論文 Response of RC Bridge Piers under Kushiro-oki and Great Hanshin Earthquakes

Afzaal H. HAMDANI *1 Tamon UEDA *2 Yoshio KAKUTA *3

ABSTRACT: The Response characteristics and collapse mechanism of Matsu-no-e bridge pier which was damaged in the Kushiro-oki earthquake of January 15, 1993 and Pilz-type bridge pier which collapsed in the Great Hanshin earthquake of January 17, 1995 are investigated through non-linear dynamic analysis. It was clarified that the design shear capacity of the bridge piers was not adequate to withstand the input seismic forces due to insufficient lateral tie reinforcement. It was found that Kushiro-oki earthquake could be more destructive to the bridge piers than the Great Hanshin earthquake.

KEYWORDS: collapse mechanism, response characteristics, lateral tie reinforcement

1. INTRODUCTION

The present investigation deals with the non-linear dynamic analysis of the reinforced concrete bridge piers. The Matsu-no-e bridge pier was damaged during the Kushiro-oki earthquake of January 15, 1993, while the Pilz-type bridge pier collapsed during the Great Hanshin earthquake of January 17, 1995. This paper studies the differences in the response characteristics of the pier when subjected to different input ground motions. To achieve this purpose the piers were subjected to both Kushiro-oki and Great Hanshin earthquakes. The response characteristics are also obtained for reduced magnitude of ground motions. The effect of direction of earthquake(EW, NS, UD) is also an important dynamic characteristic for a particular ground motion. Through this analysis it will be helpful to clarify the collapse mechanisms of the Matsu-no-e bridge pier and the Pilz-type bridge pier.

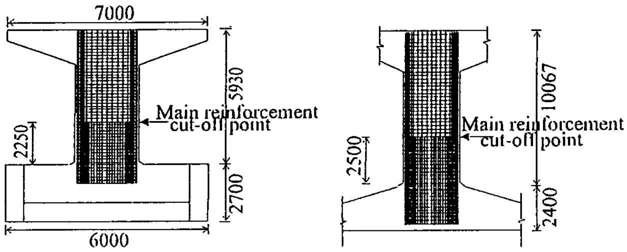
2. DIMENSIONS AND MATERIALS

2.1 STRUCTURAL DIMENSIONS AND EARTHQUAKE RECORDS

The shape and dimensions of the bridge piers are shown in Fig.1[10]. The material properties for concrete and steel used in both types of piers at the time of construction are

*1 Department of Civil Engineering, Hokkaido University, Graduate Student, Member of JCI
*2 Department of Civil Engineering, Hokkaido University, Assoc. Professor, Member of JCI
*3 Department of Civil Engineering , Hokkaido University, Professor, Member of JCI

given in Table.1. The axial force was obtained as the sum of the weight of the superstructure and 30% weight of the pier itself. The Kushiro-oki earthquake ground motion used for the present analysis was recorded at the Kushiro Meteorological Agency office[7], while the Great Hanshin earthquake was recorded at the Kobe Ocean Meteorological Agency office[8] (see Fig. 2).



(a)Matsu-no-e bridge pier (b) Pilz-type bridge pier
Fig. 1 Shape and dimensions of target structures

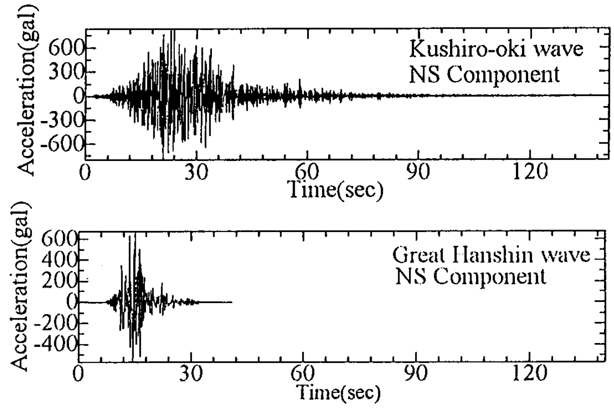


Fig.2 Input ground acceleration records used for the analysis

2.2 CONSTITUTIVE LAWS

Stress-strain relationship for concrete is assumed parabolic up to a strain of 0.002 and a constant stress level of $0.85f_c^{'}$ up to crushing strain of 0.004. The reinforcement is considered as an ideal elasto-plastic material.

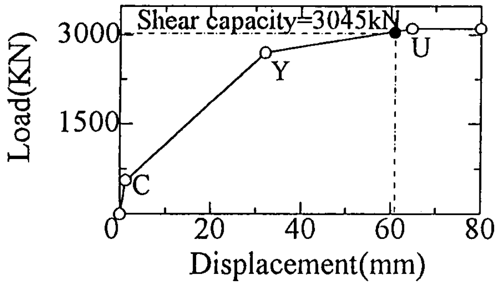
3. STRUCTURAL CHARACTERISTICS OF THE BRIDGE PIERS

The ideal moment-curvature curve for each pier was obtained using the constitutive relations described in Sec.2.2. The yield moment was obtained by the elasto-plastic approximation for moment-curvature behavior[2]. The moment-curvature curve was

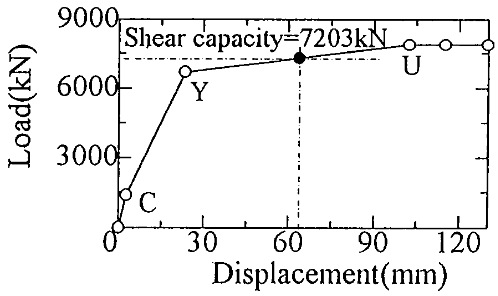
Table.1 Material properties of concrete and reinforcement

Pier		Matsu-no-e	Pilz-type
Concrete	Compressive strength $f_c^{'}$ (MPa)	18	34
	Tensile strength f_t (MPa)	2.64	3.63
	Modulus of elasticity E_c (MPa)	2.45×10^4	2.45×10^4
Main Reinforcement	Yield strength f_y (MPa)	441	352
	Modulus of elasticity E_s (MPa)	2.06×10^5	2.06×10^5
Tie Reinforcement	Yield strength f_y (MPa)	441	355
	Modulus of elasticity E_s (MPa)	2.06×10^5	2.06×10^5

approximated by three straight line segments connecting three limit states which are occurrence of a flexural crack, member yielding and flexural ultimate state. The cracking displacement and cracking load were computed by the linear elastic bending theory. The yield load was calculated from the yielding moment and the corresponding displacement was determined by considering the ACI Code expression for the effective moment of inertia developed by Branson[3]. The ultimate flexural displacement was calculated from the knowledge of ultimate curvature, yield curvature and the plastic hinge length[3]. It was found that all the calculated three limit states at the root of the pier took place before those at the cut-off section. The flexural deflections and the corresponding loads for the Matsu-no-e bridge pier and the Pilz-type bridge pier are shown in Figs.3(a) and (b), respectively.



(a) Matsu-no-e bridge pier



(b) Piltz-type bridge pier

Fig.3 Envelope curves for the bridge piers

The shear capacity of both bridge piers which is calculated by JSCE equation[4] is less than the flexural strength as shown in Fig.3. The ductility factors of the bridge piers are estimated by the method in the previous study which considers the effect of cut-off section on ductility[5]. They are 3 for the Matsu-no-e bridge pier and 2.6 for Pilz-type bridge pier, which are much less than that of a bridge pier failing in bending.

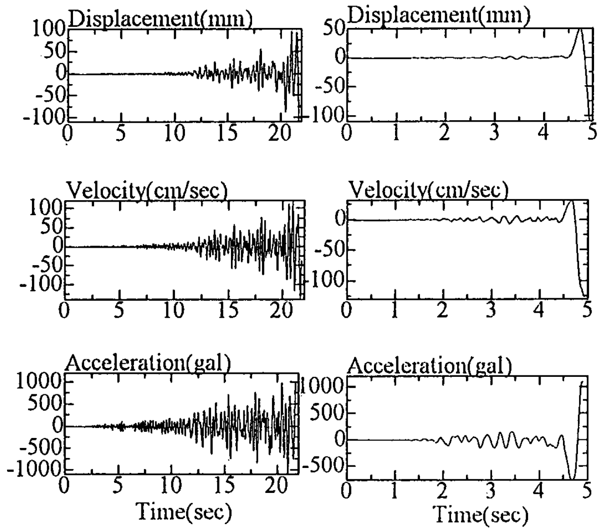
4. DYNAMIC ANALYSIS

Each of the bridge pier is idealized as a single degree of freedom system. The mass of the superstructure is lumped at the top of the pier. Step-by-step time integration technique is employed to obtain the response quantities. This method assumes a linear acceleration variation during any given time increment. The mass and damping are assumed constant during the whole time history. Takeda model[1] with the skeleton curve shown in Fig.3 was used to calculate the stiffness for each time step. The stiffness is assumed constant during each time step. The natural periods of Matsu-no-e bridge pier and Piltz-type bridge pier for their initial stiffness are 0.20sec and 0.40sec, respectively. The integration time step was 0.002 second. The damping factor was assumed to be 5% for both type of bridge piers.

5. DISCUSSION AND CONSIDERATIONS

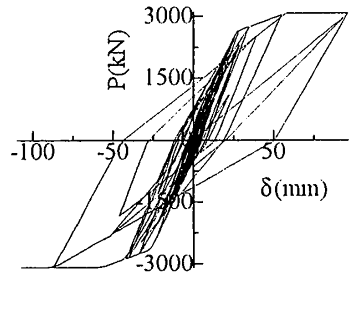
The ground acceleration records available for Kushiro-oki and Great Hanshin earthquakes are shown in Fig.2. It can be observed that the Kushiro-oki wave shows considerable acceleration ordinates for about 60 seconds. Whereas, the Great Hanshin wave shows sudden increase in acceleration within 10 to 20 seconds period. This characteristic implies that the Great Hanshin wave was almost a sudden input inducing large deformations in the pier within a short period of time as can be seen in Fig.4(b). It might be said that if

Matsu-no-e bridge pier were subjected to the Great Hanshin earthquake, it might have shown large damage(see Fig.5(b)). The response displacement of Matsu-no-e bridge pier reaches the ultimate displacement of $3\delta_y$ within 5 seconds in case of the Great Hanshin earthquake, while

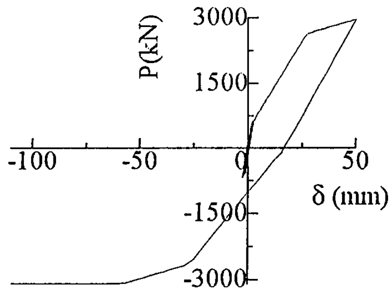


(a) Kushiro-oki earthquake (b) Great Hanshin earthquake

Fig. 4 Response quantities for Matsu-no-e bridge pier



(a)Kushiro-oki earthquake



(b)Great Hanshin earthquake

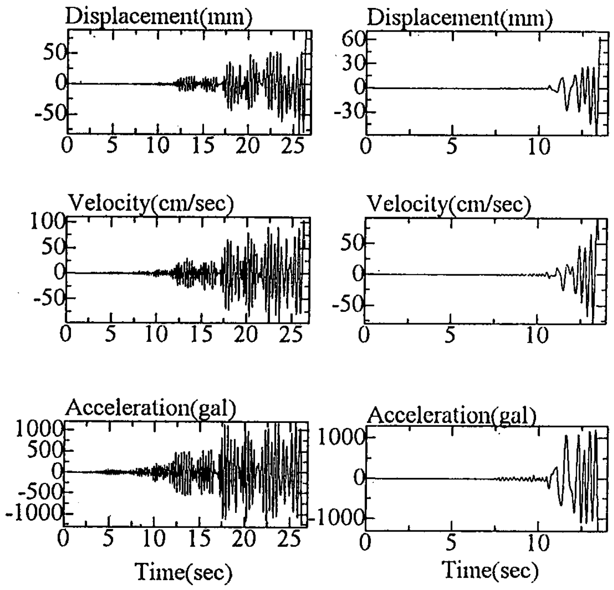
Fig.5 Force-displacement loops for Matsu-no-e bridge pier

the same condition is reached in 20 seconds for the Kushiro-oki wave(see Fig.4(a)). The response quantities for Pilz-type bridge pier are shown in Fig.6. The Pilz-type bridge pier also exhibits similar response characteristics and attains its ultimate displacement of $2.6\delta_y$ for both earthquake waves as shown in Fig.7. It is also clear from Fig.5(a) and Fig.7(a), the considerable number of loops are nicely carried by the bridge piers before and after the yielding of the main reinforcement. However, this fact is not observed in the case of Great Hanshin wave(see Figs.5(b) and 7(b)).

The present analysis predicts a shear failure of both the target structures. This prediction agrees with reported actual damage[9] caused to Matsu-no-e bridge pier due to the Kushiro-oki earthquake which was the appearance of major shear cracks. The collapse mechanism of the Pilz-type bridge pier has been discussed by K. Maekawa and A. A. Shawky[6]. Their analytical investigation indicated that the Pilz-type bridge piers contained insufficient amount of lateral reinforcement. Based on the above discussion it can be said that an improvement in the structural ductility is possible by increasing the amount of lateral reinforcement.

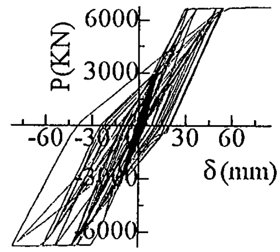
To study the effects of the degree of destruction of the earthquakes, the two bridge piers were subjected to earthquakes with reduced magnitude and considering EW and NS components. It was found that 60% of the Kushiro-oki earthquake and 70% of Great Hanshin earthquake(see Fig.8) were the limits beyond which the shear failure was obtained for both bridge piers. This shows that the Kushiro-oki earthquake is more destructive to both

the bridge piers. Furthermore, it was found that NS component with the maximum the bridge
the bridge piers. Furthermore, it was found that NS component with the maximum acceleration of 817.44gal of Kushiro-oki earthquake was more destructive as compare to its EW component with the maximum acceleration of 922.2gal.

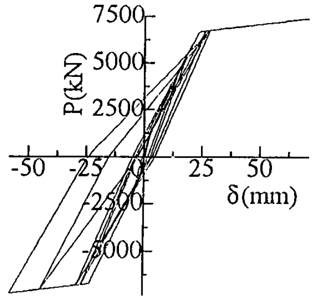


(a)Kushiro-oki earthquake (b) Great Hanshin earthquake

Fig.6 Response quantities for Pilz-type bridge pier

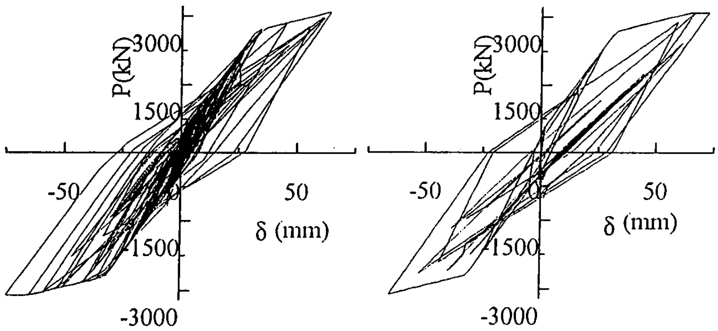


(a) Kushiro-oki earthquake



(b)Great Hanshin earthquake

Fig.7 Force-displacement loops for Pilz Type bridge pier



(a)60% of Kushiro-oki earthquake (b)70% of Great Hanshin earthquake

Fig.8 Force-displacement loops for reduced magnitude of earthquakes for Matsu-no-e bridge pier

6. CONCLUSIONS

Both the analyzed bridge piers which are the Matsu-no-e bridge pier and the Pilz-type bridge pier were found flexuraly critical at the base rather than at the cut-off section. The calculated ductility factors for Matsu-no-e bridge pier and the Pilz-type bridge pier with consideration of cut-off section were 3 and 2.6, respectively. From the dynamic analysis it can be said that the Great Hanshin earthquake was a sort of sudden impact on the structures and hence induced almost instantaneous deformations in the bridge piers analyzed. The dynamic analysis also indicated that both the bridge piers reached their respective shear capacities during the occurrence of the Kushiro-oki earthquake as well as the Great Hanshin earthquake. Both of the bridge piers contained insufficient amount of tie reinforcement and hence showed poor ductility during the earthquake. The increase in the amount of lateral reinforcement will enhance the shear strength and hence the structural ductility. Within the scope of the present analysis it was found that the Kushiro-oki earthquake is more destructive to the analyzed bridge piers as compared to the Great Hanshin earthquake, and that NS component of the Kushiro-oki wave with the maximum acceleration of 817.4gal is more destructive than EW component with the maximum acceleration of 922.2gal. The response characteristics predicted in the present analysis can be considered satisfactory for the structures with natural periods ranging from 0.2 to 0.4 second.

AKNOWLEDGMENT

The authors would like to express their gratitude to Dr. Masashi Sato, Hokkaido Development Bureau for his assistance to obtain the information of the Matsu-no-e bridge pier. Thanks are also due to Mr. Satoshi Tsuchiya, the graduate student, University of Tokyo for his assistance to obtain the information on Pilz-type bridge pier.

REFERENCES

1. Takeda, T., "Reinforced Concrete Response to Simulated Earthquakes,"J. of Structural Div., ASCE. Vol.96, Dec., 1970, pp.2557-2573
2. Priestly, M. J. N. and Park, R. (1987). "Strength and Ductility of Concrete Bridge Columns Under Seismic Loading," ACI Struct. J., 84, Jan-Feb., 61-76.
3. Park, R. and Pauly, T. "Reinforced Concrete Structures," John Wiley & Sons, New York, 1975, pp.237-247
4. Japan Society of Civil Engineers, Standard Specification for Design and Construction of Concrete Structures, Ist edition, 1986, Part 1(Design).
5. Yamamoto, T., Ishibashi, T., Otsubo, M. and Kobayashi, S., "Experimental Studies on seismic design of a pier with Reinforcement Terminated Halfway in a tension zone," Concrete Library of JSCE NO.5, August 1985, pp 105-120.
6. Maekawa K. and Shawky A. A., "Collapse Mechanism of Hanshin RC Bridge Piers," EASEC-5, Australia, 1995, pp.2475-2482.
7. Record of Kushiro-oki Earthquake(1993) by Electro-magnetic Accelogram(87), Meteorological Agency.
8. Provided by Dr. Hajime Ohuchi, Member of Damage Analysis WG of Special Committee on Great Hanshin Earthquake.
9. Kagami, H., "Investigation on Damage due to Kushiro-oki Earthquake in 1993", Report of Research Project, Grant-in-Aid for Scientific Research, No. 04306025, , March, 1993.
10. Committee on Measures against Damage of Bridges due to the Hyogo-ken Nambu Earthquake, "Report on Investigation for Damage of Bridges due to the Hyogo-ken Nambu Earthquake", December 1995.