Longitudinal damping parameter sensitivity analysis of self-anchored suspension bridge with viscous dampers

Feng miao, Ping tian, Ping guan

***Abstract*— In order to study the influence of various parameters on the dynamic response of the self-anchored suspension bridge with viscous dampers, based on a self-anchored suspension bridge, a model was establish by Midas/Civil finite element software, and the longitudinal seismic response of the bridge under the position change(placement between the main girder and the side pier, the main girder and the main tower ,and placement between the main girder and side piers and the main beam and the main tower at the same time) of the viscous damper is analyzed by nonlinear time history analysis method. Point at the seismic response of beam end displacement, tower top displacement and tower bottom bending moment, considering damping scheme, viscous damper velocity index α and viscous damper damping coefficient C, the orthogonal test was carried out according to the levels of each factor selected. The results of orthogonal test showed that the damping coefficient C has the most significant effect on beam end displacement, tower top displacement and tower bottom bending moment; damping scheme has a great influence on tower top displacement and tower bottom bending moment, but the influence on the beam end displacement is not sensitive; Velocity index α has a great influence on beam end displacement, but the influence on the tower top displacement and tower bottom bending moment are not sensitive.**

***Index Terms*— self-anchored suspension bridge; longitudinal damping; viscous damper; sensitivity analysis; orthogonal test**

I. INTRODUCTION

China is a country that suffers more and stronger earthquakes in the world. As the lifeline of the traffic, bridge plays an important role in the disaster relief. Once the bridge was destroyed by earthquake, it will bring immeasurable consequences for life safety and property damage. Because of the advantages such as clear mechanical behavior, less influenced by limitation of terrain, economic and beautiful, self-anchored suspension bridge win the selection in small and medium sized bridge. Due to the randomness and spatial variation of earthquake motion, and the nonlinear behavior and the long period of self-anchored suspension bridge, seismic response analysis becomes very complex[1-3]. Therefore, it is necessary to analyze the sensitivity of the longitudinal vibration parameters of the self-anchored suspension bridge.

Based on a self-anchored suspension bridge, three kinds of damping scheme was designed, and the whole bridge seismic response analysis model with viscous damper was established respectively, the effect of viscous damper on the self-anchored suspension bridge is analyzed by nonlinear time history analysis method. Point at the seismic response of beam end displacement, tower top displacement and tower bending moment, considering damping scheme, viscous damper velocity index α and viscous damper damping coefficient C, the orthogonal test was carried out according to the level of each factor selected, and the sensitivity analysis of the seismic response of the beam end displacement, the tower top displacement and the tower bottom moment is carried out by using the range analysis method.

II. ENGINEERING SURVEY

A self-anchored suspension bridge, the site is classified as type two, basic intensity is VII, the span arrangement is 15+70+160+70+15=330 m. Main girder consist of five span continuous box girder, center distance of main cable is 26.5 m, the sling spacing along the bridge is 5 m. The span ratio of the main cable is 1/6; the main beam adopts GPZ type pot rubber bearing. The elevation layout of bridge is shown in figure 1.

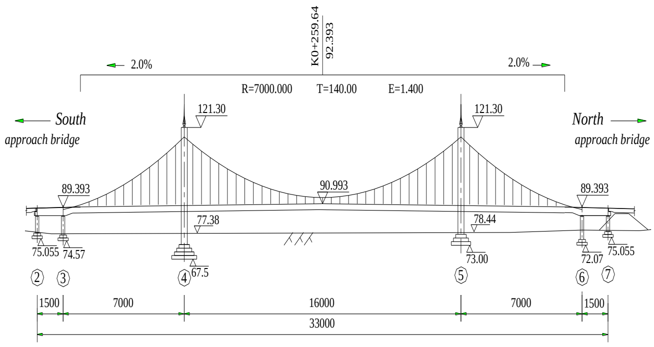

Figure1: elevation layout of bridge

III. THE ESTABLISHMENT OF FINITE ELEMENT MODEL

3.1 The parameter selection and simulation of viscous damper

In order to control the displacement of the tower top and the beam end, the viscous damper with strong energy dissipation capacity is adopted to reduce the seismic response. The viscous damper does not change the lateral stiffness of the vehicle and the wind load, but it limits the maximum static limit force of the limiting component[4].

According to the principle of damping force generation， viscous dampers can be classified into two types. (1) Displacement related damper, energy dissipation through the displacement caused by viscous liquid in an open containers, prefer selection it if the acceleration control can meet the

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requirements of comfort. (2) Speed related damper, energy dissipation through the current speed caused by viscous liquid in a close containers, prefer selection it when the shear structure is subjected to energy dissipation design[5-6]. Speed related viscous damper was selected in this article and its damping force is small under slow loading such as temperature, shrinkage and creep, the damping force increases with the increase of piston motion velocity under the action of earthquake, which plays a role of energy dissipation[7]. The relation between damping force F provided by viscous damper and piston motion velocity v is:

$$F = Cv^{\alpha} \tag{1}$$

In this formula: C represents damping coefficient, which is related to the internal structure of the damper and the viscosity of the fluid; α represents speed index (range 0.1-2.0; from the seismic of view, often take 0.2-1.0)

Maxwell model is used to simulate the restoring force model of viscous dampers[8]. When considering the parameter selection of viscous damper, the influence of viscous damper on longitudinal displacement of main girder, displacement and bending moment of main tower is mainly considered. The parameters are selected as shown in the following table.

Table 1 parameters of viscous damper

Velocity index α	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Damping coefficient C	0	1000	2000	4000	6000	8000	10000	15000	20000

The location of the viscous damper has a direct influence on the stiffness of the structure. According to the different arrangement of the viscous damper, three kinds of damping schemes have been set up for the self-anchored suspension bridge. Scheme one only place viscous dampers between the main girder and the side pier; scheme two only place viscous damping between the main girder and the main tower; in scheme three viscous dampers are arranged between the main girder and the side pier and between the main beam and the main tower(As shown in Figure 2). Through the combination analysis of velocity index and damping coefficient, get the best combination of seismic parameters.

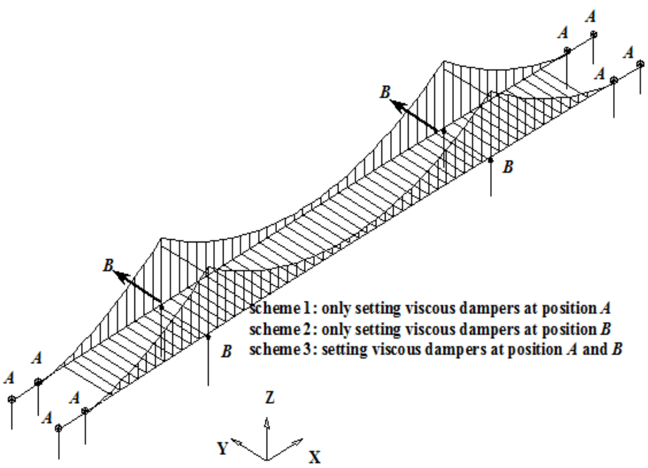

Fig. 2 Schematic diagram of viscous damper

3.2 Full bridge model

Midas/Civil finite element software was used to establish a three-dimensional finite element model. In order to connect the suspension cable to the main beam, the backbone model was adopted, in this model each unit of the stiffness and mass are concentrated in the intermediate nodes[9]. Spatial beam element is selected to simulate main girder, pylon and beam; and truss element is selected to simulate the main cables and hangers. The main girder and the main tower stay longitudinal relative freedom and transverse master-slave constraint; the main girder and pier girder keep master-slave constraint to constraint the vertical, the transverse and the around the axis rotation of the bridge; set free the longitudinal rotation.

IV. Selection of Seismic Wave

The bridge is located in the site class of Ⅱ, fortification intensity is VII. Accordance to the "guidelines for seismic design of highway bridges (JTG/T B02-01-2008)", the design acceleration response spectrum under E1 earthquake motion was ensured，the basic design of horizontal peak ground acceleration is 0.10g. The maximum value of acceleration response spectrum for the time history analysis is 0.225g, the characteristic period is 0.40s. The EI Centro wave of strong earthquake records which are similar to the bridge site are selected as the target seismic excitation, the acceleration of EI Centro wave is 0.357g, and the time history of seismic acceleration is 53.7S[10]. In order to make the input ground vibration meet the specification requirements, the amplitude characteristics of EI Centro wave was adjusting according to load criterion of seismic design and the original spectral characteristics and duration of the seismic wave was retained. The peak value of seismic wave acceleration is 0.225g after adjusted, which is shown in figure 3..

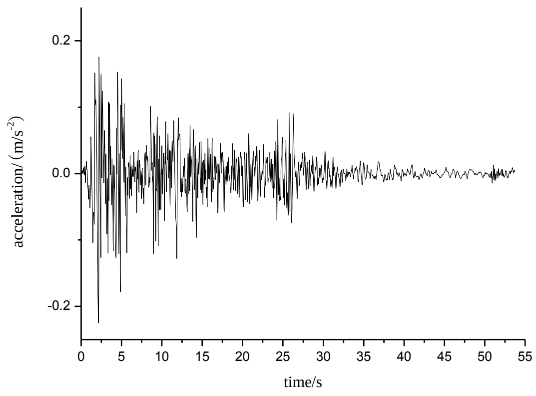

Fig. 3 seismic waveform

V. Parameter Sensitivity Analysis Based on Orthogonal Experiment

5.1 design of orthogonal experimental

In the industrial production and scientific research, there are many factors that need to be considered, and the number of factor levels is more than two. If each level of each factor are mutual collocation comprehensive test, the number of tests is amazing, but using the orthogonal design to arrange the test, the number of the tests would greatly reduce, and the statistical analysis will be easy[11-12]. For the self-anchored suspension bridge with viscous damper device, the beam end displacement, the tower top displacement and the tower bottom bending moment is the seismic response that needs to be focused on. Damping scheme of viscous damper, speed index α and viscous damper damping coefficient C will affect the seismic response most, clearly determine the degree of influence of the factors is the key for better self-anchored suspension bridge seismic isolation design. There will be 273 times numerical analysis for a full test about the effect of factor levels combination, and only 18 times numerical analysis by orthogonal test. Therefore, in order to reflect the comprehensive test information with the least number of numerical analysis, orthogonal test method was carried out, the 2 factors with 9 levels and 1 factor with 3 levels were mixed with the orthogonal test, as shown in Table 2 and table 3.

Table 2 factor levels

Factor / Levels	1 Damping scheme	2 Velocity index α	3 Damping coefficient C
Levels 1	Scheme 1	0.2	0
Levels 2	Scheme 2	0.3	1000
Levels 3	Scheme 3	0.4	2000
Levels 4		0.5	4000
Levels 5		0.6	6000
Levels 6		0.7	8000
Levels 7		0.8	10000
Levels 8		0.9	15000
Levels 9		1.0	20000

Table 3 L18（92×31）Orthogonal table

Number	Scheme number	Velocity index α	Damping coefficient C
1	1（Scheme 1）	1（0.2）	1（0）
2	1（Scheme 1）	2（0.3）	1（0）
3	1（Scheme 1）	3（0.4）	2(1000)
4	1（Scheme 1）	4（0.5）	2(1000)
5	1（Scheme 1）	5（0.6）	3(2000)
6	1（Scheme 1）	6（0.7）	3(2000)
7	2（Scheme 2）	7（0.8）	4(4000)
8	2（Scheme 2）	8（0.9）	4(4000)
9	2（Scheme 2）	9（1.0）	5(6000)
10	2（Scheme 2）	1（0.2）	5(6000)
11	2（Scheme 2）	2（0.3）	6(8000)
12	2（Scheme 2）	3（0.4）	6(8000)
13	3（Scheme 3）	4（0.5）	7(10000)
14	3（Scheme 3）	5（0.6）	7(10000)
15	3（Scheme 3）	6（0.7）	8(15000)
16	3（Scheme 3）	7（0.8）	8(15000)
17	3（Scheme 3）	8（0.9）	9(20000)
18	3（Scheme 3）	9（1.0）	9(20000)

Table 4 orthogonal test results of longitudinal seismic response of self-anchored suspension bridge under earthquake

Number	Factor			Seismic response		
	Damping scheme	α	C	Displacement of beam end（mm）	Displacement of tower top（mm）	Moment of tower bottom (kN·m）
1	1	1	1	0.131	0.125	491
2	1	2	1	0.131	0.125	491
3	1	3	2	0.124	0.125	504
4	1	4	2	0.131	0.125	491
5	1	5	3	0.131	0.125	491
6	1	6	3	0.131	0.125	490
7	2	7	4	0.125	0.105	795
8	2	8	4	0.125	0.105	791
9	2	9	5	0.132	0.110	844
10	2	1	5	0.126	0.099	755
11	2	2	6	0.126	0.098	762
12	2	3	6	0.124	0.095	829
13	3	4	7	0.121	0.101	838
14	3	5	7	0.121	0.102	830
15	3	6	8	0.121	0.104	821
16	3	7	8	0.132	0.101	753
17	3	8	9	0.113	0.107	741
18	3	9	9	0.121	0.107	789

5.2 Analysis of orthogonal test results

Range analysis method was adopted for the analysis of orthogonal test results. The magnitude of the range reflects the effects of each factor in the experiment. The range shows large impact that the factor has a great influence on the test results, which is the main factor; the range shows little impact that the factors has a small influence on the test results, which is the secondary factor or an unimportant factor. The range analysis method calculates the sum value and average value of each test index levels first, and then calculated the range, according to the size of range, the influence degree of each factor on the index value was analyzed, and the main factor and secondary factor was determined.

The orthogonal test results according to Table 4 are showed in Table 5. According to the damping scheme、velocity index α and damping coefficient C and the corresponding level，range analysis table about the seismic response of beam end displacement, tower top displacement and tower bottom bending moment was gained by range analysis method. It can be seen from table 5, the damping coefficient C has the most significant effect on beam end displacement, tower top displacement and tower bottom bending moment; damping scheme has a great influence on tower top displacement and tower bending moment, but the influence on the beam end displacement is not sensitive; Velocity index α has a great influence on beam end displacement, but the influence on the tower top displacement and tower bottom bending moment are not sensitive.

Table 5 results of range analysis

Levels	Displacement range analysis results of beam end			displacement range Analysis results of tower top			The analysis results of the tower bottom moment		
	Damping scheme	Velocity index α	Damping coefficient C	Damping scheme	Velocity index α	Damping coefficient C	Damping scheme	Velocity index α	Damping coefficient C
1	0.130	0.129	0.131	0.125	0.112	0.125	493	623	491
2	0.126	0.129	0.128	0.102	0.112	0.125	796	627	498
3	0.122	0.124	0.131	0.104	0.110	0.125	795	667	491
4		0.126	0.125		0.113	0.105		665	793
5		0.126	0.129		0.114	0.105		661	800
6		0.126	0.125		0.115	0.097		656	796
7		0.129	0.121		0.103	0.102		774	834
8		0.119	0.127		0.106	0.103		766	787
9		0.127	0.117		0.109	0.107		817	765
difference	0.008	0.010	0.014	0.021	0.012	0.023	303	194	343
patch	3	2	1	2	3	1	2	3	1

VI. Conclusion

(1) The beam end and tower top displacement of the self-anchored suspension bridge can be effectively reduced by installing the viscous dampers.

(2) For the displacement of beam end, the sensitivity degree of the influence factors were: damping coefficient C > velocity index α> damping scheme; for the displacement of tower top, the sensitivity degree of the influence factors were: damping coefficient C > velocity index α> damping scheme; for the bending moment of tower bottom, the sensitivity degree of the influencing factors were: C > α > damping scheme.

(3) The damping coefficient should be greater and the speed index should be smaller if aimed at reduce displacement of the beam end and tower top. But the moment and tower bottom is bigger when the damping coefficient becomes bigger and the speed index becomes smaller.

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