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EFFECT OF EARTHQUAKE VERTICAL MOTION ON RC BRIDGE PIERS

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SUMMARY

In seismic design of RC bridge piers, the effect of earthquake's vertical motion is usually neglected, how ever the site measurements of ground motion during the previous earthquakes indicate that the vertical acceleration may exceed the horizontal acceleration.
In this paper a model of existing four span RC bridge is selected and analyzed using the finite element method. The dynamic linear and nonlinear analysis of model is carried out using different accelograms and under horizontal motion or simultaneously to the horizontal and vertical motions, and the time history of piers, axial and shear forces and also longitudinal displacements are studied. Results show the important variation of axial force, which could produce circumferential cracks in RC piers.

INTRODUCTION

Structural motions were the main cause of damage and failure of many bridges during the san Fernando earthquake of Feb 1971. This subject was studied by several researchers both analytically and experimentally and some of their results are illustrated in ATC reports. Most of previous researches which have been used in seismic codes for design of highway bridges only consider the horizontal motion of earthquake. For example the AASHTO code, only consider the two horizontal components of ground motion in analysis and design of highway bridge structures.
A lot of previous studies are limited to the study of the flexural behavior of RC columns under constant axial load. In 1980 Gibertsen and Moehle and in 1987 Abrams did some experimental research considering the variation of axial forces. The theoretical research done by Emori and Schnobrich (1978), and Keshavarzian and Schnobrich (1984) also consider the effect of alternative vertical forces on the response of RC frames. However, in these studies, the axial force variation was proportional to the moment and the lateral load, and its value was small compared to the balance load of the section.
In 1986 Kreger and Linbech studied the uncoupled variation of axial and lateral forces in an experimental test on a single column. They showed that the behavior of the column depends greatly on the time history of the axial load. The results of analytical study by Saadeghvaziri and Foutch (1988) also indicated that the non proportional variation in axial load is not just another parameter to be considered in the framework of current approaches.

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The uncoupled variations in axial and lateral load prevail when structures are under the combined effects of vertical and horizontal earthquake motion. The non-proportional fluctuation in axial force have significant effect on post-elastic cyclic response of RC columns, [1] and the hysteresis loops are very unstable and asymmetric.
In 1991 Saadeghvaziri and Foutch have reported that the variable forces induced by the vertical motion on the abutments are not included in seismic codes. For major earthquakes, the intensity of these forces can be so high that the compressive forces are as large as three times of the dead load. Also a great tensile axial load is generated.
Field observations indicate possibility of compressive over stressing or failure due to direct tension. Vertical motion may induce failure in shear and flexure, and the moment capacity and ductility of RC columns is reduced (Elnashai 1996).
Experimental and analytical studies performed by Ishikawa [4] about reappearance of circumferential crack on RC piers during Hyogoken-Nanbu earthquake indicate large positive inertial force which cause tensile force and circumferential creak in RC piers.
The steel jacket reinforcement is effective to prevent these cracks, while the inner reinforcement bars could not be effective (Ishikaua 1999). [5]
Vertical failure caused change of final failure collapse in some of the studied piers from flexure case to sever diagonal shear failure. Due to vertical motion, ductility level of piers decrease and the included plastic strain increase, (Machida 2000) [6].
A new program of research was done on 186 strong motion records from 142 earthquakes with Ms>5.8 and d<15Km, mainly from North America (72%). The results show that the ratio of the maximum vertical ground acceleration to maximum horizontal acceleration for strike-slip and normal earthquakes are 0.73 and 0.61 respectively.

MODEL OF STUDY

In this research, a four spans existing reinforced concrete bridge as shown in figure 1 is selected as the model of study. Each pier consists of three columns bent spaced 4 meters. Every column has a circular cross section of 1.2 m diameter and 25 steel bars of 32mm.
The longitudinal bars are confined by 2×14 mm spiral bars with a 75 mm of space at the end parts, and 125 mm of space at central part. The material properties are shown in table1.

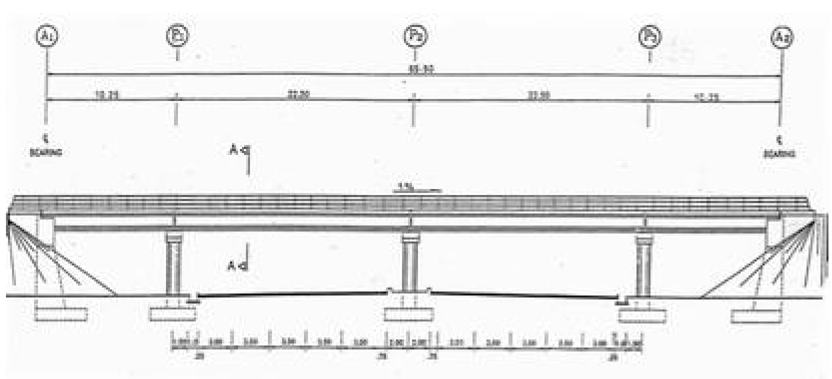

Figure 1. RC bridge model

Table 1. Materials properties

Concrete	f_c (Mpa)	E_c (Mpa)
	30	27000
Steel	f_y (Mpa)	E_s (Mpa)
	300	210000

MODELING

In a 3D model, which was realized for numerical study, The concrete was modeled with a 8 node iso-parametric 3D element (Solid 45), and the longitudinal reinforcing bars were modeled with a 2 node 3D element (link 8). The super structure and live loads were represented by concentrated mass and distributed force at the top of the pier respectively. The Drucker Prager criterion was adopted, to consider the nonlinear behavior of concrete and the Von-Mises criterion is used for steel bars (a bilinear elasto-plastic material). Figure 2 shows the 3D finite element model.

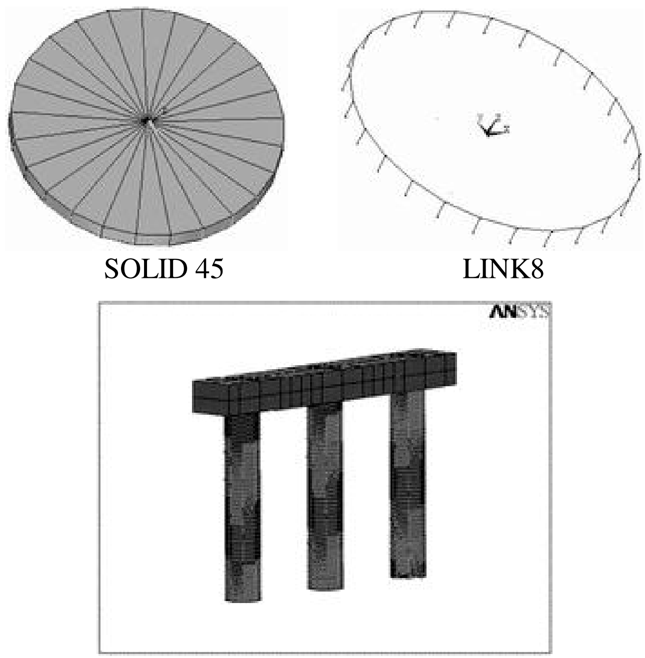

Figure 2. The 3D finite element model

In this study, the nonlinear time history analysis is done using Tabas (1978), Northridge (1994) and Kobe (1995) scaled records and under two loading conditions: first with horizontal motion, and second under horizontal and vertical motions. The records characteristics are shown in table 2.

Table 2. Records characteristics

Records	Date	M_s	Peak of H.M	Peak of V.M
Tabas	1978	7.7	0.932g	0.741 g
North ridge	1994	6.8	0.838g	0.532 g
Kobe	1995	7.2	0.889g	0.337 g

The records are scaled by IBC and UBC codes. (Table 3 & 4)

Table 3. Scaled factor according to IBC code

IBC CODE	RECORD		
	TABAS	NORTHRIDGE	KOBE
Y	.475	.63	.688
Z	.261	.484	.472

Table 4. Scaled factor according to UBC code

UBC CODE	RECORD		
	TABAS	NORTHRIDGE	KOBE
Y	.383	.532	.592
Z	.299	.889	.726

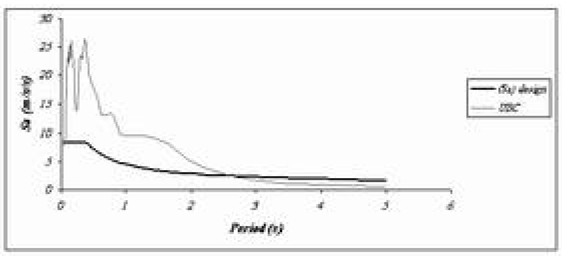

Figure 3. Northridge record – Y

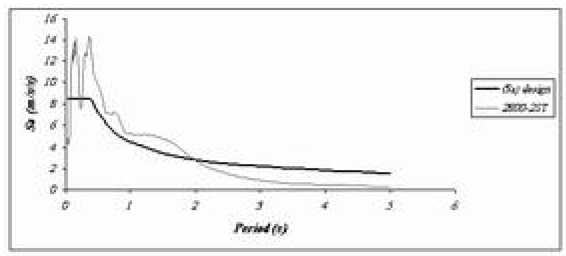

Figure 4. Northridge record – Y

ANALYTICAL RESULTS

Linear time history analysis

Figure 5 shows the axial force variation of Northridge record for the interior column under horizontal or horizontal and vertical excitation. According to this diagram, the fluctuation of axial force is small in the first case and about 25% in second case.

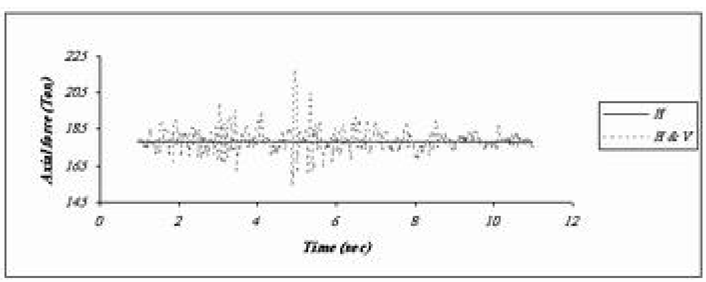

Figure 5.Time history of pier axial load

Figures 6 and 7 indicate the effect of vertical motion on shear force and longitudinal displacement of piers column. The variation of axial force in the same column under Northridge and Tabas records is presented in Table 5.

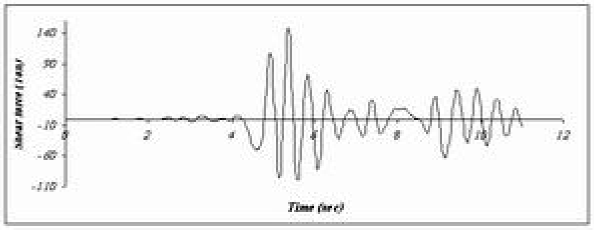

Figure 6. Time history of pier shear force

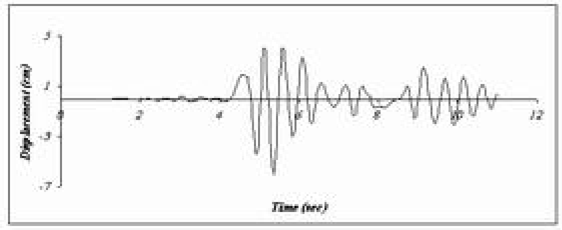

Figure 7. Time history of pier longitudinal displacement

Table 5. Max & min of axial loads

Records	Hz	N	
		Min	Max
Tabas	178	154.6	207.8
Northridge	178	154.6	216.8

Nonlinear analysis

Figure 8 shows the axial force time histories for the interior column under horizontal or horizontal and vertical excitation of Northridge earthquake record. Also in this case the fluctuation of axial force under horizontal excitation is small, but the maximum and minimum of compressive axial force is respectively 155.7 to 211.8 under horizontal and vertical excitation.

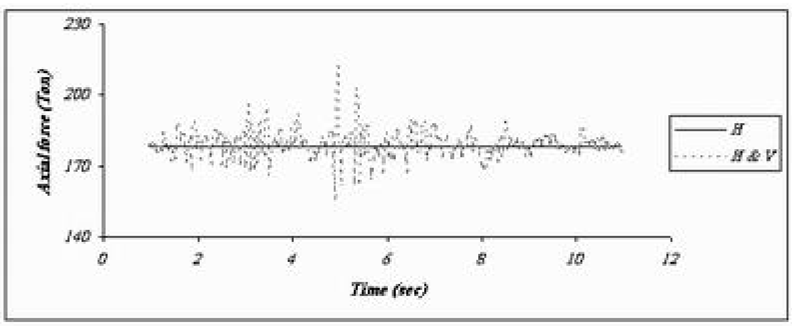

Figure 8. Time history of pier axial load

Table 6 shows the extreme axial force using Northridge earthquake record. The maximum and minimum axial forces in the same column are 155.7 ton and 211.8 ton under horizontal and vertical excitation.

Table 6. Max & min of axial loads

Records	Hz	N	
		Min	Max
Tabas	178	157.4	203.8
Northridge	178	155.7	211.8

Figures 9 and 10 indicate that the effect of vertical motion on shear response and longitudinal displacement of pier are negligible. The effect of vertical motion on axial strain of RC column is shown in figure 11, which indicates increasing of tensile and compressive strain due to the vertical motion.

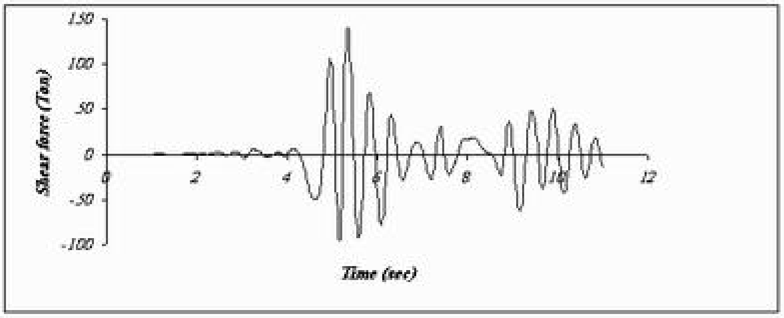

Figure 9. Time history of pier shear force

Figure 12 shows the effect of vertical motion on shear strain response of RC column. This strain in the second case changed significantly due to the vertical motion.

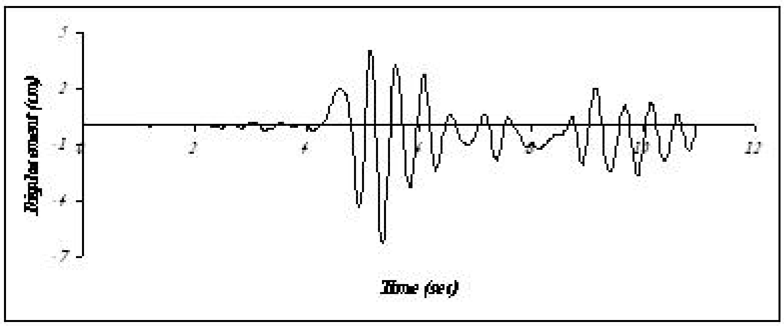

Figure 10. Time history of pier longitudinal displacement

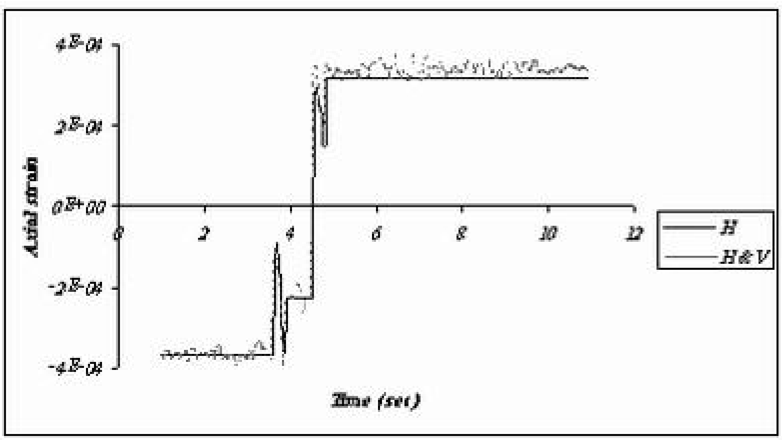

Figure 11. Time history of pier axial strain

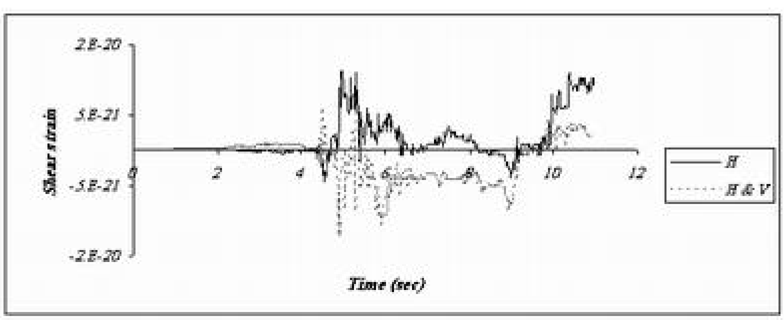

Figure 12. Time history of pier shear strain

CONCLUSION

Linear and nonlinear analysis of bridge piers under Tabas, Kobe and Northridge earthquake records considering horizontal or horizontal and vertical excitation indicates that:

-The variation of axial force is not proportional to the lateral force.

-Vertical motion induced fluctuating axial force in the piers. The magnitude of variation is more than $\pm 25\%$

- Shear and axial strains increased significantly due to vertical motion.
- The maximum and minimum of longitudinal displacement for both cases are equal.

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