

Research on anti-buckling restraint support for damping control of long-span steel truss deck-type arch bridge

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Abstract. In this paper, the principle of energy dissipation of anti-buckling support and the simulation method in finite element are introduced. A large-span steel truss deck type arch bridge with a large span is selected as the research object. Based on the analysis of seismic response characteristics, the anti-buckling restraint support is used to systematically study the damping control of long-span steel truss arch bridges. By comparing the seismic responses of the arch bridges before and after the anti-buckling support, the arrangement position of the anti-buckling support was optimized, and the damping effect of anti-buckling support was analyzed. The results show that the reasonable anti-buckling arrangement has better damping effect for long-span arch bridges, but the damping effect of anti-buckling support under different arrangements is quite different.

1. Background study

In recent years, some developed countries such as Japan and the United States have conducted a lot of research on the vibration control of long-span bridge structures, especially the seismic isolation technology of long-span bridges has achieved some remarkable achievements. The vibration control system has been applied in some large-span bridges at home and abroad, and has achieved good seismic performance[1-2]. Many scholars have done a lot of research on the seismic design of long-span arch bridges and have achieved certain research results[3-6].

In 1973, Wakabayashi[7] et al. conducted a groundbreaking study on anti-buckling support, and proposed that the key to anti-buckling support lies in a reasonable unbonded system, and a large number of experiments were conducted to study the bonding materials. Since then, scholars from Japan, the United States, and China have conducted a lot of research. Since the anti-buckling restraint has appeared in Japan, it has been continuously applied to practical engineering, but the application of anti-buckling support in the structure of domestic large-span arch bridges is still relatively few. Therefore, the application of anti-buckling support in long-span railway steel truss arch bridge is studied.

2. Anti-buckling support device

2.1. the principle of Anti-buckling support device

Anti-buckling support is a new type of metal yielding energy-consuming support member consisting mainly of a peripheral constraining sleeve, a core steel core, and an unbonded insulation material



between the two. As shown in Figure 1.

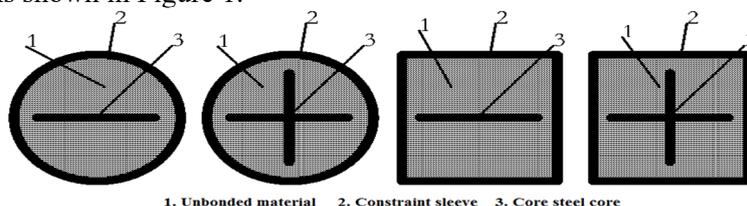


Figure 1. Common section of buckling restrained brace.

The commonly used anti-buckling support is to apply a non-bonding material between the core steel support and the peripheral restraint sleeve to form a sliding interface, so that the core steel support and the peripheral restraint sleeve can slide freely. In the range of elastic deformation, the anti-buckling support is the same as the traditional support, but when the seismic load is large, the traditional support will be unstable, and the anti-buckling restraint support constrains the lateral deformation of the core steel support due to the peripheral constraining sleeve, thus the core steel support does not destabilize under pressure, but enters the stage of plastic deformation (Figure 2). Therefore, the anti-buckling support can not only overcome the shortcomings of the traditional support due to the different deformation of the tensile and compressive bearing capacity, but also has the energy consuming ability of the metal damper, and can achieve sufficient yield under the action of tension and pressure, and the hysteresis curve is stable. Its hysteresis characteristics are significantly better than ordinary steel support. As shown in Figure 3.

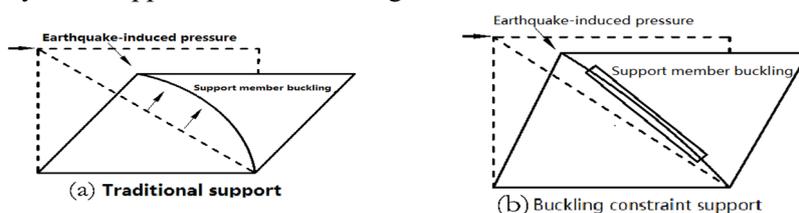


Figure 2. Deformation comparison of traditional brace and BRB under seismic loading.

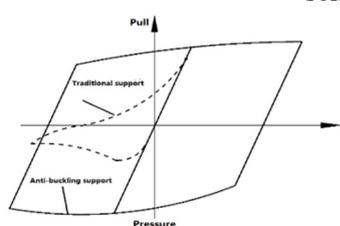


Figure 3. The hysteresis curves of traditional support and BRB.

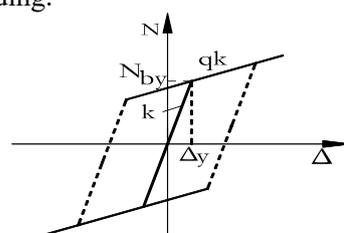


Figure 4. Restoring force model of BRB.

2.2. Mechanical properties of anti-buckling support

In the dynamic time history analysis, the anti-buckling support hysteresis model can adopt the bilinear follow-up strengthening model as shown in Figure 4.

Elastic stiffness of anti-buckling support:

$$k_1 = EA/L \tag{1}$$

Elastoplastic stiffness at the yield stage:

$$k_2 = \frac{E_t A}{L} = qk_1 = \frac{qEA}{L} \tag{2}$$

In the middle: E is the core steel core elastic modulus; E_t is the core steel core tangential modulus; A is the cross-sectional area of the core steel core; L is the length of the core steel core; q is the strengthening coefficient of the core steel core after buckling.

The yield bearing capacity of the anti-buckling support is the axial force when the support enters the first time of yielding. Calculated as follows:

$$N_{by} = \eta_y f_y A \quad (3)$$

In the middle: N_{by} is the yield bearing capacity of buckling restraint support;

η_y is the super strong coefficient of the core steel core. It is determined according to Table 3-4 in [8].

3. Finite element model and seismic response characteristics

3.1. Bridge overview

The main bridge of the bridge is a 490m upper steel truss arch bridge. The rise span ratio of arch bridge is $109.5/490=1/4.475$. Arch axis coefficient is 2.0. The section of the column is a steel box section, and the pier is a hollow concrete pier with variable section. The support adopts spherical steel support, four supports are arranged above each column, the outer two are longitudinally sliding, laterally fixed, and the inner two are two-way fixed bearings; the outer two ends of the beam are two-way sliding, and the inner two are sliding along the bridge, the cross bridge is fixed. The overall layout of the large span steel truss arch bridge, as shown in Figure 5.

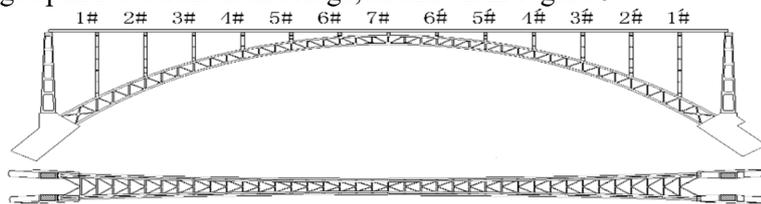


Figure 5. General layout of the long span deck steel truss arch bridge.

3.2. Analysis of natural vibration characteristics of long-span steel truss arch bridge

The bridge is analyzed based on the subspace iteration method in ANSYS. The self-vibration frequency and mode shape are described in Table 1. The first ten-order natural vibration period of the bridge is 0.66s~2.67s, avoiding the characteristic period of the site where the bridge is located is 0.45s, which is beneficial to structural earthquake resistance.

Table 1. The first ten natural frequencies and mode shapes.

Order	frequency	description of vibration mode
First-order mode	0.3739	Transversely symmetric bending mode
Second-order mode	0.5579	Vertical symmetric bending mode
Third-order mode	0.7355	Lateral anti-symmetric bending mode
Fourth-order mode	0.9414	Transversely symmetric bending mode
Fifth-order mode	1.0016	Vertically symmetric bending mode
Sixth-order mode	1.1871	Torsional mode
Seventh-order mode	1.1926	Torsional mode
Eighth-order mode	1.2071	Lateral anti-symmetric bending mode
Ninth-order mode	1.2793	Transversely symmetric bending mode
Tenth-order mode	1.5088	Vertically symmetric bending mode

4. Analysis of anti-buckling support for damping effect of long-span deck-type steel truss arch bridge

4.1. Anti-buckling support position setting

In order to arrange the buckling restraint support reasonably and achieve better damping effect with the least buckling support, it proposes four schemes of buckling restraint support arrangement:

Option One: Replace the flat joint slant rod support in the middle of the original bridge column of the long-span steel truss deck-type arch bridge with the buckling restraint support.

Option two: Replace the flat joint slant rod support on each side of the vertical column of the large-span steel truss deck-type arch bridge with the buckling restraint support.

Option three: Replace all the flat joints of the large-span steel arch bridge with the buckling restraint support.

Option four: The upper arch rib buckling constraint support arrangement is to replace the flat joint slant rod support in the middle of each two columns of the original bridge into buckling restraint support; The lower arch rib buckling restraint support arrangement is to replace the flat joint slant bar in the middle of the 1#, 2#, 3# column and the flat joint slant bar in the middle of the 5#, 6#, 7# column with buckling restraint support. The flat slanting bars between the 3#, 4# and 5# columns remain unchanged and are symmetrically arranged along the middle of the span.

4.2. Analysis of shock absorption effect of anti-buckling support device

In this paper, the buckling constraint support is simulated by the LINK180 element in ANSYS. Material constitutively adopts BKIN simulation of bilinear follow-up strengthening model with strengthening stage. The finite element model for buckling restraint of long-span steel-truss arch bridges with four spans under different layout schemes were created separately, and shock absorption effect of long-span deck-type steel truss arch bridge under earthquake action were calculated. Due to the limitation of space, only the scheme 4 with the best shock absorption effect is taken as an example.

4.2.1. Arch ring transverse bridge response to internal force

Table 2. Comparison of transverse shear force of arch rib between BRB and common brace.

Section position		Shear force (N)			bending moment (N*m)		
		Original bridge	Option four	Damping rate	Original bridge	Option four	Damping rate
Arch springing	Upper rib	3.93E+05	3.40E+05	13.69%	4.61E+06	3.78E+06	18.02%
	Lower rib	7.28E+05	6.43E+05	11.65%	9.62E+06	8.51E+06	11.57%
L/4 arch rib	Upper rib	7.11E+05	4.67E+05	34.26%	4.69E+06	3.78E+06	19.44%
	Lower rib	1.78E+05	1.46E+05	18.11%	1.67E+06	1.55E+06	7.35%
apex of arch	Upper rib	2.23E+05	1.26E+05	43.68%	2.79E+06	2.65E+06	4.95%
	Lower rib	9.10E+04	5.96E+04	34.48%	1.26E+06	1.13E+06	10.21%

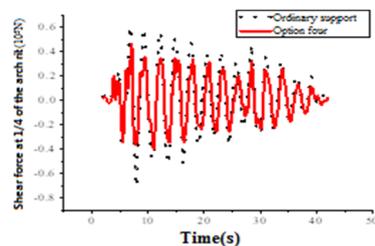


Figure 6. Transverse shear force time history diagram of L/4 upper arch rib.

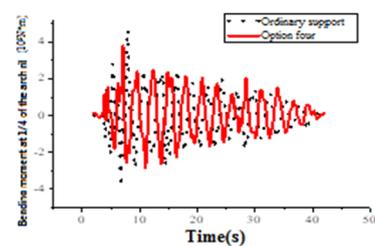


Figure 7. Transverse moment time history diagram of L/4 upper arch rib.

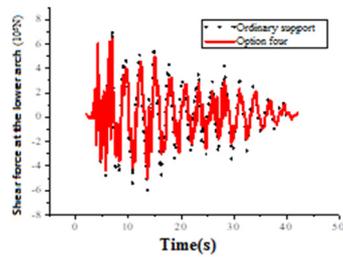


Figure 8. Transverse shear force time history diagram of lower arch springing.

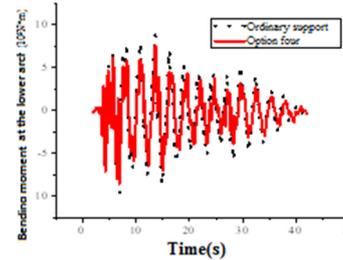


Figure 9. Transverse moment time history diagram of lower arch springing.

4.2.2. Column cross bridge response to internal force on the arch

Table 3. Comparison of transverse shear force of spandrel column between BRB and common brace.

Section position	Shear force (N)			bending moment (N*m)		
	Original bridge	Option four	Damping rate	Original bridge	Option four	Damping rate
Column 1	2.84E+05	2.64E+05	7.25%	4.33E+06	3.62E+06	16.37%
Column 2	2.45E+05	1.93E+05	21.36%	3.75E+06	2.95E+06	21.37%
Column 3	1.60E+05	1.41E+05	11.86%	2.65E+06	2.37E+06	10.74%
Column 4	1.56E+05	1.37E+05	12.15%	2.41E+06	2.11E+06	12.31%
Column 5	1.41E+06	1.28E+06	8.62%	7.81E+06	7.05E+06	9.70%
Column 6	1.82E+06	1.59E+06	12.61%	4.13E+06	3.49E+06	15.33%
Column 7	1.51E+06	1.38E+06	8.73%	1.69E+06	1.52E+06	9.87%

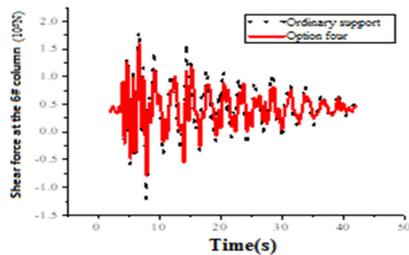


Figure 10. The transverse shear force time history diagram of 6# spandrel column.

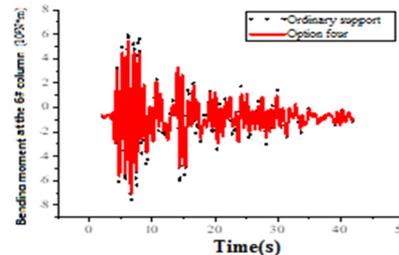


Figure 11. The transverse shear force time history diagram of 5# spandrel column.

4.2.3. Response of the key section of the arch ring to the displacement

Table 4. Comparison of transverse displacement of arch rib between BRB and common brace.

displacement (m)	Original bridge	BRB	Damping rate
L/4	0.258	0.257	0.48%
apex of arch	0.455	0.398	12.57%

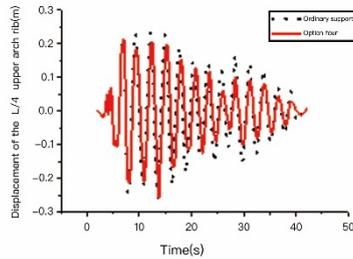


Figure 12. The transverse displacement time history diagram of L/4 arch ring.

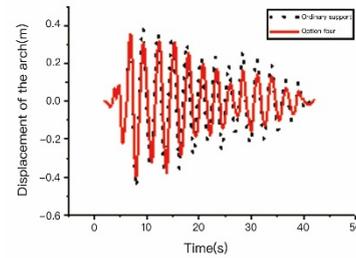


Figure 13. The transverse displacement time history diagram of arch rib vault.

From the analysis of the calculation results, we can see that:

1) When adopting the fourth scheme, the buckling-proof support has better damping effect on the inward force of the transverse bridges of the long-span deck-type steel truss arch bridge, especially the dangerous sections of the arch ring. The shear absorbing rate of the upper L/4 arch rib is 34%, the bending moment damping rate is 19%, and the shearing force and bending moment damping rate of the transverse arch rib arch section are both 12%.

2) Anti-buckling support has better damping effect on arched upper column of long-span steel arch bridge. The damping rate of the transverse bridge to the shear force and bending moment of the cross section of each column is between 7% and 21%.

3) The arrangement position of buckling restraint supports has a great different influence on the transverse bridge displacement of each section of the arch ring. In this paper, when the rational arrangement of scheme 4 is adopted, the transverse bridge displacement at the L/4 arch rib section is basically the same as that of the original bridge, and the transverse bridge displacement at the dome is reduced by about 13%.

5. Conclusion

In this paper, a large-span deck-type steel truss arch bridge is taken as the research object. Based on ANSYS, the damping effect of the buckling-supporting damping device on the long-span steel truss arch bridge is analyzed. Its conclusion is as follows:

1) The buckling-proof support has better damping effect on the inward force of the transverse bridges of the long-span deck-type steel truss arch bridge, especially the dangerous sections of the arch ring. The shear absorbing rate of the upper L/4 arch rib is 34%, the bending moment damping rate is 19%, and the shearing force and bending moment damping rate of the transverse arch rib arch section are both 12%. The damping rate of the transverse bridge to the shear force and bending moment of the cross section of each column is between 7% and 21%. The transverse bridge displacement at the L/4 arch rib section is basically the same as that of the original bridge, and the transverse bridge displacement at the dome is reduced by about 13%.

2) Anti-buckling support is provided between the arch ribs of the large-span steel truss arch bridge, which can not only reduce the internal force response of the cross-section of the arch ring and the column on the arch, but limit the lateral displacement of the cross section of the arch, for the large-span steel truss arch bridge has a good shock absorption effect.

3) The damping effect of anti-buckling support under different layout schemes is quite different. It is suggested that for large-span steel truss arch bridges, the anti-buckling support should be avoided in the joint between column and arch ring, and placed in the middle of the two columns as far as possible.

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