Seismic response analysis of high-pier long-span continuous rigid-frame bridges under far-field long-period ground motions

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Abstract. The seismic response of a high-pier long-span continuous rigid frame bridge under the action of far-field long-period ground motions is studied. A numerical calculation model of a high-pier long-span continuous rigid frame bridge whose span layout is (95+170+95)m is established by using finite element software. According to the established wave selection criteria, 10 long-period far-field seismic records and 10 ordinary seismic records are selected from the strong earthquake record database. Using the dynamic time history analysis method, the seismic response of the bridge structure under the far-field long-period seismic record and the ordinary seismic record was obtained through calculation, and a comparative analysis was carried out. The results show that the seismic response of a high-pier long-span continuous rigid frame bridge under far-field long-period ground motions is significantly greater than that of ordinary ground motions, the effect of ground motion spectrum characteristics should be considered in seismic design of such Bridges.

1. Introduction
The continuous rigid frame bridge is one of the most competitive bridge types in the selection of long-span bridges [1]. In the past 20 years, the construction of transportation infrastructure in the western region of my country has made rapid progress. In order to meet the needs of the complex terrain and geomorphic conditions in the western region, high-pier and large-span continuous rigid frame bridges have been widely used. This type of bridge has the characteristics of pier height, flexible system, and large natural vibration period, which is beyond the scope of regular bridges, its dynamic stability, seismic response and damping measures under earthquake action are currently one of the research hotspots in the field of earthquake engineering [2-7]. Li Li et al. [2] studied the influence of seismic wave input direction, damping ratio and different constraints on the first class of dynamic stability problems of long-span continuous rigid frame Bridges with high piers. Zhang Qian et al. [3] studied the effects of ground motion characteristics, damping ratio, and structural characteristics on the dynamic stability of high-pier long-span continuous rigid frame bridges. He et al. [4] analyzed the dynamic characteristics and seismic response of a high-pier long-span continuous rigid frame bridge. Wu et al. [5] conducted seismic damage analysis on an asymmetric continuous rigid frame bridge. Jia Yi et al. [6] studied the influence of pile-soil interaction and traveling wave effect on the seismic response of long-span curved continuous rigid frame bridge with high piers. Shan Deshan et al. [7] studied the
influence of the change of the fault distance on the seismic response of a high-pier long-span continuous rigid frame bridge based on the Wenchuan ground motion record. Qin Chang et al. [8] studied the effects of long-period ground motions on the shear and displacement responses of high-pier and long-span continuous rigid-frame bridges, and the results showed that long-period ground motions greatly amplify the seismic response of key sections of high piers. Zhao Jidong et al. [9] studied the seismic response of rigid frame bridges with viscous dampers on the abutment, the results show that viscous dampers can significantly reduce the seismic internal force response of high-pier long-span continuous rigid-frame bridges.

At present, there are relatively few studies on the dynamic behavior of high-pier and long-span continuous rigid frame bridges under the action of long-period ground motions, most existing studies use ordinary strong ground motion records. However, compared with ordinary strong ground motions, long-period ground motions are more likely to have adverse effects on long-period structures such as high-rise buildings, seismic isolation structures, and long-span bridges due to their 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 long-span continuous rigid frame bridges under far-field long-period ground motions.

2. Project overview and analysis model

A high-pier long-span continuous rigid frame bridge with a span layout (95+170+95) m. The main beam adopts a single-box double-chamber box girder with variable section, the beam height at the fulcrum of the pier column is 7m, the side fulcrum and the height of the mid-span beam are 3.5m, the changing section of the beam bottom adopts a secondary parabola, the main beam adopts C50 concrete, and the cross-sectional dimensions of the box beam at the fulcrum and the middle span are shown in Figure 1. The bridge pier adopts double-limbed thin-walled pier with a height of 30m and a cross-sectional size of 1.5m×6.0m, the pier body is made of C50 concrete. A basin-type GPZ50DX support is set between the main beam and the abutment. The seismic fortification intensity of the area where the bridge is located is 8 degrees (0.2g), and the construction site is classified as Class II site.

Figure 2 shows the finite element analysis model of the high-pier long-span continuous rigid frame bridge. Among them, the main beam is simulated by beam elements, the bridge piers are simulated by fiber elements, the supports are simulated by spring elements, and the main beam and piers are treated by rigid connection.
3. Seismic record selection and spectral characteristic analysis

In order to study the seismic response of a long-span continuous rigid frame bridge with high piers under long-period ground motions in the far field, from the strong earthquake record database of the Pacific Earthquake Engineering Research Center (PEER), 10 far-field long-period seismic records and 10 ordinary seismic records are selected, for detailed information, see Table 1 and Table 2.

### 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   | 856           | Landers(1992)           | Arcadia - Arcadia Av    | 7.28      | 137.25                 | 0.030 |
| 3   | 844           | Landers(1992)           | Bell Gardens - Jaboneria| 7.28      | 154.26                 | 0.047 |
| 4   | 847           | Landers(1992)           | Brea - S Flower Av      | 7.28      | 137.44                 | 0.041 |
| 5   | 849           | Landers(1992)           | Buena Park - La Palma   | 7.28      | 150.09                 | 0.054 |
| 6   | 873           | Landers(1992)           | Burbank - N Buena Vista | 7.28      | 157.94                 | 0.058 |
| 7   | 874           | Landers(1992)           | Duarte - Mel Canyon Rd. | 7.28      | 126.33                 | 0.021 |
| 8   | 1063          | Landers(1992)           | El Monte - Fairview Av  | 7.28      | 135.88                 | 0.037 |
| 9   | 5860          | Landers(1992)           | Huntington Bch - Waikiki| 7.28      | 156.00                 | 0.056 |
| 10  | 5868          | Landers(1992)           | LA - E Vernon Ave       | 7.28      | 157.69                 | 0.040 |

### 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 Onofre-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           | Victoria Mexico        | SAHOP Casa Flores       | 6.33      | 39.30                  | 0.10  |
| 6   | 280           | Trinidad               | Rio Dell Overpass       | 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  |

Figure 3 shows the Fourier amplitude spectrum of the far-field long-period seismic record and the ordinary seismic record. It can be seen from the figure that, compared with ordinary seismic records, the low-frequency components in the far-field long-period seismic records dominate, with (0~2.0) Hz dominated.
4. Dynamic characteristic analysis

The dynamic characteristics of the high-pier long-span continuous rigid frame bridge are analyzed, and its natural vibration period and mode shape are obtained. Table 3 lists the first five-order natural frequency and mode shape of the bridge structure. It can be seen from the table that the fundamental frequency of the bridge structure is relatively small and the system is relatively flexible. Combined with the analysis of the Fourier amplitude spectrum, it can be found that the bridge structure is more susceptible to long-period ground motions than ordinary ground motions.

| Modal order number | Natural frequency of vibration/Hz | Vibration mode | Modal characteristics |
|--------------------|----------------------------------|----------------|-----------------------|
| 1                  | 0.34                             |                | The piers bend in the same direction and the main beam swings longitudinally |
| 2                  | 0.59                             |                | The piers bend in the same direction and the main beam swings laterally |
| 3                  | 0.63                             |                | The piers are bent in reverse and the main beams rise and fall |
| 4                  | 1.04                             |                | Bridge pier reverse transverse bend, the main beam is S-shaped transverse swing |
| 5                  | 1.25                             |                | The piers are bent in the same direction, and the main beam rises and falls in S-shape |

5. Seismic response analysis

Taking the far-field long-period seismic records and ordinary seismic records listed in Table 1 and Table 2 as input, adjust the amplitude uniformly to 0.2g, and the seismic response comparison analysis of the high-pier long-span continuous rigid frame bridge is performed.

Figure 4 shows the displacement response comparison of a high-pier long-span continuous rigid frame bridge under far-field and ordinary ground motions. It can be seen from the figure that the displacement response under the action of far-field long-period ground motions is significantly greater than ordinary ground motions, no matter at the support or the top of the pier. Taking the support as an example, the average displacement response of the support under the long-period ground motion of the far field is 343.1mm, and the average displacement response of the support under the ordinary ground motion is only 164.0mm, which is quite different. Displacement is an index closely related to the
seismic damage of structural members, when the seismic design of high-pier long-span continuous rigid frame bridges is carried out, attention should be paid to the effect of ground motion spectrum characteristics on the displacement response of such Bridges.

![Displacement comparison between far-field and ordinary seismic records](image1)

**Fig 4.** Displacement comparison between far-field and ordinary seismic records

Figure 5 shows the comparison of the shear response of a high-pier long-span continuous rigid frame bridge under far-field and ordinary ground motions. It can be seen from the figure that the shear response under the action of far-field long-period ground motions is significantly greater than ordinary ground motions regardless of whether it is at the bottom or top of the pier. Taking the pier bottom as an example, the average shear force of the pier bottom under the action of far-field long-period ground motion is 7355.2kN, and the average shear force of the pier bottom under the action of ordinary ground motion is only 1356.9kN, the average shear force at the bottom of the pier under the action of far-field long-period ground motions is 5.4 times that of ordinary ground motions.

![Comparison of shear force between far-field and ordinary seismic records](image2)

**Fig 5.** Comparison of shear force between far-field and ordinary seismic records

Figure 6 shows the comparison of the bending moment response of a high-pier long-span continuous rigid frame bridge under far-field and ordinary ground motions. It can be seen from the figure that the bending moment response under the action of far-field long-period ground motions is obviously greater than that of ordinary ground motions regardless of whether it is at the bottom or top of the pier. Taking the pier bottom as an example, the average bending moment of the pier bottom under the action of far-field long-period ground motion is 107920kN \( \cdot \) m, and the average bending moment of the pier bottom under the action of ordinary ground motion is only 20923kN \( \cdot \) m, the average bending moment at the bottom of the pier under the action of long-period far-field ground motions is 5.2 times that of ordinary ground motions.
6. Conclusion
Through the comparative study of the seismic response of the high-pier long-span continuous rigid frame bridge under the action of far-field long-period ground motion and ordinary ground motion, the following conclusions are mainly obtained:

1. Compared with ordinary ground motions, the low-frequency components of far-field long-period ground motions dominate, mainly 0~2.0 Hz.

2. The high-pier long-span continuous rigid frame bridge has a lower fundamental frequency and a softer system, compared with ordinary ground motions, it is more susceptible to long-period ground motions.

3. Under the action of far-field long-period ground motions, the displacement and internal force response of high-pier long-span continuous rigid frame bridges are significantly greater than ordinary ground motions, the effect of ground motion spectrum characteristics should be considered in seismic design of such Bridges.

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