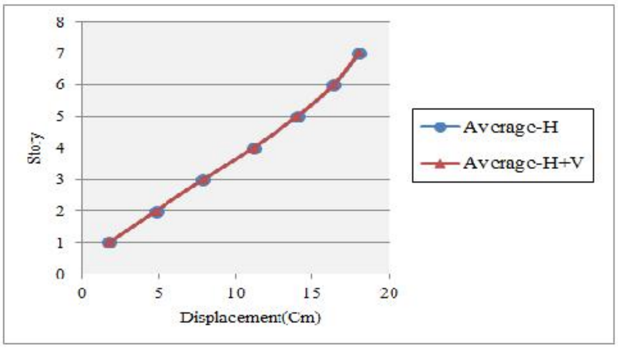
The lateral displacement of roof story is shown in Table 3 and lateral displacement of selected building under horizontal and vertical and horizontal effects are explored. According to Table 3, it is seen that inserting the vertical component of earthquake force have small effects on buildings 3, 7, 10, and 13 that is negligible. As it is seen, increasing in the number of floors influences on increasing the effect of vertical component on lateral displacement.

Table 3- Lateral displacement influenced by horizontal & vertical and horizontal components

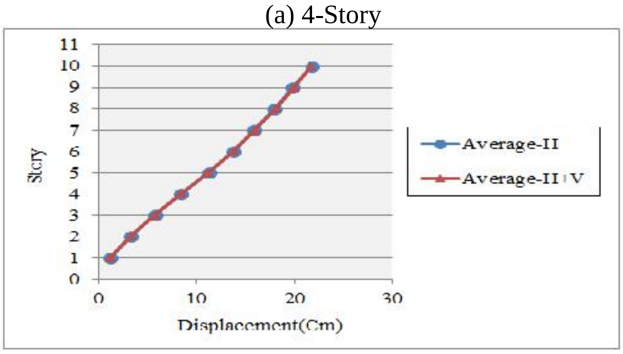
| Story | H (Cm) | H+V (Cm) | Difference H and H+v (Cm) | Difference H and H+v **(%)** |
|---|---|---|---|---|
| 4-Story | 13.84 | 13.8 | 0.04 | 0.3 |
| 4-Story | 18.7 | 18.05 | 0.02 | 0.11 |
| 10-Story | 21.77 | 21.65 | 0.12 | 0.55 |
| 13-Story | 26.06 | 26.23 | 0.16 | 0.61 |



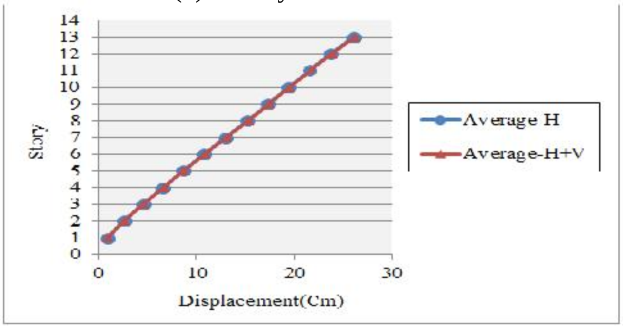

(a) 4-Story




(b) 7-Story




(c) 10-Story




(7) 13-Story

Figure 4. Average changes in lateral displacement for models: a) 4-Story, b) 7- Story, c) 10- Story, and d) 13- Story

Lateral displacement is shown in Figure 4, as it is seen, the vertical component doesn't have much effect on building lateral displacement. The results also show that the horizontal period is more elongated when the time interval is small. It can observe from results that mean ductility demand of the late arriving pulse motions is higher compared to the mean demand of the early arriving pulse motions.

## CONCLUSION

The aim of this paper was exploring the vertical component of earthquake on columns axial forces and changes in structures place in flexural frame. The buildings were modeled in 4, 7, 10, and 13 stories. Non-linear time history analysis were done by 7 accelerograms and the following results were obtained:

1) The vertical component of earthquake has significant effect on columns axial force and increases them. By comparing axial force of internal, corner, and external columns, it is seen that the vertical components lead to increase axial force significantly for columns near to the center of mass. The internal columns in all models are more influenced by vertical force than corner and external columns. It can be stated that the vertical component has the least effect on corner columns than the other ones.
2) As more the number of floor increases, the axial force difference among vertical and horizontal and horizontal components reduces more, because by increase the number of floors, the gravity loads increases more and leads to reduce sensitivity of columns axial force to seismic vertical effects.
3) As it was seen, the proportion of vertical and horizontal to horizontal component for lateral displacement in analyzed model is negligible. By increasing floors, this proportion for lateral displacement increases a little and consequently, vertical component effect is negligible.
4) Contribution of vertical ground motion to the axial force variation tends to be reduced as time interval increases. Shear capacity of critical columns tends to decrease due to vertical ground motion. Changes in arrival time interval have no clear correlation with moments of critical columns and lateral displacement. The arrival time interval has a rather important effect on the shear capacity.

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