Application research of seismic isolation device in long-span continuous beam bridge

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Abstract. The three-dimensional finite element model of pre-stressed concrete continuous girder bridge with span (76+144+76)m is established by using finite element structural analysis software Ansys in this paper. The dynamic time history analysis method is used to study the influence of viscous dampers and friction pendulums with different parameters on the seismic response of long-span continuous beam bridges, which provides a basis for rational selection of seismic isolation measures. The results show that reasonable seismic isolation measures can effectively reduce the seismic response of long-span continuous beam bridges; both the viscous damper and the friction pendulum can have good seismic isolation effects, but the damping effects are related to their parameter settings.

1. Introduction
At present, most of the existing seismic design codes for bridge engineering at home and abroad are only applicable to ordinary bridges with medium spans. The seismic design of long-span bridges beyond the applicable range is not standardized[1]. The seismic design code for highway engineering in China is only applicable to girder bridges and arch bridges with a main span of not more than 150 m. The seismic design codes for railway engineering propose that “special research and design should be carried out for buildings and new structures with special seismic requirements”. At the same time, due to the unpredictability of earthquakes, traditional seismic design methods do not have self-adjusting ability. Therefore, seismic isolation devices are increasingly being applied to engineering practice, and they are also receiving more and more scholars' attention[2-7]. The research results at home and abroad show that the seismic performance of continuous beam bridge can be improved by reasonable seismic isolation design to meet the expected seismic requirements. However, most of the seismic isolation devices are usually analyzed by specific bridges, and there is no uniform usage rule. Moreover, the research mainly relies on the damping effect of different damping devices alone, which is seldom studied on the combined application of various damping devices to the continuous girder bridge.

The application of two commonly used seismic isolation devices (viscous dampers and friction pendulum devices) on large-span continuous beam bridges is analyzed in this paper. By studying the influence of the device parameters on the damping effect of the bridge and the analysis of the damping effect when the two devices are used together, it provides a theoretical basis and reference for the selection of the seismic isolation device in the same type of bridge.

2. Seismic isolation device

2.1 The viscous damper
The viscous damper structure[8] is shown in Figure 1. The specific working principle is: When the relative displacement of the two ends of the device occurs, the piston will move in the working cylinder, and the high viscous damping material on both sides of the piston creates a pressure difference, which causes the damping medium to generate a damping force through the damping hole, thereby hindering the movement of both ends of the device and passing the structural energy. The viscous energy consumption of the damping material in the damper is dissipated.

![Figure 1. Viscous damper basic structure diagram](image)

It should be noted that the damping force of the device is mainly related to the speed of the piston movement. Therefore, it is a speed damper whose damping force is related to the speed of the damping piston and is independent of the relative displacement of the two ends of the damper. Can be expressed as:

\[
f_d(t) = C\left|\dot{u}(t)\right|^\alpha \text{sgn}(u(t))
\]

Where: \(f_d(t)\) is the damping force; \(C\) is the damping coefficient; \(\dot{u}(t)\) is the relative velocity of the piston movement; \(u(t)\) is the relative displacement of the damper; \(\alpha\) is the velocity index, and its value is generally between 0.1 and 1.0.

2.2 The friction pendulum bearing

The structure of the friction pendulum isolation bearing is simple[9] (Figure 2). The principle of isolation and energy dissipation is that it uses the concave spherical sliding surface to extend the vibration period of the structure, thereby avoiding the excellent period of input seismic waves, reducing the response of the bridge structure under earthquake action, and playing the role of isolation. At the same time, when the structure reciprocates back and forth under the action of earthquake, the large friction between the sliding surface and the sliding block due to friction consumes most of the seismic energy, thereby further reducing the damage of the earthquake. In addition, its unique spherical sliding surface has an automatic reset function, which can effectively limit the displacement of the friction pendulum bearing, so that it can quickly return to its original position after the earthquake.

![Figure 2. Friction pendulum structure diagram](image)

3. Project Overview and Finite Element Model

An actual large-span railway bridge was studied with a span of (76+144+76) m. The beam section was a single-box single-chamber, variable-height box girder. The height of the beam at the bearing is 11m, and the height of the beam at the mid-span and the end of the span is 6m. From left to right, the pier numbers are 1# ~ 3#, and the 2# pier is a fixed pier and the other piers are movable piers.

Using the finite element software Ansys, the finite element model shown in Figure 3 was established and the dynamic time history analysis was carried out.
4. Selection of seismic waves
The continuous beam bridge used in this paper is located in the Class II site, and the seismic fortification intensity is 9 degrees. According to “the GB50111-2006 Railway Engineering Seismic Design Code” [10], the peak acceleration of the ground motion under the intensity of the fortification level is 0.64g. This paper selects the typical El-Centro wave actually recorded for seismic wave loading, as shown in Figure 4.

5. Response characteristics and damping effect of shock absorbing bridge

5.1 Damping effect of viscous dampers
In order to study the influence of damper parameters on the damping effect of continuous beam, the viscous damper is only set at each movable bearing, and the seismic response of the structure under different damper parameters is compared. The damper parameter analysis conditions are shown in Table 1. Structural seismic response analysis of different viscous damper parameters was carried out by dynamic time history analysis. The specific analysis values are shown in Figure 5-8.

| Speed index $\alpha$ | Damping index $C/(kN \cdot (s/m)^{\alpha})$ |
|----------------------|-----------------------------------------------|
| 0.1                  | 1000 2000 3000 4000 5000                     |
| 0.3                  | 1000 2000 3000 4000 5000                     |
| 0.5                  | 1000 2000 3000 4000 5000                     |
| 0.7                  | 1000 2000 3000 4000 5000                     |
| 0.9                  | 1000 2000 3000 4000 5000                     |

As can be seen from Figures 5 to 8, when the damper parameter $C$ is constant, the main beam displacement increases with the increase of the damper's speed index $\alpha$; when the damping coefficient $C$ is small, the bending moment of the tower bottom increases as $\alpha$ increases, and when the damping coefficient $C$ is larger, it decreases first and then increases. Therefore, the damping coefficient $C$ should take a larger value, and the velocity index $\alpha$ tends to take a smaller value. For the continuous beam bridge, a suitable damper parameter value is: $C=4000$, $\alpha=0.7$. Figure 7 and Figure 8 further compare the magnitude of the damping rate under various operating conditions. It can be seen that after the damper is installed, the displacement of the main beam is reduced by about 46%, the bending moment of the longitudinal bridge of the fixed pier is reduced by 55%, and the force of each pier is more uniform, indicating that the damping effect of the damper is obvious.
5.2 Friction pendulum support shock absorption effect

In order to study the influence of the parameters of the friction pendulum on the damping effect of the continuous beam, the fixed bearing in the original bridge is replaced by the friction pendulum. The parameter analysis of the friction pendulum is given in Table 2. The results of the finite element numerical simulation are shown in Figures 9-12.

| Coefficient of friction $\mu$ | Friction radius (m) |
|-----------------------------|---------------------|
| 0.01                        | 2                   | 3                   | 4                   |
| 0.03                        | 2                   | 3                   | 4                   |
| 0.05                        | 2                   | 3                   | 4                   |
| 0.07                        | 2                   | 3                   | 4                   |
| 0.09                        | 2                   | 3                   | 4                   |

It can be concluded from Figure 9 to 12 that after the friction pendulum bearing is replaced by the fixed support of the original bridge, the bending moment of the fixed pier bottom is obviously reduced under the action of seismic load, but the displacement of the main beam is increased. The bending moment of the pier bottom increases with the increase of the friction coefficient, but with the increase of the radius of curvature of the sliding surface, the bending moment of the pier and the displacement of the main beam are gradually reduced. Therefore, the optimum friction swing bearing parameters are $R$ (Sliding surface radius of curvature) = 4m, $\mu$ (Coefficient of friction) = 0.01.
5.3 Damping effect of combined use of viscous damper and friction pendulum bearing
From the calculation results in Sections 4.1 and 4.2, it can be seen that both the viscous damper and the friction pendulum can reduce the seismic response of the bridge, but the application of the friction pendulum significantly increases the displacement of the main beam. In order to solve the adverse effects caused by excessive displacement, the combined damping effect of the two devices with optimal parameters is studied. The numerical calculation results are shown in Table 3.

Table 3. Comparison table of seismic isolation plan

|                  | Original bridge | Only dampers (C=4000,α=0.07) | Rc (%) | Only friction pendulum bearings (R=4m, μ=0.01) | Rc (%) | Combination | Rc (%) |
|------------------|-----------------|-------------------------------|--------|-----------------------------------------------|--------|-------------|--------|
| Ma (kN·m)        | 1.80E+06        | 8.24E+05                     | 54.18  | 6.97E+05                                     | 61.20  | 7.11E+05    | 60.44  |
| Db (mm)          | 273.20          | 168.02                        | 38.50  | 375.18                                        | -37.33 | 214.32      | 21.55  |

\[a\] The bending moment of the bottom of the fixed pier.

\[b\] Main beam displacement.

\[c\] The damping rate.

In particular, -37.33% in the table indicates that the main beam displacement is greater than the original bridge. From the point of view of reducing the bending moment of the fixed pier, the friction pendulum isolation device has a relatively obvious advantage. The use of the viscous damper is very effective for reducing the displacement of the main beam. The combination of the above two devices can be better than using the friction pendulum alone.
6. Conclusions
Through the above analysis and calculation, the following conclusions can be drawn:

1) The viscous damper at the long-span continuous beam movable pier can make the movable pier share the seismic force of a part of the fixed pier, which is beneficial to the structural design and is an effective measure for the seismic response of span bridges. The damping effect of viscous dampers depends on the values of damping coefficient C and the damper's speed index α.

2) Viscous dampers can effectively reduce the seismic response of long-span beam bridges, especially the bending moment of the fixed pier and the displacement of the main beam. From the parameter optimization results, it is known that for the bridge, the reasonable damper parameter values are: C=4000, \( \alpha = 0.7 \), and the damping rate can reach about 55%.

3) The use of the friction pendulum effectively reduces the bending moment of the continuous beam fixed pier under earthquake action. The damping effect decreases with the increase of the radius of the sliding surface of the bearing, which increases with the increase of the friction coefficient. Therefore, the optimal parameters in the bridge are: R=4m, \( \mu = 0.01 \), and the damping rate can reach 61.2%.

4) The use of the friction pendulum seat alone reduces the internal force response of the continuous beam, but at the same time increases the displacement of the main beam. Therefore, when the displacement of the long-span continuous beam is high, the combined use of the viscous damper and the friction pendulum can be considered.

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