EFFECT OF VERTICAL MOTION OF EARTHQUAKE ON RC BRIDGE PIER

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ABSTRACT :

In seismic design of RC piers, designers usually don't consider effect of vertical motion, however, measurements of ground motion during past earthquakes indicate that the vertical acceleration maybe exceed the horizontal acceleration.

Analyses of actual bridges indicate that, in general, the vertical motion will increase the level of response and the amount of damage sustained by a highway bridge. Vertical motion generates fluctuating axial forces in the columns, which cause instability of the hysteresis loops. Furthermore, vertical motion can generate forces of high magnitude in the abutments and foundations that are not accounted for by the current seismic design guidelines. Also, the impulsive vertical motion induces the circumferential crack on RC piers.

This paper presents analytical study for investigation of vertical motion effects on actual RC bridge.

In this study, linear and nonlinear time history analysis (Tabas, Northridge and Kobe scaled records) under two case of loading; in the first case, bridge was subject to horizontal motion of earthquakes whereas in the second case bridge was subject to horizontal motion of case1 in addition to vertical motion.

Analyses indicate vertical motion will increase the axial loads, axial and shear strain and variation of longitudinal displacement and shear force are negligible.

KEYWORDS: VERTICAL MOTION, BRIDGE PIER, RC.

1. INTRODUCTION

Structural vibration was the main cause of damage to or failure of, many bridges during the San Fernando earthquake of Feb. 9, 1971. This problem has been studied by researches both analytically and experimentally. A compilation of literature resulting from some of this work can be found in a report published by the Applied Technology Council. Although the previous work has been extensive and has contributed significantly to the enhancement of seismic design of highway bridges, it is not complete in a sense that most of this work considered only the horizontal motion of earthquake. As result of this, the current guideline for seismic design of highway bridges, recommended by AASHTO, consider only the two horizontal component of ground motion in the analysis and design of highway bridge structures.

Most of the previous research was limited to studies of flexural behavior of RC columns under constant axial load. Studies by Gilbertsen and Moehle (1980) and Abrams (1987) have done some experimental studies that considered the variation in axial force. Theoretical research done by Emori and Schnobrich (1978) and Keshvarzian and Schnobrich (1984) also considered the effects of fluctuating axial force on the response or RC frame- wall structures. However, in these studies the axial force variation was proportional to the moment or lateral load. Further more; the level of the axial force was small compared to the balance load of the section.

One of the few studies where uncoupled variations of axial and lateral forces have been considered is an experimental test on a single column Kreger and Linbeck (1986). It is shown that the behavior of the column depends greatly on the time history of the axial force. The result of analytical study by the Saadeghvaziri and Foutch (1988) also indicates the no proportional variation in axial load are not just another parameter that be considered in the framework of current approaches, but that it s effects are so significant that new methodology and models are needed to assess the inelastic cyclic response of RC column under uncoupled fluctuation in axial and lateral loads. [2]

Note that uncoupled variation in axial and lateral loads prevails when structures are under the combined effects of vertical and horizontal earthquake motion. Results show that nonproportional fluctuations in the axial force have significant effect on post-elastic cyclic response of RC columns. Also the hysteresis loops are not of Massing type. [3]

Owing to uncoupled variations in the axial and lateral forces, the hysteresis loops are very unstable and asymmetric. They demonstrate significant fluctuation in the stiffness and strength of the column. As a result of compressive axial load the column stiffness increases. Consequently, the amount of lateral shear and moment that is carried by the column increases. This, in turn, increases the possibility of failure in the column, its foundation and abutments. On the other hand, tensile axial force reduces the shear and moment capacity of the cross-section. This may lead to shear failure or yielding under bending moments that are much lower than anticipated design. Note that unexpected yielding of columns has been reported for many bridges during past earthquakes. [3]

Experimental and analytical studies performed about reappearance of circumferential crack RC piers during Hyogoken-Nanbu earthquake (1995). Results indicate large positive inertia force will cause large tensile force and a circumferential crack in RC piers. (Ishikawa, 2000). [4]

Vertical motion caused change of final failure collapse of some of the studied piers from flexural to sever diagonal shear failure. For other cases, failure mode did not change but severity of diagonal cracking was higher due to Hz & Vl motion than that due to Hz motion. Due to vertical motion, ductility level of piers decreases and the included plastic strain increases. (Machida, 2000). [5]

2. METHOD OF STUDY

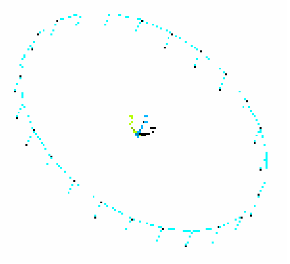
The actual RC bridge that consists of four spans (10.25, 22.5, 22.5, 10.25 m) with three - column bent. The cross - section of piers is circles of 1.2 m in diameter that spaced 4 m apart. Every pier has 25 reinforcement of 32 mm steel bar. The confinement to piers is provided by 2*14 mm spiral bars arranged at 75 mm centers at the pier ends and by 125 mm centers in non-critical sections. The material properties of concrete and steel bar are shown in table1.

Table1: material properties of concrete and steel bar

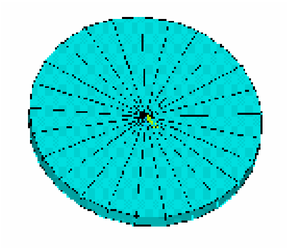
Concrete N/mm2	Compressive strength	Young's modules
	30	2.70E+04
Steel N/mm2	Yield stress	Young's modules
	300	2.10E+05

3. MODELING

In 3D model, concrete was modeled as 8-node isoparametric 3D element (solid 45) and 2-node 3D truss–element (link 8) for modeling both of longitudinal and transverse reinforcement. The superstructure and live loads were represented by concentrated mass and distributed force at top of the pier respectively. Finite element software named ANSYS was utilized in the analysis. Drucker-Prager criterion was adopted to consider nonlinearity of concrete. Nonlinearity of steel reinforcement was adopted by Von-Misses criterion. A bilinear elasto-plastic material model was used or reinforcement. Figure 1shows the 3D finite element model.



LINK 8



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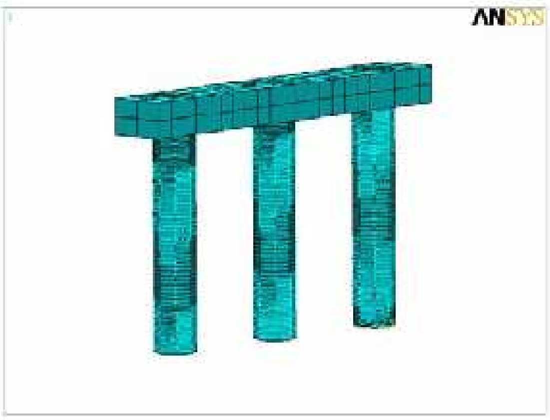

Figure 1: 3D finite element model

In this study, nonlinear time history analyses was used with Tabas (1978), Northridge (1994), Kobe (1995) scaled records under two cases of loading, in the first Hz motion only and in the second case Hz & Vl motion is performed. Characteristics of records are shown in table2

Table2: Characteristics of records

Record	Date	Ms	Peak of Hz	Peak of V1
Tabas	1978	7.7	.932g	.741g
Northridge	1994	6.8	.838g	.532g
Kobe	1995	7.2	.889g	.337g

The records scaled by UBC codes. (table 3)

Table3: Scaled factor (UBC code)

Direction	Record		
	TABAS	NORTHRIDGE	KOBE
Hz	0.383	0.532	0.592
V1	0.299	0.889	0.726

4. RESULT OF ANALYSIS

4.1. linear time history analyses

Figure 2 shows the axial force time histories of Kobe record for the central pier under horizontal and horizontal and vertical excitation. It is clear that fluctuation of axial forces under horizontal ex citation is small (178 ton). Contrary, when vertical motion is included in the analysis the maximum compressive axial load is equal to 199.4 ton and the minimum compressive axial load is equal to 157.5 ton.

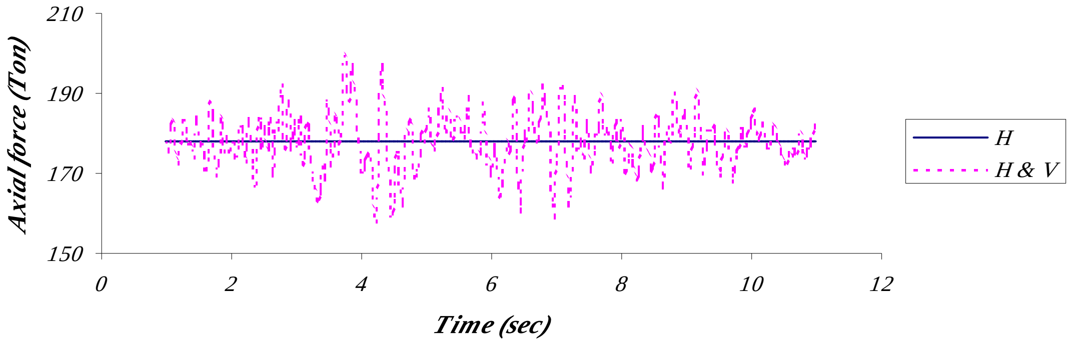

Figure 2: Time history of pier axial load (Kobe)

Figure 3 and figure 4 indicate that effect of vertical motion on shear response and longitudinal displacement of pier are negligible.

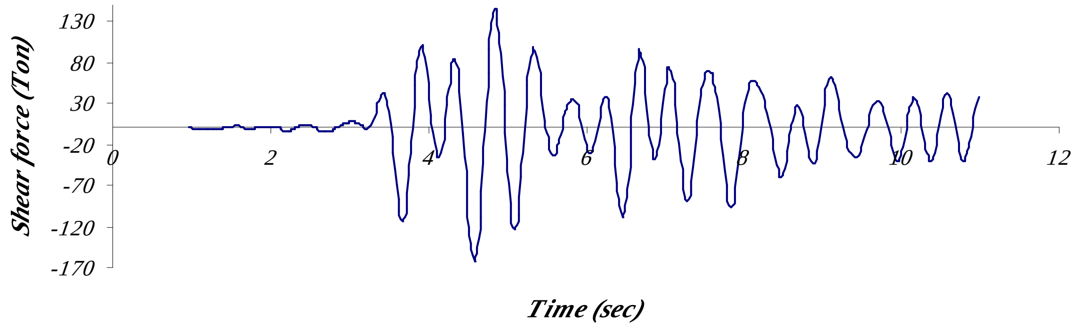

Figure 3: Time history of pier shear load (Kobe)

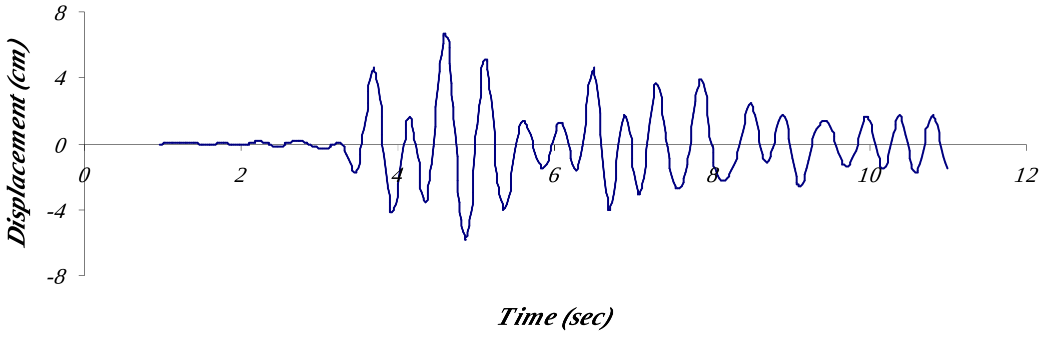

Figure 4: Time history of pier longitudinal displacement (Kobe)

Table 4 shows maximum and minimum compressive axial loads of Northridge and Tabas records for two cases.

Table 4: Max & Min of axial loads

Record	Hz	V1	
		Min	Max
	Ton	Ton	Ton
Tabas	178	154.6	207.8
Northridge	178	154.4	216.8

4.2. Nonlinear time history analyses

Figure 5 shows the axial force time histories of Kobe record for the central pier under horizontal and horizontal and vertical excitation. It is clear that fluctuation of axial forces under horizontal excitation is small (178 ton). Contrary, when vertical motion is included in the analysis the maximum compressive axial load is equal to 199 ton and the minimum compressive axial load are equal to 157.7 ton.

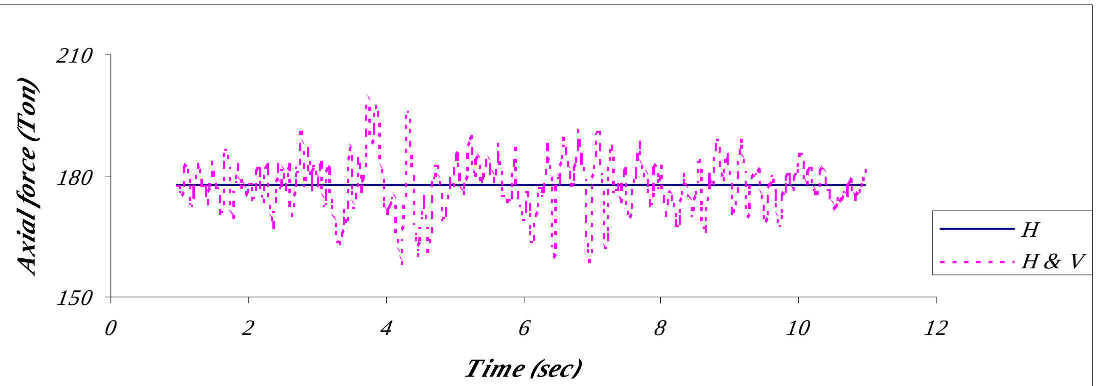

Figure 5: Time history of pier axial load (Kobe)

Figure 6 and figure 7 indicate that effect of vertical motion on shear response and longitudinal displacement of pier are negligible.

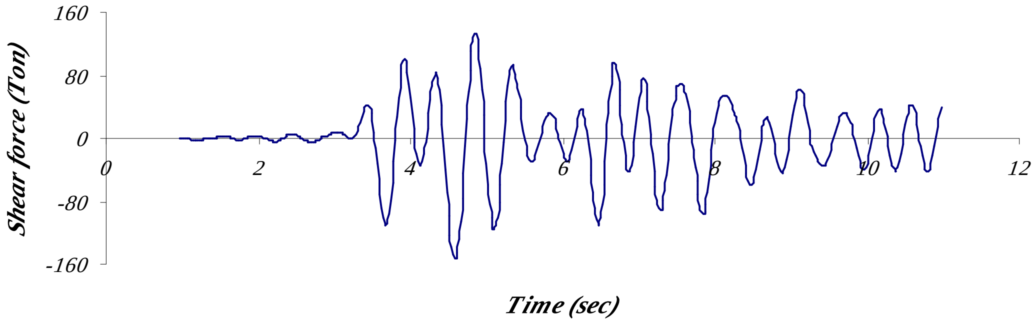

Figure 6: Time history of pier shear load (Kobe)

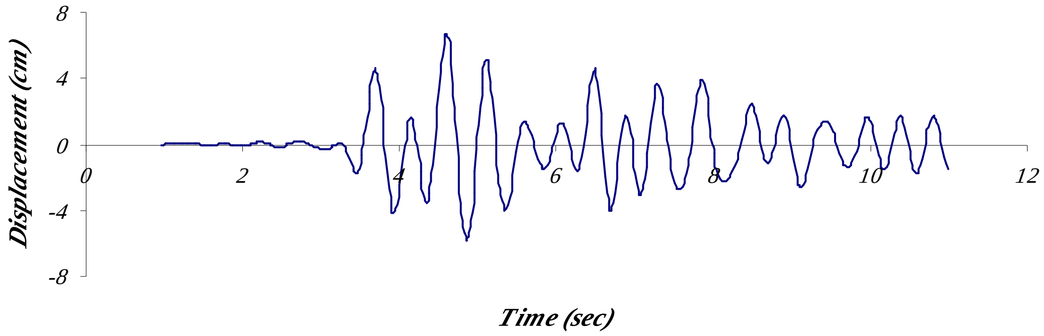

Figure 7: Time history of pier longitudinal displacement (Kobe)

Figure 8 illustrates the effect of vertical motion on axial strain response for RC pier. Both tensile and compressive strain increased due to vertical motion. Figure 9 indicates the effect of vertical motion on shear strain response for RC pier. Shear strain in the second case changed significantly due to vertical motion.

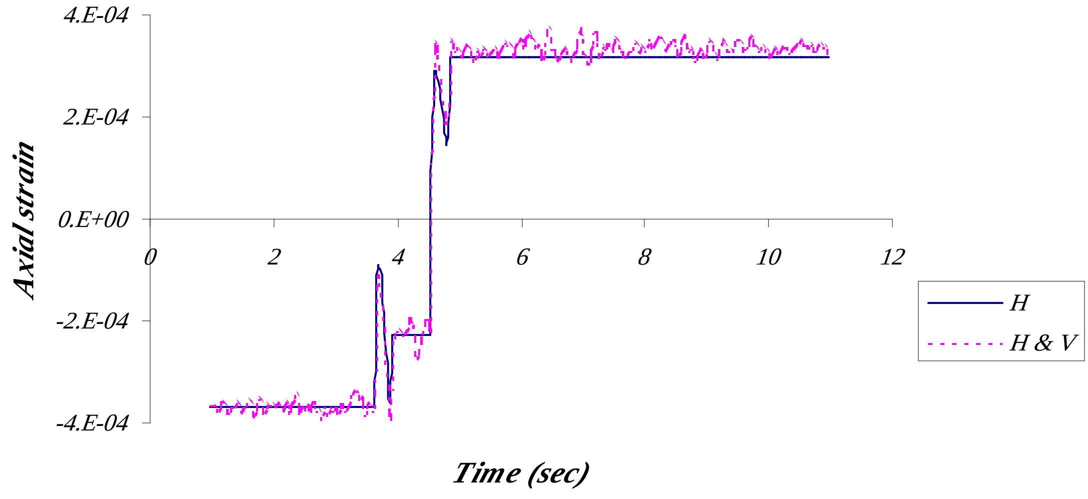

Figure 8: Time history of pier axial strain (Kobe)

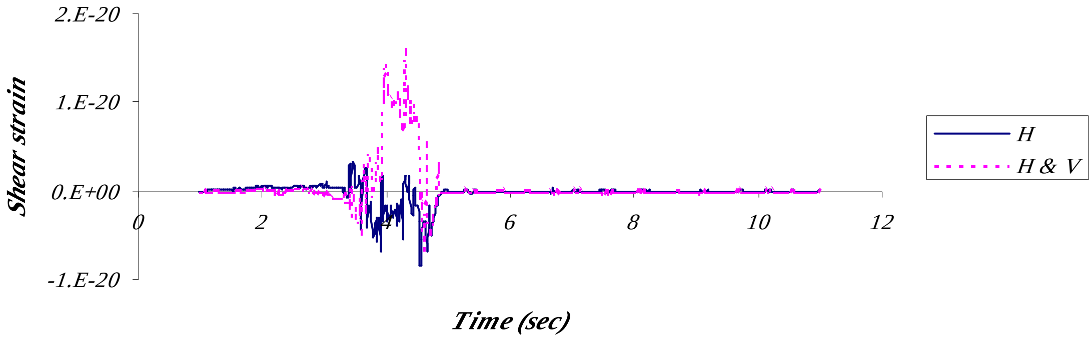

Figure 9: Time history of pier shear strain (Kobe)

5. CONCLUTION

Vertical component has remarkable influence on the inelastic response of RC piers and should be included in the seismic design of such structural elements.
Due to vertical motion:

1- Fluctuating axial force will increase.
2- Axial strain will increase.
3- Shear strain will increase.
4- Variation of longitudinal displacement and shear force are negligible.

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