Effect of Curvature and Seismic Excitation Characteristics on the Seismic Response of Seismically Isolated Curved Continuous Bridge

Li Yu[1], Zhong Tieyi[1], Yang Fengli[1] and Yan Guiping[1]

1 School of Civil Engineering and Architecture, Beijing Jiaotong University, Beijing , 100044,China

Abstract: According to the characteristic of seismically isolated curved beam bridge design, the bidirectional nonlinear behavior of lead rubber bearing is taken into account by using two orthogonal nonlinear spring element. Reasonable strong seismic motion records are selected. Considering the effect of characteristic of curved beam bridge, the FEA software is used to do the nonlinear time history analyses for the curved beam bridges with and without lead rubber bearing under bidirectional seismic motions. The study results are obtained as follow: 1) vibration models of curved beam bridge are correlative with the connection between pier and beam and the natural period of seismic isolated curved beam bridge can not be affected by the radius of curvature; 2) the principal natural period of the seismically isolated curved beam bridge can be prolonged to avoid the predominant period of seismic motions. Therefore, the seismic response of the seismically isolated curved bridge can be reduced; 3) the seismic response of structure is greatly discrepant under different seismic motions. Especially, when the duration of seismic motion prolongs or the natural period of seismically isolated bridge approaches to the predominant period of seismic motion, the seismic response of structure can be enhanced.

Keywords: lead rubber bearing (LRB); seismic response; curved continuous bridge

1. Introduction

With the development of transportation, especially the rapid development of urban viaduct network, more requirements on the function and outlook should be fulfilled in the bridge design. These bring out the wide use of curved continuous bridge. But there still is a lot of work to do to understand the seismic response specialty of the curved continuous bridge, the application of seismic isolation bearing in the curved continuous bridges and many factors related to seismic isolation of bridge [1-3].

In this paper, according to the characteristic of seismically isolated curved beam bridge design, the bidirectional nonlinear behavior of lead rubber bearing is taken into account by using two orthogonal nonlinear spring element. Reasonable strong seismic motion records are selected. Considering the effect of characteristic of curved beam bridge, the FEA software is used to do the nonlinear time history analyses for the curved beam bridges with and without lead rubber bearing under bidirectional seismic motions.

2. Analysis Model of Seismically Isolated Curved Continuous Bridge

A typical seven-span seismically isolated curved continuous bridge [4] is selected for this study and shown in Fig.1. The shape of curve is assumed circular arc, and the variation rang of the radius of curvature (R) is from 60m to ∞ (straight line). The total length of bridge is 165m (1×20m+5×25m+1×20m). The superstructure, which is made of C40, is designed to be constant section single-chamber box girder with area of 3.099m^2, longitudinal bending inertia moment of 0.5989m^4, cross bending inertia moment of 16.5811m^4. All piers that are entirely made of C30, with height of 11m, are designed to be circle solid pier with area of 1.7671m^2, bending inertia moment of 0.2485m^4. Spiral reinforcements (φ20) are used as stirrups with pitch of 10cm, and longitudinal tendons are designed to be 15φ28 and the thickness of covering layer is 5cm.

The lead rubber bearing (LRB) is used in the seismic isolation of curved continuous bridge and its restoring force is simulated by a bilinear model which was brought forward by Park in 1986. In this paper, the bidirectional nonlinear behavior of LRB is taken into account by using two orthogonal nonlinear spring elements. Meanwhile, the yield strength (Q), the initial stiffness (K_1), the post yield stiffness (K_2) and the stiffness hardening ratio (η), where η is the ratio of K_2 to K_1, are used as the mechanical parameters of LRB. Then, the nonlinear model of LRB can be simplified to be bilinear model. During the process of actual calculation, it is assumed that the hysteretic performance of LRB can accord with bilinear model and the restoring forces of LRB in two orthogonal directions are identical. In the following paper, the mechanical parameters of LRB with different lead core diameters (D) which refer to reference [5] are applied in the FEA model and shown in Tab.1.

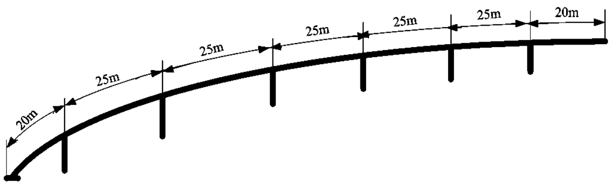

Fig.1: Seismically isolated curved continuous bridge

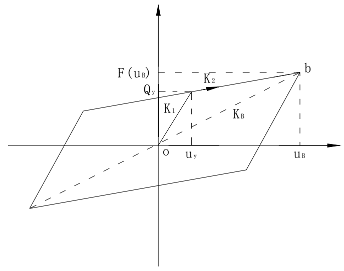

Fig.2: Bilinear hysteretic model of LRB

Tab.1: Basic mechanical parameters of LRB

Lead core diameter /mm	70	90	100	110	130
The initial stiffness /(N/m)	3688108	6096668	7526750	9107368	12720208
Yield strength /N	47616	76100	93012	111705	154430

Seismically isolated curved continuous bridge models with different radius of curvature (R=60m~∞) are established by using the general FEA program SAP2000. Meanwhile, the straight line connecting two abutments and the centerline of bridge is, respectively, chosen as the longitudinal axial (axial X) and the cross axial (axial Y) of the bridge. Axial Z stands for the vertical axial. During the process of designing the absorption and isolation for curved continuous bridge, effect of the principal component of seismic motion along the longitudinal and cross axial of the bridge should be taken into consideration [6]. Additionally, when the analysis model is three-dimensional, it is needed to input three-dimensional seismic motions into structure. And, the PGA in three directions should be adjusted according to the ratio of 1 (X): 0.85 (Y): 0.65 (Z) [7]. In this study, the design seismic intensity is 7 degree. The seismic motions El-centro (NS), El-centro (EW), and El-centro (vertical) with adjusted PGA of 0.25g, 0.2125g, 0.1625g are simultaneously input into the analysis model to research the energy response of seismically isolation curved continuous bridge, and the propagation directions of the earthquake waves is respectively assumed to paralleling to the axial X, Y, Z.

3. Effect of Radius of Curvature

In order to study the effect of variation of radius of curvature (R) on the curved continuous bridges, principal natural periods for different radius of the curved continuous bridges, which are seismically isolated by LRB with ξ of 5%, η of 0.15 and different lead core diameters of 70mm, 90mm, 100mm, 110mm shown in Tab.1, are studied by varying R from 150mm to ∞ under the three-dimensional seismic motion El-centro.

Tab:2 Principal natural periods for different radius

R/m	Seismically isolated curved continuous bridge		Non-isolated curved continuous bridge	
	X-direction	Y-direction	X-direction	Y-direction
150	2.0125	2.0580	0.6184	0.8685
200	2.0053	2.0765	0.6117	0.8736
300	2.0005	2.0821	0.6055	0.8794
400	2.0003	2.0863	0.6030	0.8816
500	1.9994	2.0865	0.6017	0.8827
600	1.9994	2.0867	0.6008	0.8836
700	1.9993	2.0874	0.6003	0.8839
800	1.9991	2.0875	0.5999	0.8843
900	1.9991	2.0887	0.5997	0.8845
∞	1.9989	2.0898	0.5988	0.8853

(1) As shown in Tab.2, vibration models of curved beam bridge are correlative with the connection between pier and beam and the natural period of seismic isolated curved beam bridge can not be affected by the radius of curvature.

(2) By using lead rubber bearing, the principal natural period of the curved beam bridge can be prolonged so that the seismically isolated curved beam bridge can avoid the predominant period of seismic motions. Therefore, the seismic response of the seismically isolated curved bridge can be reduced.

4. Effect of the different seismic motions

In actual engineering, bridges may suffer unknown seismic motions and the seismic response of structure is discrepant under different seismic motions. Consequently, the seismic responses of the seismically isolated curved bridge under the different seismic motions are studied in this paper.

Tab.3: Characteristics of seismic excitation

Earthquake name	PGA/g			Lasting time/s			Predominant period /s		
	NS	EW	Vertical	NS	EW	Vertical	NS	EW	Vertical
Northridge	0.88	0.37	0.34	57.01	59.98	59.98	0.21	0.11	0.16
Kobe	0.83	0.63	0.34	150.0	150.0	150.0	0.34	0.38	0.29
El-centro	0.36	0.21	0.21	53.7	53.46	53.78	0.46	0.41	0.36
Tianjin wave	0.15	0.11	0.07	19.2	19.19	19.19	0.95	1.13	0.89

Four dissimilar seismic motions are input into the analysis model. Especially, El-centro has something in common with other earthquake waves, Kobe is the near field wave, Northridge has some obvious characteristics of impulse waves, and Tianjin wave also has the characteristics of soft soil waves. The detail information of these earthquake waves is listed in Tab.3. Because of the length of this article, only a part of the results are listed in the following paper. When D equals to 200m, the results of E_{I} (the seismic input energy) and $E_{\mathrm{H}}(t)$ (the hysteretic dissipation of LRB) for seismically isolated curved continuous bridge with the lead core diameter of 90mm, the damping ratio of 5%, the stiffness hardening ratio of 0.15, are shown in Tab.4. And, the study results are obtained as following:

Tab.4: Effect of dissimilar seismic excitation on E_{I} /(kN.m) and E_{H} /(kN.m)

R/m	El-centro		Kobe		Northridge		Tianjin wave	
	E_{I}	E_{H}	E_{I}	E_{H}	E_{I}	E_{H}	E_{I}	E_{H}
60	640.3	495.1	512.9	399.0	161.3	106.8	1037	811.3
80	645.1	499.6	512.2	397.4	155.5	101.4	1042	814.6
100	647.9	502.5	512.1	396.8	152.5	98.50	1044	816.1
200	673.6	523.3	495.2	379.2	131.0	78.94	1047	816.2
500	682.0	529.8	491.8	375.8	128.3	76.30	1047	816.1
∞ (straight line)	683.8	531.3	491.2	375.2	128.1	75.90	1048	816.1

(1) The seismic energy response of seismically isolated curved continuous bridge is highly sensitive to the characteristics of seismic motions. According to this example, The seismic energy response corresponding to dissimilar earthquake waves has an discrepancy of 6～7 times. Consequently, in the course of analyzing the seismic energy response for actual engineering, it's suggested that more earthquake waves in similar ground should be chosen to do the analysis and the maximum response values should be use as the design parameters.

(2) Although the seismic energy response corresponding to dissimilar seismic motions has a great discrepancy, they still present relatively accordant rule with the variation of radius of curvature. Namely, when R is less than 200m, the variation of different energies presents obviously; when R greater than 200m, the seismic energy response holds the line. It obviously illustrates that radius of curvature has a notable effect on the seismic response of curved continuous bridge with smaller R (R<200m).

(3) Soft soil ground condition isn't suitable for seismically isolated curved continuous bridge. In this article, the natural period of analysis model in X and Y directions, respectively, is about 1.05s and 1.16s. Additionally, after LRB yield, the structure period corresponding to the equivalent linear stiffness can be further prolonged. As a result, the natural period just enters into the range of the predominant period of earthquake wave. It leads to the acceleration amplification which makes the enlargement of seismic energy response. Consequently, it should be paid much attention on the design of absorption and isolation for curved continuous bridge under the soft soil ground condition.

5. Conclusions

1) vibration models of curved beam bridge are correlative with the connection between pier and beam and the natural period of seismic isolated curved beam bridge can not be affected by the radius of curvature;

2) the principal natural period of the seismically isolated curved beam bridge can be prolonged to avoid the predominant period of seismic motions. Therefore, the seismic response of the seismically isolated curved bridge can be reduced;

3) the seismic response of structure is greatly discrepant under different seismic motions. Especially, when the duration of seismic motion prolongs or the natural period of seismically isolated bridge approaches to the predominant period of seismic motion, the seismic response of structure can be enhanced.

References

[1] ABDEL-SALAM M N, HEINS C P. Seismic Response of Curved Steel Box Girder Bridges [J]. ASCE, 1988, 114(SEl2):2790-2800.

[2] CHANG P C, HEINS C P. Seismic Study of Curved Bridges Using the Rayleigh-ritz Method [J]. Computers & Structures, 1985, 21(6):1095-1104.

[3] QAMARUCDDIN M, ALI S M, QADEER A. Dynamic Response of Horizontally Curved Girders [J]. Journal of Structural Engineering, 1988, 15(2):51-58.

[4] He Jiang. Analysis for Seismic isolated Curve Beam Bridge [D]. Tongji University, 2000.

[5] Zhang Zhen-ge. Study on Vibration Absorption and Isolation of Continuous Beam Railway Bridge[D]. Beijing Jiaotong Universty, 2003.

[6] Eurocode 8-Design Provisions for Earthquake Resistance of S-tructures, Part 2-Bridges[S].

[7] GB50011—2001. Code for Seismic Design of Buildings [S]. (in Chinese)