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**Research Article**

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# Analysis of Self-anchored Suspension Bridge Longitudinal Damping Parameter

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**Abstract** In order to consider the dynamic response of self-anchored suspension bridge under earthquake, 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 was analysed under the position change(placement between the main girder and the side pier, the main girder and the main tower ,and placementbetween the main girder and side piers and the main beam and the main tower at the same time)of the viscous damper and the parameter variation of the viscous damper through nonlinear history analysis method, compared with the condition without placement the viscous damper.The parameter analysis shows that the viscous dampersare arranged between the main girder and the side pier and between the main beam and the main tower have the best damping effect. Compared the situation without damping measuresthe maximum damping ratio of girder end and the tower top are14.1% and 15.7% respectively.

**Keywords** self-anchored suspension bridge; nonlinear history analysis; viscous damper; damping ratio

## 1. Introduction

As the lifeline of transportation, bridge plays a crucial role in the earthquake disaster relief. Once the bridge damaged under the 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 [1-2]. Therefore, it is necessary for the seismic analysis of self-anchored suspension bridge.

Based on a self-anchored suspension bridge, three kinds of damping scheme was designed to analysis the damping effect of the self-anchored suspension bridge when the parameters changes through nonlinear time history analysis method, compared with the condition without placement the viscous damper, and evaluate the seismic damping effect of each scheme.

## 2. Engineering Overview

A self-anchored suspension bridge, the site is classified as type two, basic intensity is VII, the length of main span, side span and anchor span are 160 m, 70 m and 15 m respective, the span arrangement is 15+70+160+70+15=330 m. Main girder consist of five span continuous box girder, the width of the main beam is 41m and the height of beam center is 2.5m.The span ratio of the main cable is 1/6, and center distance of main cable is 26.5 m, the sling spacing along the bridge is 5 m., the main beam adopts GPZ type pot rubber bearing. The main span arrangement is shown in figure 1.

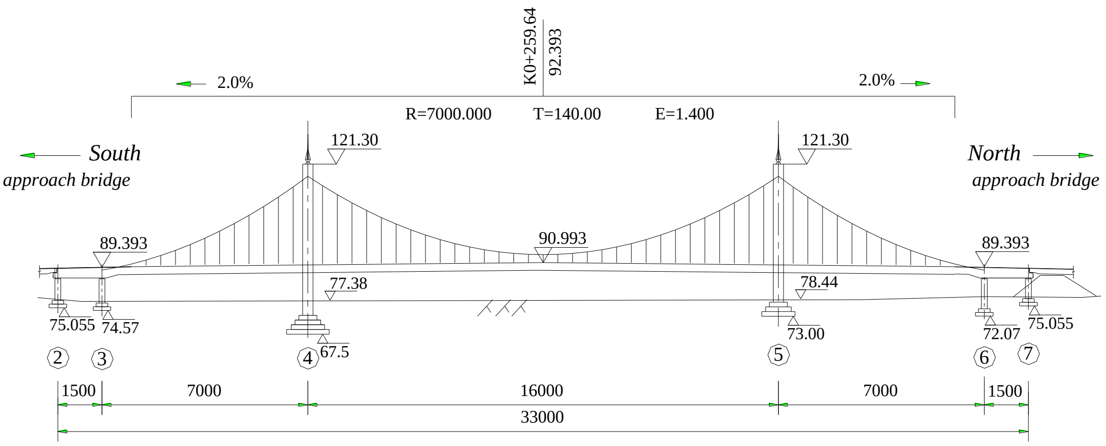

*Figure 1: The arrangement of main span*

## 3. Establishment of Finite Element Model

### 3.1. Simulation and Parameter Selection of Viscous Damper

According to the principle of damping force generation, viscous dampers can be classified into two categories: (1) One damper use viscous liquid in the open container to produce a certain displacement to energy consumption, is displacement related, prefer selection it if the acceleration control can meet the requirements of comfort. (2) One damper use viscous liquid in the closed container to produce a certain flow rate to energy consumption, is speed related, prefer selection it when the shear structure is subjected to energy dissipation design [3]. 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 [4]. The relation between damping force $F$ provided by viscous damper and piston motion velocity $v$ is:

$$F = Cv^{\alpha} \qquad (1)$$

In this formula: $C$ represents damping coefficient, which is related to the internal structure of the damper and the viscosity of the fluid; $\alpha$ 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 [5]. 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. Due to the randomness of the earthquake and the seismic response of each bridge, in order to achieve the best damping effect, the parameters are selected as shown in the following table.

**Table 1**: Parameter Selection of viscous damper

| **Speed index *a*** | 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 |

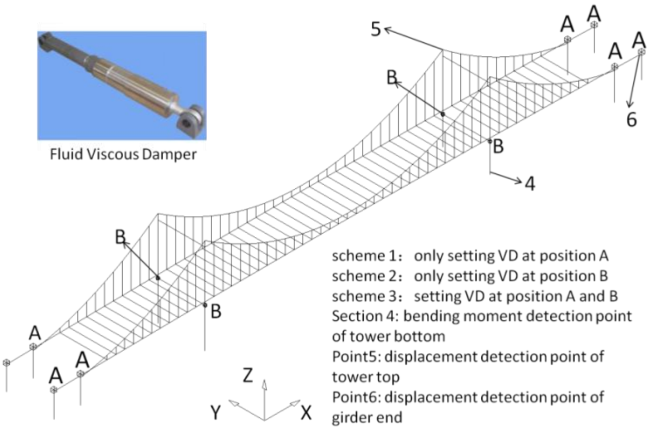

*Figure 2: Arrangement of viscous damper*

Three schemes are adopted to study the influence of seismic response of self-anchored suspension bridge with different placement of the viscous damper. 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.

### 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 [6]. 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.

## 4. Selection of Seismic Wave

The bridge is located in the site class of two, 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 parameters, the basic design of horizontal peak ground acceleration is 0.10 g. The maximum value of acceleration response spectrum for the time history analysis is 0.225 g, the characteristic period is 0.40 s. 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 0.357 g, and the time history of seismic acceleration is 53.7 S [7]. 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.

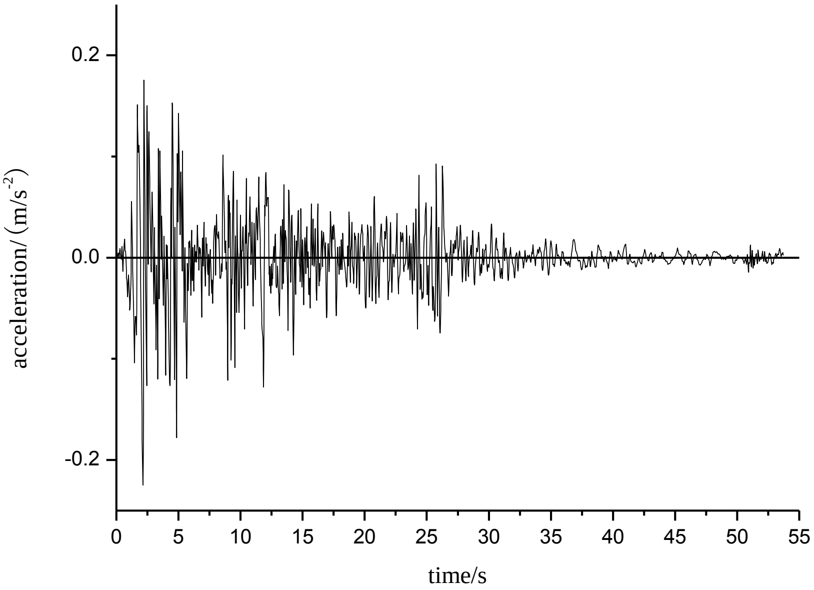

*Figure 3: Acceleration time history diagram*

## 5. Seismic Response and Analysis

### 5.1. Damping System without Viscous Damper

In the case without of viscous damper, the bending moment of tower bottom is 527.6kN·m, the displacement of the top tower and the beam end are 0.114 mm and 0.132 mm respective. In order to control the displacement of the main tower and the beam end, the viscous dampers with strong energy dissipation capacity are adopted to reduce the seismic responses. The viscous damper does not change the lateral stiffness required by vehicle and wind load, but only limits the maximum static limit force of the limiting member.

### 5.2. Seismic Dynamic Equation of Bridge Structure

When the viscous damper is not set, the dynamic equilibrium equation of the original structure is [8-9]:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=-[M]\{I\}\ddot{x}_{g(t)} \qquad (2)$$

In this formula, $[M]$ represents original structure mass matrix, $[C]$ represents original structure damping matrix (Using Rayleigh damping), $[K]$ represents original structure stiffness matrix, $[I]$ represents position vector of ground motion, $\{x\}$ 、 $\{\dot{x}\}$ 、 $\{\ddot{x}\}$ represent displacement vector, velocity vector and acceleration vector of the note respective, $\ddot{x}_{g(t)}$ representsground motion acceleration.

When the viscous damper is added in the structure, the dynamic balance equation of the structure becomes:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=-[M]\{I\}\ddot{x}_{g(t)}-[C_d]\{\dot{x}\} \qquad (3)$$

In the formula, $[C_d]$ represents additional damping matrix provided by damper.

### 5.3. Structural internal force and displacement analysis

Using damping ratio of viscous damper to compare damping effect, the formula is:

$$\lambda=\frac{P_{before\ damping}-P_{afterd\ \ damping}}{P_{before\ damping}}\times 100\% \qquad (4)$$

In the formula, $\lambda$ represents damping ratio, $P_{before\ \ damping}$ represents seismic response without viscous dampers, $P_{after\ \ damping}$ represents seismic response after setting viscous damper.

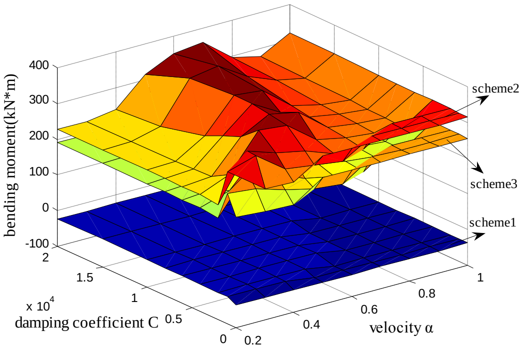

*Figure 4: bending moment of tower bottom*

In the case without of the damping measures, the bending moment of tower bottom is 527.6kN·m, in the case after taking damping measures, the bending moment of tower bottom in the three schemes are shown in figure 4. The results show that the scheme one can reduce the bottom moment of the tower, and the scheme two and scheme three increase the tower bottom moment greatly. When the damping coefficient $C$ is constant and the velocity index $a$ increases, the bottom moment increases. When the velocity index $a$ remains constant and the damping coefficient $C$ increases, the bottom moment decreases. The maximum damping rate in scheme one is 7.03%.

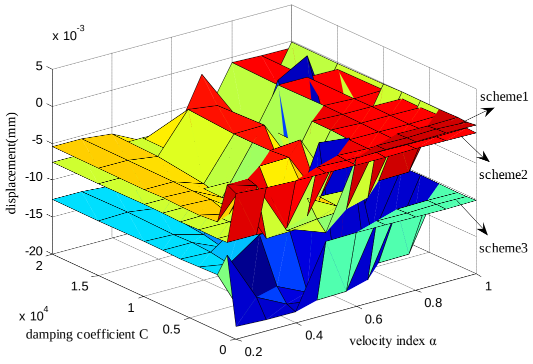

*Figure 5: displacement of girder end*

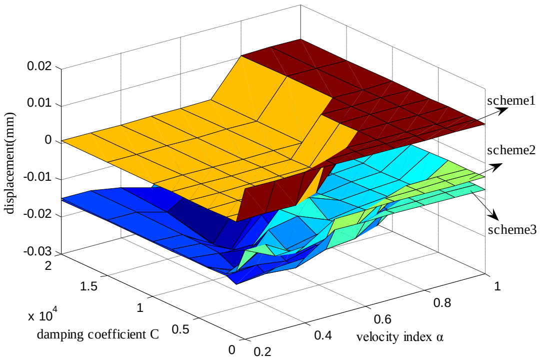

*Figure 6: displacement of tower top*

In the case without of the damping measures, the displacement of girder end is 0.132mm; in the case after taking damping measures, the displacement of girder end in the three schemes are shown in figure 5. The results show that both of the three schemes can reduce the displacement of girder end, when the damping coefficient *C* is constant, the displacement of girder end increases with the increase of velocity index *a*, when the velocity index *a* remains constant, the displacement of girder end decreases with the increase of damping coefficient *C*. The maximum damping rate in scheme one, two and three are 5.92%, 6.22% and 14.1% respective.

In the case without of the damping measures, the displacement of tower top is 0.114mm; in the case after taking damping measures, the displacement of tower top in the three schemes are shown in figure 6. The results show that both of the three schemes can reduce the displacement of tower top, when the damping coefficient *C* is constant, the displacement of tower top increases with the increase of velocity index *a*, when the velocity index *a* remains constant, the displacement of tower top increases with the increase of damping coefficient *C*. The maximum damping rate in scheme one, two and three are 9.67%, 16.7% and 15.7% respective.

### 5.4. Analysis of Internal Force and Displacement of Damper

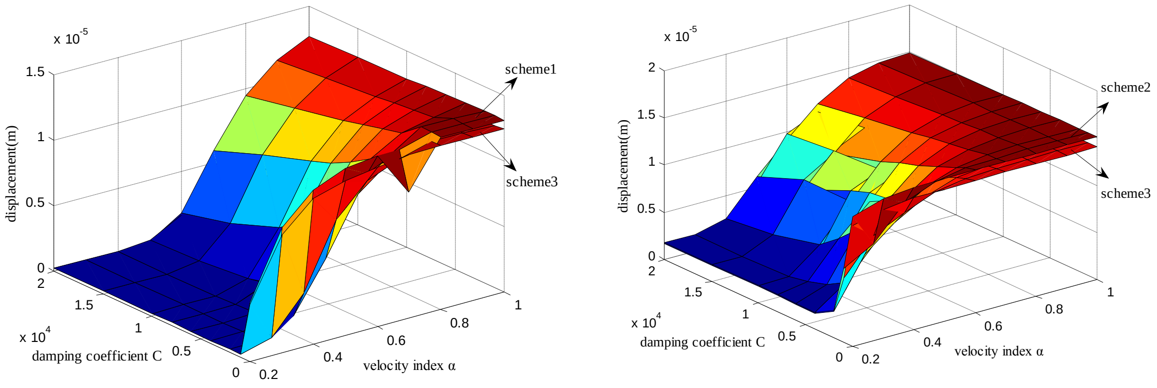

*Figure 7: displacement variation of viscous damper in side pier and tower bottom*

After installing the viscous damper, the displacement of the damper changes as shown in Figure 7. The results show that when the damping coefficient is constant, the viscous damper displacement increases with the increasing of the speed index; when the speed index remained unchanged, the displacement of damping coefficient decreases with theincreasing of the damping coefficient, the displacement of viscous damper in the third scheme is less than scheme one and scheme two.

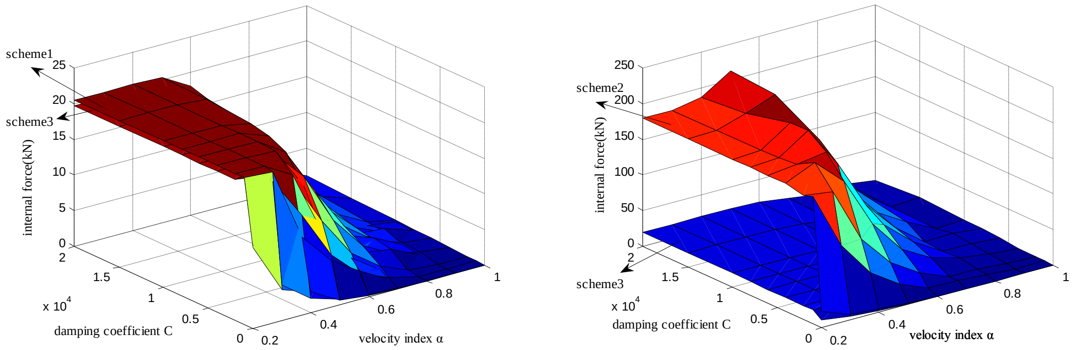

*Figure 8: Internal force variation of viscous damper in side pier and tower bottom*

After installing the viscous damper, the internal force of the damper changes as shown in figure 8.The results show that when the damping coefficient is constant, increases with the speed of the viscous damper force index decreases; when the speed index remained unchanged when the viscous damper force increases with the increase of damping coefficient, the scheme of third side piers slightly less than at the viscous damper scheme; internal force scheme three main tower of viscous damper is much smaller than the scheme two.

## 6. Conclusion

- The displacement of girder end and tower top of the self-anchored suspension bridge can be effectively reduce after installing the viscous dampers.
- The damping effect that viscous dampers are arranged between the main girder and the side pier and between the main beam and the main tower is better thanonly place viscous dampers between the main girder and the side pier oronly place viscous damping between the main girder and the main tower, and the maximum damping ratio of girder end and the tower top are14.1% and 15.7% respectively.
- The damping coefficient should be greater and the speed index should be smallerif aimed at reduce displacement of the girder end and tower. But themoment and shearofpier bottom is bigger when the damping coefficientbecomes bigger and the speed index becomes smaller.

## Acknowledgment

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## Reference

[1]. Tang Lisheng, Zhang Liangyu, Zhan Tongsheng. Nonlinear Dynamic Analysis of Structures with Viscous Dampers [J]. Engineering Mechanics, 2004, 01:67-71. (in china)

[2]. Sun Chuanzhi, Li Aiqun, Miao Changqing. Paarameter Optimization Analysis of Viscous Dampers for Dissipation Structure[J]. Journal of Civil, Architectural and Environmental Engineering, 2013,01:80-85.(in china)

[3]. Deng Wen-ping, Wang Hao, Li Ai-qun. Parametric analysis of viscous dampers for earthquakemitigation of continuous bridges in high intensity region [J]. Journal of Vibration and Shock, 2012,16:92-97.(in china)

[4]. Zhao Jidong, Zhang Yongliang, Chen Xingchong. Research on seismic reduction of tall-pier and long-span railway continuous rigid-framed bridge based on viscous damper[J].World Earthquake Engineering,2016,02:93-99.(in china)

[5]. Song Lixun. Study on the Formula of Equivalent Damping Ratio of Viscous Damper [J]. Earthquake Resistant Engineering and Retrofitting, 2014,05:52-56. (in china)

[6]. Song Xuming, Dai Gonglian, Zeng Qingyuan. Study on the Formula of Equivalent Damping Ratio of Viscous Damper [J]. Journal of South China University of Technology (Natural Science Edition),2009,03:104-108.(in china)

[7]. Study on seismic response control of a single-tower self-anchored suspension bridge with elastic-plastic steel damper[J]. Science China (Technological Sciences), 2012,06:1496-1502.

[8]. Billie F SPENCER. Damper placement for seismic control of super-long-span suspension bridges based on the first-order optimization method [J]. Science China (Technological Sciences), 2010,07:2008-2014.

[9]. Pan Peng, Yan Hong, Wang Tao, Xu Peizhen, Xie Qiang. Development of steel dampers for bridges to allow large displacement through a vertical free mechanism [J]. Earthquake Engineering and Engineering Vibration, 2014, 03:375-388.