Study on seismic performance of high pier multi-span beam bridge

Liu Manhui, Han Xiaodong, He Yiyang, Li Zhigang, Niu Zhe, Li Zihao
Chang'an University Xi'an Shaanxi Province P.R.China
3094808857@qq.com

Abstract: Girder bridge with high piers has obvious advantages in crossing deep gorges, and is commonly applied to highway construction in the western mountainous area of China. In Qinghai province, the earthquake response is very complicated, and the seismic design is absolutely necessary. In this paper, the seismic performance of the typical span of a high-pier-girder bridge in seismic zone of Qinghai province is analyzed by the time-history analysis method based on the existing seismic design code. The seismic response characteristics and development rules of the bridge are obtained, and the methods to effectively improve the integrating stiffness and seismic performance of the bridge are discussed. The results can provide references for the seismic design of the same kind of bridges.

1. Preface
In order to strengthen the overall transverse and longitudinal stiffness of the bridge, pier beams are frequently consolidated. At present, there are few pieces of researches on the dynamic performance of high-pier continuous rigid frame Bridges, which belong to irregular Bridges in seismic codes. Such Bridges should select appropriate seismic waves for time-history analysis according to the site situation and dynamic characteristics. In the seismic review process, the bending moment, shear force and displacement of the top of pier should be noticed to avoid shear failure of the pier, expansion joint damage and collision of falling beams caused by excessive displacement. This paper relies on an engineering project, and obtains the dynamic characteristics of this kind of bridge through finite element calculation and seismic performance analysis, which has a strong engineering guidance significance.

2. Engineering background
Wolonggou No. 4 Bridge is an (8×40) m prestressed concrete T-beam bridge with a width of 12m. The lower structure adopts hollow pier and pile foundation, the highest pier length is 104.182m, and the pier wall thickness is 80-85cm. Pile foundations of rock-socketed pile piers are embedded in weathered bedrock, and the minimum depth is not less than 3 times the diameter of pile foundations.

3. Calculation model
The calculation model is divided into 169 units of beam element established by the finite element calculation software. The pier-beam connection is simulated by rigid connection and elastic connection, and the general support consolidation is used at the bottom of pile. The height of the 3# pier to 11# pier is shown in Table 1, and the finite element calculation model is shown in Figure 1.
Figure 1 finite element calculation model

Table 1 Bridge height statistics

| Pier number | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 |
|-------------|----|----|----|----|----|----|----|----|----|
| Pier length/m | 70.56 | 94.04 | 97.71 | 104.18 | 104.15 | 100.73 | 82.90 | 61.07 | 39.93 |

To study the dynamic characteristics of the structure, the natural frequencies and modes are analyzed by subspace iteration method. The first 10 modes of the bridge are extracted by finite element analysis, as shown in Table 2. In order to study the reasonable connection between pier and beam, this paper establishes another model in different connection method, and extracts the first 10 vibration modes through calculation and analysis, as shown in Table 3.

Table 2 Natural vibration characteristics of high pier bridges

| Vibration mode number | Vibration mode frequency /Hz | Vibration period /s | Vibration characteristics |
|-----------------------|-----------------------------|--------------------|--------------------------|
| 1                     | 0.35                        | 2.81               | Symmetrical transverse bending of main pier and main beam |
| 2                     | 0.39                        | 2.54               | Longitudinal movement    |
| 3                     | 0.40                        | 2.49               | Side pier longitudinal movement |
| 4                     | 0.46                        | 2.12               | Anti-symmetrical transverse bending main pier and main beam |
| 5                     | 0.64                        | 1.55               | Symmetrical transverse bending main pier and main beam |
| 6                     | 0.90                        | 1.11               | Side pier longitudinal movement |
| 7                     | 0.99                        | 1.01               | Transverse bending main pier and main beam |
| 8                     | 1.16                        | 0.85               | Longitudinal bending main pier |
| 9                     | 1.29                        | 0.77               | Longitudinal bending main pier |
| 10                    | 1.34                        | 0.74               | Longitudinal bending main pier |
Table 3 Structural natural vibration characteristics of bridge pier and main beam connected by abutment

| vibration mode number | vibration mode frequency /Hz | vibration period /s | Vibration characteristics                      |
|-----------------------|------------------------------|---------------------|------------------------------------------------|
| 1                     | 0.13                         | 7.42                | longitudinal movement                           |
| 2                     | 0.28                         | 3.53                | piers longitudinal movement                     |
| 3                     | 0.30                         | 3.35                | piers longitudinal movement                     |
| 4                     | 0.31                         | 3.20                | piers longitudinal movement                     |
| 5                     | 0.33                         | 3.01                | piers longitudinal movement                     |
| 6                     | 0.36                         | 2.76                | Symmetrical transverse bending of main pier and main beam |
| 7                     | 0.41                         | 2.47                | piers longitudinal movement                     |
| 8                     | 0.51                         | 1.95                | Anti-symmetrical transverse bending of main pier and main beam |
| 9                     | 0.65                         | 1.54                | piers longitudinal movement                     |
| 10                    | 0.67                         | 1.49                | Symmetrical transverse bending of main pier and main beam |

It can be seen from Table 2 that the fundamental frequency of the bridge is 0.35Hz, which is smaller than that of the bridge with normal pier height. The reason is that the bridge has a larger flexibility, and its structural stiffness is less than that of the normal bridge. The first mode of vibration of the structure is the positive symmetrical transverse bending of the main beam and the second mode is the longitudinal displacement of the whole bridge. It can be found that the longitudinal displacement and failure probability of expansion joints should be reduced by strengthening the longitudinal thrust stiffness of the high pier in the design. From Table 2 and Table 3, it can be seen that because of the connection change of the bridge has obvious changes in modal frequency, natural vibration period and mode characteristics, and the frequency decreases obviously. It is disadvantageous to the structure. The first few orders of vibration are mainly the main pier vibration, the vibration frequency is very small, which shows that under the load excitation, it is easy to stir up the vibration of the pier, which is not conducive to the bearing force and the seismic performance.

4. Seismic Time-History Response Analysis

The linear time history method is used to analyze the seismic response. The seismic fortification intensity at the bridge site is 7 degrees, the peak acceleration of ground motion is 0.1g, the characteristic period of response spectrum is 0.35s, and the environmental category is type II. According to (JTG/T B02-01-2008) and (JTG B02-2013), the seismic fortification category of the bridge is 4, and the intensity of seismic fortification is 8. The main purpose of this study is to reveal the dynamic characteristics and seismic performance of high pier bridges under earthquake action. Therefore, this paper calculates the seismic action of E1, adopts linear elastic time history analysis method, and calculates it by direct integration method. El-Centro seismic wave is used for seismic wave input, and it is revised according to the requirements of E1 seismic grade and ground motion.

In this paper, the multi-dimensionality of seismic motion is studied by inputting multiple directions of seismic wave excitation, which are along the bridge, transverse the bridge and vertical the bridge. Among them, the first two are horizontal seismic waves, the latter is vertical seismic waves. The seismic design rules of highway bridges (JTG / tb02-01-2008) and the urban bridge design code (cjj11-2011) in China adopt the vertical seismic acceleration response spectrum to be obtained by multiplying the horizontal design acceleration response spectrum by the spectral ratio function R. Figure. 2 shows the displacement time-history curve of the end of the pier-beam consolidation beam, and Figure. 3 shows the displacement time-history curve of the support connection.
Figure. 2 Time history curve of consolidation displacement of pier and beam at beam end

Figure. 3 Time history curve of supporting connection displacement of pier and beam at beam end

From Figure 2 and Figure 3, it can be seen that under seismic loads, when piers and beams are connected by bearings, the displacement along the end of the bridge increases significantly compared with consolidation. From the change of natural frequency and displacement at the end of the beam, it is suggested that high pier bridges should adopt the consolidation form of multiple piers and main girders to enhance their overall stiffness and seismic performance. In this paper, the response of pier beam consolidation connection under the action of seismic wave is discussed.

| Section | Axial force /kN | Shear force /kN | Bending moment / (kN.m) |
|---------|----------------|----------------|-------------------------|
|         | Along the bridge | Transverse | Along the bridge | Transverse |
| Bottom of pier |
| 3       | 2009           | 3087          | 6045                    | 103406 | 121748 |
| 4       | -2190          | -4234         | 5332                    | -117850 | -128802 |
| 5       | 5585           | -3948         | 5585                    | -114471 | 137916 |
| 6       | 783            | -3467         | 5465                    | -109798 | -182942 |
| 7       | -607           | -3550         | -5160                   | -108788 | -168928 |
| 8       | -819           | -3916         | -4877                   | -114531 | -141382 |
| 9       | -1694          | 6982          | 7351                    | -115447 | -130858 |
| 10      | 2565           | 4283          | 7740                    | 76778   | -141544 |
| 11      | 1317           | 3284          | -4086                   | -75504  | 76916   |

It can be seen from Figure 2, and table 4 that the response of the Wolonggou 4 bridge under the seismic load has the following characteristics:

The pier height of the bridge is significantly different, the slenderness ratio of the high pier and the low pier, and the stiffness is also different. Under the earthquake load, the force is distributed according to the stiffness, and the low pier should bear a larger proportion of the load. Therefore, the connections between the lower piers and the main beam are support connections, and the others are consolidated, in order to transfer the load of the low pier under the earthquake, and the internal force can be well-distributed.
5. Conclusion

In this paper, the high pier multi-span girder bridge in high-intensity mountainous area is taken as the research object. By establishing the finite element model of the bridge structure and using the linear time history method, the seismic response characteristics of the bridge are analyzed. The following conclusions are drawn:

1) Under seismic load, the force of transverse on the bottom section of pier is greater than that along the bridge, which is consistent with the vibration response of the first mode of structure. The hollow pier section structure adopted in the design is reasonable, and the transverse stiffness of the bridge is greater than the longitudinal stiffness of the bridge, which can meet the needs of structural stress and seismic design.

2) Under the action of seismic load, the main vibration of the high-pier bridge is the out-of-plane vibration. There are differences in the stiffness of the cross-section and along the bridge, so it is more reasonable to consider the seismic design of the structure in accordance with the force.

3) When the height difference between adjacent piers is significant, the short pier bears large forces, which is not conducive to the rational distribution of structural forces. In the design, the high pier is consolidated with the main beam, and setting abutment between the short pier and main beam, which can optimize the overall stress of the bridge. Under the seismic load, the structural response is more uniform, and the seismic resistance is improved. This design method can provide a reference for the same type of bridge.

References

[1] Zhe Jia, Weiwen Chen, Risheng Chu. Preliminary study on aftershock decay rate of the 2013 Ms 7.0 Lushan earthquake[J]. Earthquake Science. 2013(Z1).

[2] V. Valamanesh, H.E. Estekanchi, A. Vafai, M. Ghaemian. Application of the endurance time method in seismic analysis of concrete gravity dams[J]. Scientia Iranica, 2011, 18(3).

[3] Seismic Design and Retrofit of Bridges. Priestley M J N, Seible F, Calvi G M. 1996.

[4] Seismic performance of multisimple-span bridges retrofitted with link slabs. A. Caner. Journal of Bridge Engineering, March-April. 2002.

[5] Zhang, Zhongjie, Wang, Yanghua, Chen, Yun, Houseman, Gregory A., Tian, Xiaobo, Wang, Erhie, Teng, Jiwen. Crustal structure across Longmenshan fault belt from passive source seismic profiling[J]. Geophysical Research Letters. 2009 (17).