BEHAVIOR OF INVERTED L-SHAPED STEEL PIERS UNDER STRONG GROUND MOTIONS

H. H. M. Gunasoma[1] and K. A. S. Susantha[2]

[1] Central Engineering Consultancy Bureau (CECB), Colombo 07, Sri Lanka. Email: hasithaud@gmail.com
[2] Departments of Engineering Mathematics, University of Peradeniya, Sri Lanka. Email: samans@pdn.ac.lk

ABSTRACT

Seismic behavior of concentrically loaded columns differs significantly from that of eccentrically loaded piers. The behavior highly depends on the level of eccentricity given by eccentric distance to columns height ratio (*e/h*), the ratio of magnitudes of axial load to column yield load (*P/Py*), and external loading. In this study, inverted L-shaped steel bridge piers subjected to strong ground motions are analyzed using nonlinear time series analysis in order to examine the effects of above parameters on stress and displacement demands. Fiber elements available in research oriented finite element program called Opensees was employed in the analysis. Analyses were conducted using past ground acceleration records.

Key words: dynamic analysis, eccentrically loaded columns, nonlinear analysis, steel piers

1. INTRODUCTION

In some elevated highways, loads from superstructures act eccentrically on the supporting piers due to prevailing ground area conditions. The eccentric distance can sometimes reach 50 percent of the column height (*e/h*=0.50) [1]. The loading become unsymmetrical and piers experience adverse stress conditions when repeated lateral loads coming from earthquakes attack such structures. The situation become more complex when steel undergoes inelastic deformations. This can be handled by conducting nonlinear dynamic analysis incorporating elastic-plastic steel material models. When piers are loaded unsymmetrically they cannot withstand the load that can be taken by equivalent concentrically loaded piers. It is well known that when subjected to earthquake loads the lateral deformation and stresses that eccentrically loaded columns undergo depend on the axial load of the pier. This study investigates this aspect by varying axial load ratio *P/Py*, where *P* is the applied axial load and *Py* is the yield load. Similarly, the effects of *e/h* ratio on the behavior will be examined. All the analyses are carried out for several past strong motion records.

2. METHODOLOGY

2.1. Finite Element Model

Three inverted L-shaped pier models were first designed with *e/h* ratios of 0.10, 0.15 and 0.25. In addition, one concentrically loaded column was designed for comparison purpose. All the models consist of stiffened steel sections having 16 longitudinal stiffeners, as shown in Figure 1, with outer dimensions 1500 mm x 1500 mm. Thickness of the plates was 15 mm and height of the pier was 6000 mm, thus giving slenderness ratio close to 0.30. Spacing of the horizontal diaphragms was equal to width of the section. All the above dimensions were selected so that the values of flange plate slenderness, stiffened plate slenderness, slenderness ratio, and rigidity ratio [2] yield best ductility performance as specified in Japan Road Association [3].

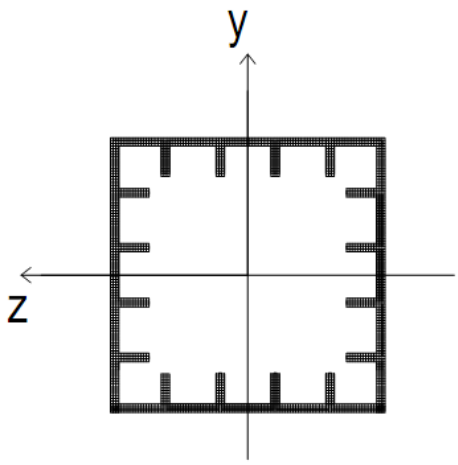

Figure 1: Cross section of column

The finite element model of each column was developed using force based beam-column element available in Opensees programe [4]. The FEM model is shown in Figure 2. The cross section of the element was modeled using fiber section option. Each fiber was assigned a bilinear steel stress-strain relation with yield stress of 355

MPa and strain hardening ratio of 0.015. Concentrated mass calculated from axial load *P* was assigned at a distance *e* from the axis of column. Three cases of axial load ratios (i.e., *P/Py* = 0.15, 0.20 and 0.25) were employed in the analysis.

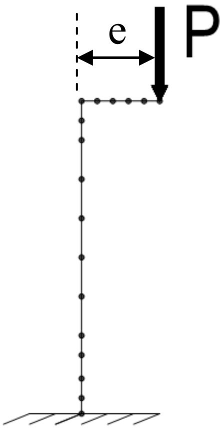

Figure 2: Finite element model

2.2. Time History Analysis

Time history analyses are conducted to check the dynamic behavior of columns subjected to different ground accelerations. This study deals with strong motion records hence steel will definitely be experienced inelastic deformations. Therefore, nonlinear time history analyses are carried out with damping coefficient of 0.05. The eigen analysis are first conducted to obtain natural periods of columns. Ten earthquake records were downloaded from Pacific Earthquake Research Center (PEER) database [5]. The peak ground acceleration (PGA) of these earthquake records vary from 0.1g to 0.8g representing minor, moderate and major earthquakes. There are 120 cases to be analyzed covering four cases representing three *e/h* ratios (i.e., 0.10, 0.20, and 0.25) and concentrically loaded case and three axial load ratios (i.e., 0.10. 0.20 and 0.25) for ten ground accelerations records.

3. RESULTS

3.1. Natural Periods

Natural period of first three modes of columns for mass given by *P/Py* of 0.15 are listed in Table 1. It is clear that natural period of each mode increased with increasing eccentricity. This indicates that columns become more flexible when they are eccentrically loaded.

Table 1: Natural Periods of columns for *P/Py*=0.15

Mode	Natural Period/(sec)			
	e/h=0	e/h=0.1	e/h=0.2	e/h=0.25
1	0.48	0.48	0.50	0.52
2	0.08	0.09	0.12	0.13
3	0.01	0.01	0.01	0.01

3.2. Base Reaction and Maximum Stresses due to Static Loads

Bending moments at column base for different eccentricities were obtained to be 4443, 8887, and 11108 kN-m for *e/h* ratio of 0.10, 0.20, and 0.25, respectively. Vertical reaction was 7301 kN for all the cases. In-plane lateral displacement became 9, 17, and 22 mm at the column top for three *e/h* ratios mentioned above. And stresses at mostly compressed location were, respectively, 126.7, 200.3, and 237.0 MPa. Maximum compressive stress of concentrically loaded column was 53.2 MPa. Thus, in the case of *e/h* ratio of 0.10, the maximum stress increased by around 2.4 times that of the concentrically loaded pier.

3.3. Displacement Demands

Maximum lateral displacement (δ_{max}) and residual displacement (δ_{res}) at column top under each earthquake load for all the cases considered were obtained from the analysis. Representative results of δ_{max} and δ_{res} for Cape Mendocino 1992 earthquake (PGA=0.178*g*) are shown in Figures 3 and 4, respectively. Figure 3 shows that a sharp increase in δ_{max} occurred when *P/Py*=0.25. This is because steel has undergone very high inelastic deformations under higher axial load and higher eccentricities. The maximum stress recorded at the mostly compressed steel fibers for this case is listed in Table 2. In the case of *P/Py* = 0.20 and 0.25, maximum stress has exceeded the yield strength of steel (σ_y=355.0 MPa) under all the *e/h* ratios considered.

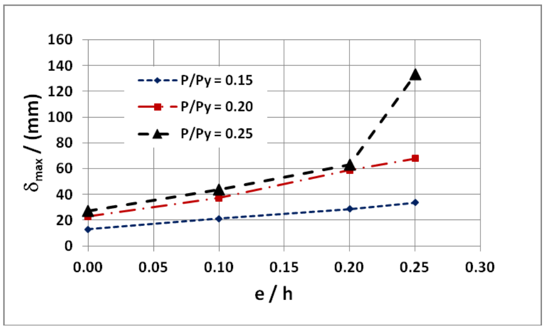

Figure 3: Variation of δ_{max} under Cape Mendocino 1992 earthquake

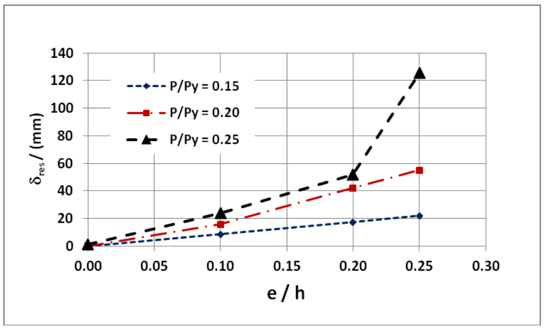

Figure 4: Variation of δ_{res} under Cape Mendocino 1992 earthquake

Table 2: Maximum stress at mostly compressed fibers under Cape Mendocino 1992 earthquake

e/h	Maximum Stress/(MPa)		
	P/Py=0.10	*P/Py*=0.20	*P/Py*=0.25
0	-216.8	-355.1	-357.6
0.10	-286.5	-360.2	-364.1
0.20	-344.6	-371.9	-370.0
0.25	-355.8	-373.6	-394.8

Maximum and residual displacements of piers under Kobe 1995 earthquake (PGA=0.821*g*) are shown in Figures 5 and 6, respectively. This was a major earthquake hence as expected very high δ_{max} and δ_{res} values were found from the analyses.

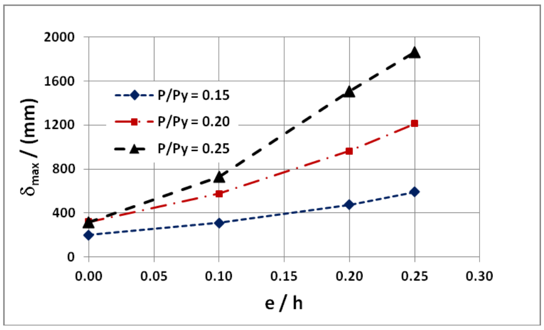

Figure 5: Variation of δ_{max} under Kobe 1995 earthquake

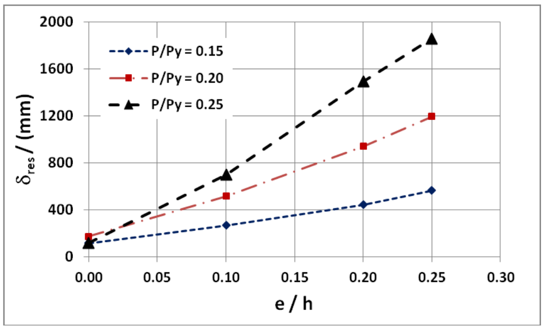

Figure 6: Variation of δ_{res} under Kobe 1995 earthquake

4. CONCLUSION

Eccentrically loaded steel bridge piers subjected to different earthquake loads are analyzed using nonlinear time series analysis using Opensees finite element programe. Axial load ratio (*P/Py*) and eccentricity ratio (*e/h*) were considered as main variables. Results showed that when subjected to moderate earthquakes, piers with *e/h* ratio greater than 0.20 undergo inelastic deformations resulting residual displacements. However, severe earthquakes likes Kobe earthquake in 1995 caused inelastic deformation even with concentric axial loads. When *e/h* ratio increased around 0.25 a sharp increased in both maximum and residual displacements could be seen.

5. REFERENCES

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