Comparative Research on Anti-Seismic Test for FPB and Ordinary Spherical bearing

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Abstract: In this paper, a two-span-32m-simply supported girder bridge is studied. The Anti-seismic experiments are conducted for two groups of two-span bridges of low pier and middle pier based on a bridge model, 1/7 large of the real bridge established by principle of similitude. The impacts of three different seismic oscillations on the seismic response(displacement of bearings, internal force of piers and etc.) of simply supported beams of ordinary spherical bearings and FPBs under 7,8 and 9 intensities are discussed. The damage under different seismic oscillations are made clear and the study shows that FPBs boast of good Anti-seismic performance under near seismic oscillations of different levels and are more suitable for low pier structures.

1. Introduction
Friction Pendulum Bearing (FPB) is an efficient Anti-seismic system characterized by dry frictional sliding and it has been successfully applied in architecture and bridge engineering due to its good performance. The design principle of FPB is to prolong the natural vibration period of the structure through pendulum principle so as to avoid the characteristic period of seismic waves. And meanwhile consuming the input energy generated by seismic wave against superstructure through utilizing the friction energy dissipation generated. Which control the seismic response of the structure and alleviate the destruction of seismic waves. Many researchers have been conducted on the basic performance of FPB, but the comparative research on the Anti-seismic for FPB and ordinary spherical bearing are still limited. Therefore, this paper, aiming at the design limitation of seismic mitigation of bridges, carried out comparative research on the seismic resistance of the FPB and ordinary spherical bearing of a simply supported girder bridge, thus comprehensively and systemically evaluating the reliability and security of the bridge on their Anti-seismic design through shaking table test.

2. The Determination of the Similitude Relation of Shaking Table Tests
The theory of similitude is the theoretical basis to determine the similitude relation of shaking table tests. There are two methods to determine the similitude relation of models: equation analysis and dimensional analysis. Both of these methods should follow the theory of similitude. The equation analysis should provide a definite mathematical equation for the relationship between the test result and the test condition, and then determine the similitude condition according to the mathematical
equation. However, the tests on bridge structure are more complex and without definite function relation, so the similitude condition of the prototype bearing and the reduced scale bearing is determined by quasi dimensional analysis. Formula (1-1) is the similitude requirement that should be met by the similitude constant of physical quantity in the dynamics problem of structural shaking table tests.

\[
\frac{S_E}{S_p S_a S_I} = 1
\]  

(1-1)

In this formula, \( S_E \) refers to the similitude constant of elasticity modulus, \( S_p \) means the similitude constant of mass density, \( S_a \) is the similitude constant of accelerated velocity and \( S_I \) is the similitude constant of length.

The model used in the tests are mainly applied in the engineering verification experiments and the material of the model is the same as that of the prototype. Considering the range of pier height and the ability of the shaking table, bridge models, 1/7 large of the real bridge are selected in the tests. According to the law of similitude in seismic experiments, the range of similitude constants of the major physical quantities is obtained between the model and the prototype. The values of the similitude constants of the dynamic model in this experiment take size, material and accelerated velocity as major controlling parameters, namely, other similitude constants are deduced by these four parameters.

3. Experiment Process

3.1. Experimental Model

At the experiment site, two two-span-32m bridge prototypes (one with 8m low piers and the other with 25 m middle piers) are selected to establish two-span models (1/7 large of the real bridge) for the seismic mitigation and isolation experiments and 2 groups of shaking table tests are conducted. FPB and ordinary spherical bearings are installed on the low pier and middle pier respectively to form two different bearing systems for the shaking table tests. Altogether, there are 6 groups of tests. Figure 4 shows the model of the high-speed rail bridge in the experiment.

![Figure 1. Model of the Railway Bridge](image)

According to the design of the shaking table tests, the FPB module of software MIDAS is used to analyze the seismic mitigation and isolation and the performance parameters of these two bearings are obtained, as shown in table 1. In the course of the tests, the ordinary spherical bearing and the FPB are arranged according to the way adopted in two-span simply supported girder bridge, as shown in Figure 2.

| Type of bearing | Pier (m) | Vertical bearing capacity(kN) | Horizontal bearing capacity (kN) | Pre-earthquake displacement (mm) | Post-earthquake displacement (mm) | Friction coefficient | Radius of seismic mitigation (mm) |
|----------------|---------|-------------------------------|----------------------------------|---------------------------------|----------------------------------|---------------------|-----------------------------|
| Ordinary       | 8/25    | 60                            | 18                               | Vertical                       | Horizontal                      | 0.01                | /                           |

2.
3.2. Plan for Seismic Excitation
According to seismic fortification and site requirements, the following seismic records are selected: Wenchuan, Kobe (Hanshin Earthquake), Northridge (the United States North Ridge Earthquake), and the proportions of the acceleration time under 7, 8, 9 intensities are amplified and reduced. The loading directions of selected seismic waves are as follows: along-span, transverse, along-span plus vertical, and transverse plus vertical. In the tests, seismic mitigation and isolation technologies are not used in the ordinary spherical bearings, thus they serve as comparison reference for the performance of FPB in seismic mitigation and isolation. Due to limited length, only the time curves of seismic waves under intensity 8 are given, as shown in Figure 3.

4. Test results and analysis
4.1. Peak value of bearing displacement test
Table 2 shows the peak value of the bearing displacement test when the 8m and 25m piers are subjected to high ground motion input. It can be seen from the test that under the action of 7 degree earthquake, the bearing shear pin of the friction pendulum bearing is not sheared, and the displacement of support is pretty close to the common spherical bearing. When the seismic intensity is loaded to 8 degrees, the bearing shear pin of the friction pendulum bearing is sheared, and the sliding of the surface friction pair is generated, so that the relative displacement of the friction pendulum bearing is much larger than the relative displacement of the bearing of the ordinary spherical bearing. With the increase of the intensity, the difference is more and more obvious.
Table 2. 8m and 25m pier bearing displacement test peak value

| Input direction | Seismic wave name | Intensity | 8m | 25m |
|-----------------|------------------|-----------|----|-----|
|                 | Displacement of friction pendulum bearing along bridge (mm) | Longitudinal displacement of common spherical bearing along bridge (mm) | Displacement of friction pendulum bearing along bridge (mm) | Longitudinal displacement of common spherical bearing along bridge (mm) |
|                 | Fixed support | Sliding bearing | Fixed support | Sliding bearing | Fixed support | Sliding bearing | Fixed support | Sliding bearing |
| Along bridge direction | Kobe/North ridge/wench uan | 7 | 3/3/2 | 2/4/1 | 0/0/0 | 1/1/0 | 1/1/2 | 2/0/1 | 0/0/0 | 1/1/0 |
|                     |                 | 8 | 7/4/2 | 9/6/3 | 1/0/0 | 2/1/1 | 1/5/4 | 1/5/2 | 0/0/0 | 1/1/0 |
|                     |                 | 9 | 9/8/4 | 17/13/5 | 2/1/1 | 21/16/7 | 15/15/4 | 16/14/4 | 1/0/0 | 13/11/7 |
| Along bridge and longitudinal direction | Kobe/North ridge/wench uan | 7 | 3/2/1 | 3/3/2 | 0/0/0 | 1/1/1 | 2/1/2 | 3/1/1 | 0/0/0 | 1/1/2 |
|                     |                 | 8 | 5/4/2 | 9/7/4 | 1/0/0 | 2/1/1 | 5/4/2 | 7/5/1 | 0/0/0 | 1/1/2 |
|                     |                 | 9 | 11/8/4 | 22/14/5 | 1/1/1 | 8/9/4 | 16/16/5 | 13/14/7 | 1/1/1 | 2/5/5 |
| Transverse direction | Kobe/North ridge/wench uan | 7 | 2/2/1 | 1/1/1 | 2/1/0 | 1/1/1 | 4/4/3 | 3/2/1 | 1/1/1 | 1/0/0 |
|                     |                 | 8 | 10/4/2 | 6/5/2 | 1/1/1 | 2/1/1 | 5/5/3 | 8/5/2 | 2/1/1 | 2/1/1 |
|                     |                 | 9 | 27/14/8 | 19/13/5 | 3/3/0 | 3/3/0 | 14/15/5 | 13/12/6 | 3/3/2 | 3/2/2 |
| Transverse and longitudinal direction | Kobe/North ridge/wench uan | 7 | 2/2/2 | 1/1/1 | 1/1/1 | 1/1/0 | 4/3/3 | 4/1/1 | 2/1/1 | 1/0/0 |
|                     |                 | 8 | 12/5/3 | 6/4/2 | 2/1/1 | 2/1/1 | 5/5/3 | 8/5/4 | 1/2/1 | 1/1/1 |
|                     |                 | 9 | 23/10/6 | 18/10/6 | / | / | 16/20/6 | 19/19/6 | 2/4/1 | 2/2/1 |

4.2. Concrete strain
For the 8m pier bridge model, the concrete strain at the bottom of pier increases with the increase of loading amplitude. At the same time, there are obvious isolation and energy dissipation effects that the friction pendulum bearing compared with the ordinary spherical bearing.
Figures 4 and 5 are the concrete strain peak values of the ordinary spherical bearings and the friction pendulum bearings, which are input by the transverse bridge to the ground motion. The concrete strain reduction rate can be obtained according to the concrete strain value. The test data show that the damping ratio of the friction pendulum bearing system is 67.3% - 74.5% for 8m pier model, and the damping ratio of the friction pendulum bearing system is 22.5% - 52% for 25m pier model, which means that there is good seismic isolation effect for the friction pendulum bearing. The damping ratio of 8m pier model is generally higher than that of 25m pier model is also means that the isolation effect of the friction pendulum bearing under the low pier is better than that of the middle pier.

4.3. Model damage state analysis

The damage contrast diagram of the test bench model before and after the 9 degree earthquake as shown in Figure 6. From this figure, a few protective layers of concrete were peeled off on the surface of the model, but no obvious cracks appeared. A circular crack can be seen at the bottom of the model pier with the ordinary spherical bearing; in addition, the crack development degree of 8m pier model is higher than that of 25m pier model. The 8m pier model is seriously damaged and basically loses the horizontal bearing capacity. The 25m pier model is in a slight and moderate damage level. It can be seen from the experimental phenomena, there is a good effect of seismic isolation that the friction pendulum bearing compared with the conventional spherical bearing.

5. Conclusion

In this paper, the typical railway of 32m simply supported girder bridge is taken as the research object. Seismic isolation tests of 2 groups of two span bridges under different ground motions are carried out.
The conclusions are as follows:

1) The friction pendulum bearing has good Anti-seismic effect. The friction pendulum bearing can replace all the functions of the ordinary spherical bearing under the frequent earthquake. The friction pendulum bearing can protect the bridge pier members, prolong the structural period and consume the seismic energy during severer earthquake. The seismic response of simply supported girder bridge is better than ordinary spherical bearing. it has good generality and can be widely used in simply supported girder bridge in earthquake areas.

2) Compared with the middle pier, there are larger rigidity, short period, quick earthquake response and also better Anti-seismic effect reduction for low pier, which is more suitable for low pier structure.

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