Response analysis of long-period seismic action in far field to long-span continuous beam bridge with isolated high piers

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Abstract.In order to study the influence of far-field long-period seismic waves on high-pier and long-span continuous beam bridge, taking a high-pier and long-span continuous beam bridge with span arrangement of (95+170+95) m as an example, a numerical analysis model is established based on finite element software. According to the established wave selection criterion, 10 far-field long-period seismic records and 10 ordinary seismic records are selected from the strong earthquake record database. Using nonlinear time history analysis method, the difference of seismic response of long-span continuous beam bridge with isolated high piers under the action of ordinary ground motion and far-field long-period ground motion is studied. The results show that compared with the ordinary ground motion, the seismic response of long-span continuous beam bridge with isolated high piers is obviously increased under the action of long-period ground motion in the far field. When building isolated long-span bridges in areas with great influence of long-period ground motion in the far field, attention should be paid to the adverse effects caused by the frequency spectrum characteristics of ground motion.

1 Introduction

With the development of the western region, long-span bridges with high piers with large overall stiffness, good structural stress and strong spanning capacity have been widely used. However, the design response spectrum in China's current bridge seismic code "Seismic Design rules for Highway Bridges (JTG/TB02-01-2008)" (hereinafter referred to as "Specification") [1] is mainly based on ordinary ground motions with short-period components, and the influence of long-period ground motions in far field is not fully considered. Because the natural vibration period of high-pier and long-span continuous beam bridge is large, which has gone beyond the scope of conventional bridges, it is very important to study its seismic response under long period in far field. Jia Yi [2] studied the seismic system of multi-span continuous girder bridges in high intensity areas. Yang Qing [3] studied the influence of different pier height on the seismic response of continuous girder bridge. Gao Neng [4] analyzes the seismic vulnerability of long-span continuous beam bridges. Li Xuehong [5] studies the dynamic response of continuous girder bridges with low piers under long period earthquake. The results show that the damping and isolation performance can not be brought into full play under the action of long period ground motion in the far field. Li Yong [6] studied the damping effect of viscous dampers on the seismic response of continuous girder bridges. The results show that viscous dampers can significantly reduce the seismic internal force response of continuous girder bridges.

At present, there are relatively few studies on the dynamic behavior of high-pier and long-span continuous beam bridges under long-period ground motions, most existing studies use ordinary strong ground motion records. However, compared with ordinary strong ground motion, long-period ground motion is more likely to have adverse effects on long-period structures such as high-rise buildings, seismic isolated structures and long-span bridges due to its rich low-frequency components.Therefore, based on the selection of far-field long-period seismic records, this paper studies the seismic performance of high-pier and long-span continuous beam bridges under far-field long-period ground motions.

2 Project overview and analysis model

The span arrangement of high pier and long span continuous beam bridge is (95+170+95)m, the main girder adopts variable cross section single box double chamber box girder, the pier column fulcrum beam height is 7m, the side fulcrum and middle span beam height is 3.5m, the variable cross section of beam bottom adopts quadratic parabola, the main girder adopts C50 concrete, the section dimensions of fulcrum and middle span box girder are shown in figure 1. The pier adopts double-leg thin-walled pier, the height is 30m, the section size is 1.5m×6.0m, and the pier body is made of C50 concrete. A J4Q rectangular lead isolation rubber bearing is arranged between the main beam and the abutment and between the main beam and the top of the pier, and the

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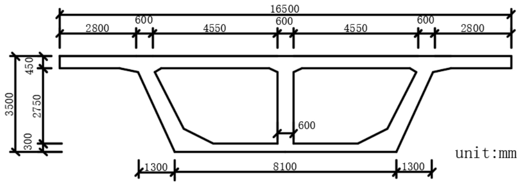
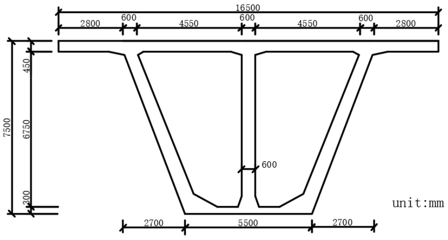
maximum allowable displacement is. The seismic fortification intensity in the area where the bridge is located is 8 degrees (0.2g), and the construction site is classified as Class II site.



(a)Side fulcrum and cross section of mid-span box girder



(b)Section of box beam at pillar fulcrum

Fig 1. The box girder section

Figure 2 shows the finite element analysis model of the high-pier and long-span continuous beam bridge. Among them, the main beam is simulated by beam element, the pier is simulated by elastic-plastic fiber element, the isolation bearing is simulated by spring element, the isolation bearing is arranged between the main beam and pier top and abutment, and the bottom of pier is consolidated.

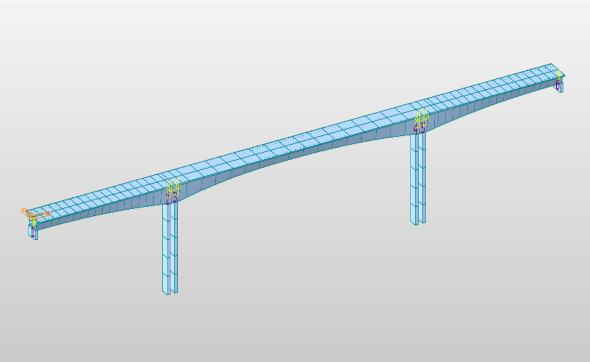


Fig 2. Finite element analysis model

3 Selection and analysis of seismic records

3.1 Selection of seismic waves

As shown in tables 1 and 2, in order to analyze the seismic response of long-span continuous girder bridges with high piers, 10 long-period seismic waves and 10 ordinary seismic waves are selected from the strong earthquake record database of Pacific earthquake Engineering Research Center (PEER).

Table 1. Long period seismic records in the far field

NO.	Serial number	Name of the earthquake	The name of the station	magnitude	The fault distance/km	PGA/g
1	833	Landers(1992)	Anaheim - W Ball Rd	7.28	144.9	0.039
2	844	Landers(1992)	Bell Gardens - Jaboneria	7.28	157.94	0.058
3	847	Landers(1992)	Brea - S Flower Av	7.28	161.23	0.064
4	873	Landers(1992)	Burbank - N Buena Vista	7.28	163.96	0.059
5	874	Landers(1992)	Duarte - Mel Canyon Rd.	7.28	160.85	0.058
6	1307	Chi-Chi, Taiwan	ILA001	7.62	103.2	0.027
7	1352	Chi-Chi, Taiwan	KAU003	7.62	114.44	0.019
8	1761	Hector Mine	Altadena - Eaton Canyon	7.13	166.11	0.033
9	5860	El Mayor-Cucapah	North Shore - Durmid	7.20	84.7	0.061
10	5868	El Mayor-Cucapah	San Jacinto CDF Fire Station 25	7.20	168.48	0.051

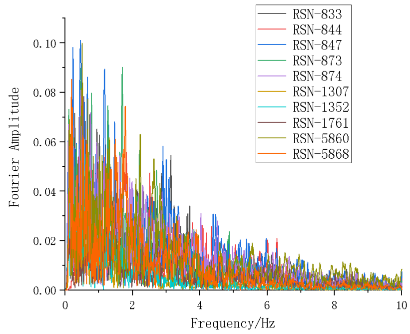
Table 2. Ordinary seismic records

NO.	Serial number	Name of the earthquake	The name of the station	magnitude	The fault distance/km	PGA/g
1	17	Southern Calif	San Luis Obispo	6	73.41	0.04
2	40	Borrego Mtn	San Onefre-So Cal Ed	6.6	129.11	0.04
3	166	Imperial Valley-06	Coachella Canaal #4	6.53	50.10	0.12
4	188	Imperial Valley-06	Plaster City	6.53	30.33	0.04
5	268	Vietoria Mexico	SAHOP Casa Flores	6.33	39.30	0.10
6	280	Trinidad	Rio Dell Overpass-FF	7.2	76.26	0.06

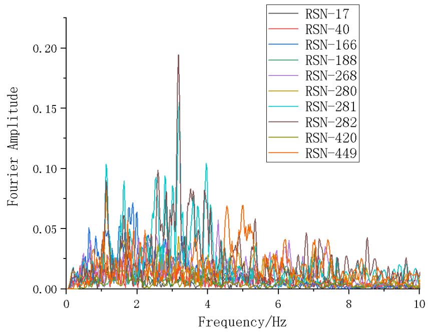
7	281	Trinidad	Rio Dell Overpass	7.2	76.26	0.16
8	282	Trinidad	Rio Dell Overpass	7.2	76.26	0.15
9	420	Ierissos-Greece	Ierissos	6.7	65.67	0.03
10	449	Morgan Hill	Capitola	6.19	39.08	0.10

3.2 comparison of frequency spectrum characteristics of ground motion

Figure 3 shows the Fourier amplitude spectrum of far-field long-period seismic waves and ordinary seismic waves. It can be seen from the diagram that, compared with ordinary seismic waves, the maximum amplitude of far-field long-period seismic waves is mainly concentrated in 0-2Hz, and that of ordinary seismic waves is 2-4Hz. Compared with it, far-field long-period seismic waves are mainly concentrated in the low frequency part.



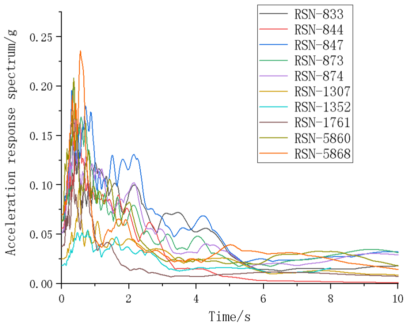
(a)Long period seismic records in the far field



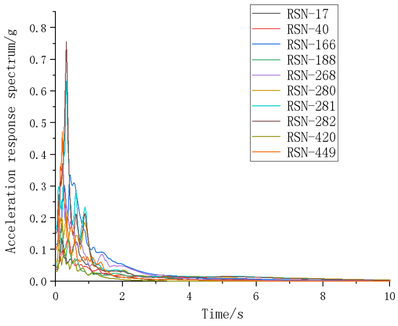
(b) Ordinary seismic records

Fig. 3 Fourier amplitude spectrum

Figure 4 shows the acceleration response spectrum of far-field long-period seismic waves and ordinary seismic waves. It can be seen from the diagram that the amplitude of ordinary seismic wave is mainly distributed in 0-2s, and the amplitude of long-period seismic wave in far field is mainly distributed in 0-8s, which is much larger than that of ordinary seismic wave after 1 s, that is, far-field long-period seismic wave has a great influence on long-period structure.



(a)Long period seismic records in the far field



(b) Ordinary seismic records

Fig. 4 Acceleration response spectrum

4 Dynamic characteristic analysis

The dynamic characteristics of high-pier and long-span continuous beam bridge with isolation bearings are analyzed, and its natural vibration period and vibration mode are obtained. Table 3 lists the fifth-order vibration modes of the long-span continuous beam bridge with high piers. From the first five vibration modes, it can be seen that the natural vibration period of the bridge structure is larger and the low-frequency component of the structure is higher. Combined with Fourier amplitude spectrum analysis, it can be found that bridge structures are more easily affected by long-period seismic waves than ordinary ground motion.

Table 3 dynamic characteristics of bridges

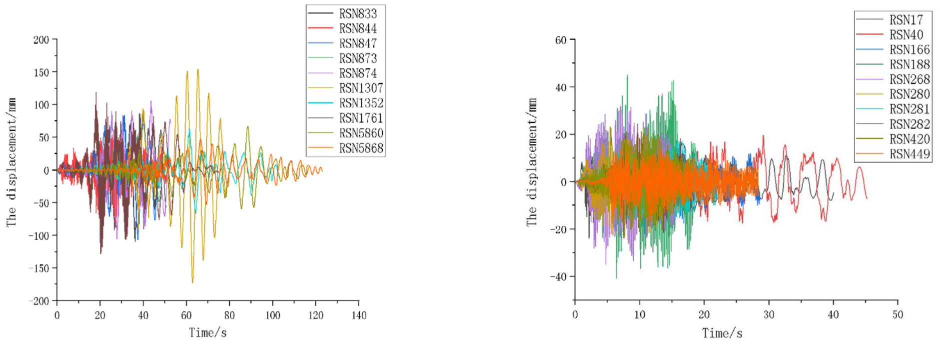
Modal order number	Free vibration period/s	Natural frequency of vibration/Hz	Modal characteristics
1	5.423	0.184	The piers bend in the same direction and the main beam swings longitudinally
2	4.548	0.219	The piers bend in the same direction and the main beam swings laterally

3	4.094	0.244	The piers are bent in reverse and the main beams rise and fall
4	3.054	0.327	Bridge pier reverse transverse bend, the main beam is S-shaped transverse swing
5	1.991	0.502	The piers are bent in the same direction, and the main beam rises and falls in S-shape

5 Seismic response analysis

Taking the long-period far-field seismic records and ordinary seismic records listed in Table 1 and Table 2 as inputs, the amplitude modulation is unified to 0.2g, and the seismic responses of high-pier and long-span continuous beam bridges are compared and analyzed.

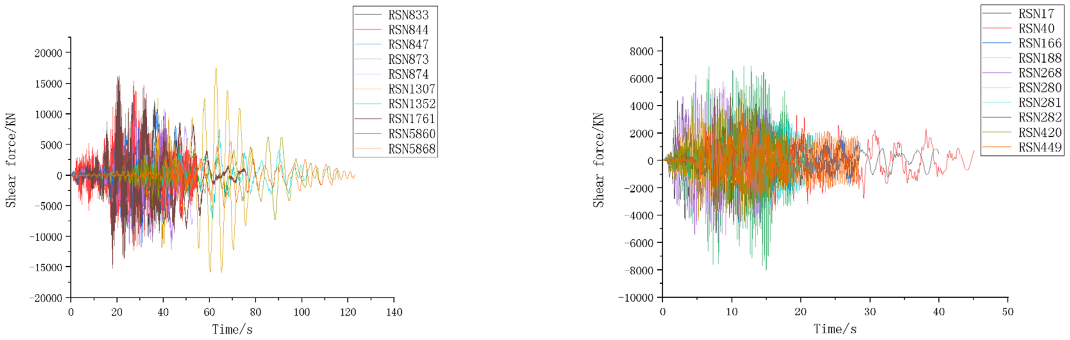
Figure 5 shows the comparison of displacement responses of high-pier and long-span continuous rigid frame bridges under far-field and ordinary ground motions. It can be seen from the figure that the displacement amplification effect of long-period ground motion on long-period flexible structures is very significant. The reason is that the low frequency component of long period seismic wave is high, which is easy to cause the resonance phenomenon of flexible structure. At the support, the displacement response of the far-field long-period ground motion is obviously larger than that of the ordinary ground motion. Under the action of long-period ground motion in the far field, the maximum displacement response of the bearing is mainly distributed between 20-60s, and the average displacement response is 90.0mm. The maximum displacement response of the ordinary ground motion support is mainly distributed between 5-15s, and the average displacement is 24.2mm. As an index closely related to the earthquake damage of structural members, attention should be paid to the influence of seismic spectrum characteristics on the displacement response of long-span continuous beam bridges with high piers.



（a）Long period ground motion in far field （b）Ordinary ground motion

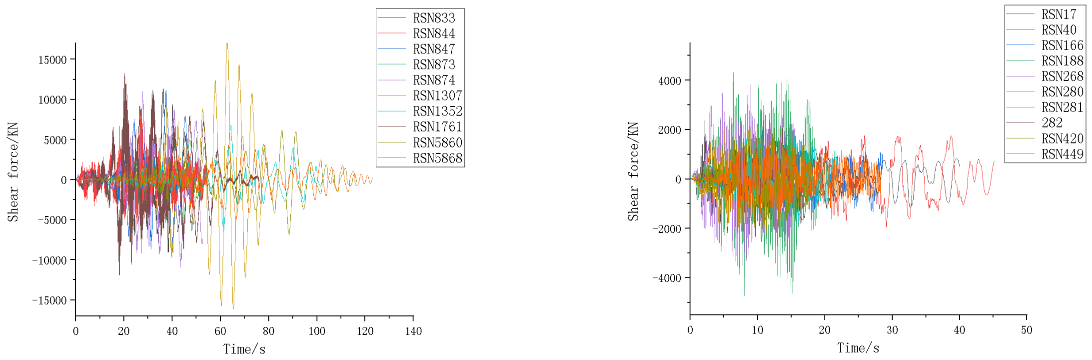
Fig. 5 Bearing displacement

Fig. 6 and 7 show the comparison of shear response of a continuous rigid frame bridge with high pier and long span under far field and ordinary ground motion. As can be seen from the figure, no matter at the bottom or top of the pier, the shear response under the far-field long-period ground motion is obviously larger than that of ordinary ground motion. Taking the pier top as an example, the maximum shear force at the pier bottom under the action of long period ground motion in the far field is mainly distributed between 20 and 60s, and the average shear force is 10055.5kN; the maximum shear force at the pier bottom under the action of ordinary ground motion is mainly distributed between 5 and 15s, and the average shear force is only 2512.9kN.



（a）Long period ground motion in far field （b）Ordinary ground motion

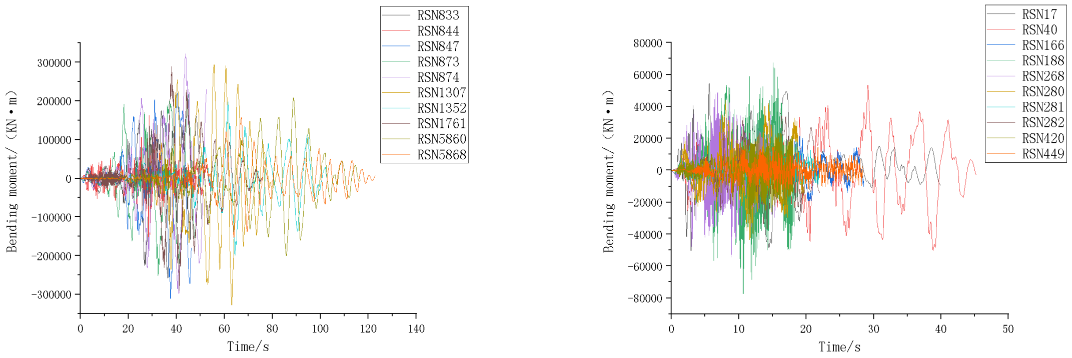
Fig. 6 Shear force at the bottom of pier



（a）Long period ground motion in far field （b）Ordinary ground motion

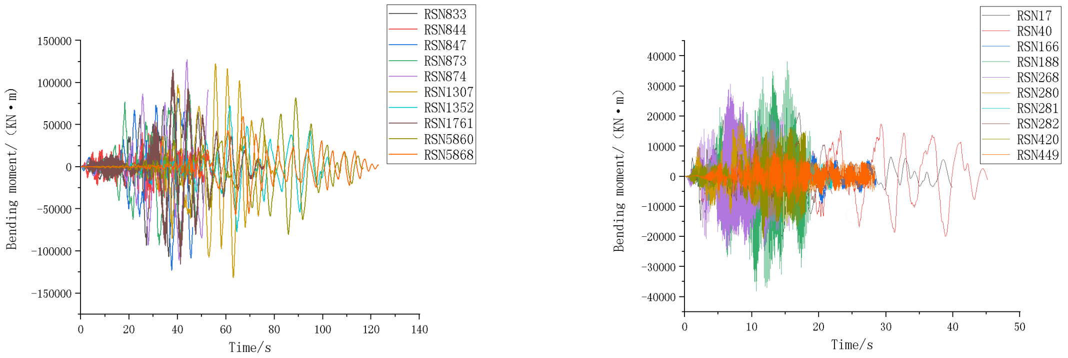
Fig. 7 Pier top shear force

Fig. 8 and 9 show the comparison of bending moment response of a continuous rigid frame bridge with high pier and long span under far field and ordinary ground motion. It can be seen from the figure that the bending moment response under long period ground motion in far field is obviously larger than that under normal ground motion, no matter at the bottom or top of the pier. Taking the pier top as an example, the maximum bending moment of the pier bottom under the action of long period ground motion in the far field is mainly distributed between 30 and 60s, and the average bending moment is 17938.7kN·m. Under the action of ordinary ground motion, the maximum bending moment of the pier bottom is mainly distributed between 5 and 10s, and the average bending moment is only 856460.6kN·m.



(a)Long period ground motion in far field （b）Ordinary ground motion

Fig. 8 Bending moment at the bottom of pier



（a）Long period ground motion in far field （b）Ordinary ground motion

Fig. 9 Pier top bending moment

6 Conclusion

Through the comparative study of the seismic response of long-span continuous beam bridge with high piers under the action of far-field long-period ground motion and ordinary ground motion, the following conclusions are mainly obtained:

(1) The analysis of Fourier spectrum shows that the biggest difference between long-period seismic waves

and ordinary seismic waves lies in the distribution range of dominant frequency. The former is mainly concentrated in the low frequency band of 0-2.0Hz, while the latter is generally 2-4Hz. Compared with ordinary seismic waves, the low frequency components of long period seismic waves in far field are more abundant.

(2) Based on the analysis of the dynamic characteristics of the whole bridge, it is shown that the basic natural period of the high-pier and long-span continuous beam bridge is more than 5s, which is a typical long-period structure. Compared with the ordinary ground motion, it is more easily affected by the long-period ground motion.

(3) The displacement and internal force response of high-pier and long-span continuous beam bridge under far-field long-period ground motion is obviously larger than that of ordinary ground motion. The influence of seismic spectrum characteristics should be taken into account in the seismic design of this kind of bridges.

(4) The displacement response of the long-span continuous beam bridge with high piers is large under the long-period earthquake in the far field, and the influence of beam end collision on the response analysis needs to be further studied.

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