SHOCK CONTROL OF BRIDGES IN CHINA USING TAYLOR DEVICES' FLUID VISCOUS DEVICES

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ABSTRACT :

Fluid Viscous Devices are a successful structural protective system for bridge vibration. The structural protective technique and the dampers have been introduced to China since 1999. The Taylor Devices' damper systems has already been successfully installed or will be installed in large or the super large bridges in China for protection from earthquake, wind. vehicle and other vibration. Seventeen different bridge projects introduced here include the Sutong Yangtze River Bridge, the longest cable stayed bridge in the world, the Nanjing 3rd Yangtze River Bridge, the fifth longest suspension bridge in the world, and the Xihoumen Across Sea Bridge, the second longest suspension bridge in the world. The performance of the bridges and dampers have been reported as "very good" during the May 12, 2008 Wenchuan earthquake. All of the dampers produced have been subjected to rigorous static and dynamic testing, which show the dampers will perform well for the next 50 years and possibly a lot longer.

KEYWORDS: Lock-Up Devices, Fluid Viscous Dampers, Limited Displacement Damper

1. INTRODUCTION

Along with the rapid economic development in China over the past two decades, a large number of highways and bridges have been built in China. By 2004 China constructed 1.81 millions kilometers of roads and 30 thousand kilometers of highways. Hundreds of bridges were built over the Yangtze, Yellow, Qiantang and Pearl Rivers as well as several bridges across the sea.

Since the beginning of this century, China began to recognize the fact that the Taylor Devices' protective system is very helpful in controlling structural vibrations of bridges，especially in areas that encounter seismic and high wind events. Ms. Yufeng Duan (China Highway Planning and Design Institute) is probably the first engineer in China to be asked to learn this technique. As the representative company of Taylor Devices, we have made strong efforts in the following areas:

Doing our utmost in introducing and recommending damping devices to our Chinese colleagues and clients. Taylor Devices has sent sales engineers 5 times to China to introduce its latest technology and hosted 5 Chinese delegations of Bridge experts to visit its factory in Buffalo, New York and several bridge construction sites during installation of Taylor Devices' dampers. Dr. Constantinou (SUNY Buffalo) was invited by us to visit China and to give lectures at 5 Chinese Universities on the structural protection systems. We have printed catalogues, made design manuals and published papers to let more and more Chinese designers know what is and how to use this new technology.

1. As this is the first time for most of the Chinese structural designers to analyze and to design the protection system, we not only do whatever we can to help them with their design but also try to analyze them at no cost to the client. Now we have already grown into the biggest analysis team in China for the protective system and structure vibration. We help train our Chinese designers and clients how to perform bridge dynamic analysis and furthermore, we also help them to choose the appropriate damping devices.
2. All of the different shock control devices, Lock-Up Devices, Fluid Viscous Dampers, Fuse Dampers, Limited Displacement Dampers, Metal Bellows Dampers and Cable Dampers include the analysis.
3. The top priority for us when we started to introduce this technique to China is to convince our Chinese colleagues that the qualification inspection is the most important work. Several important papers have been published in the Chinese magazines to introduce the *Pre-qualification Testing of Viscous Dampers for the Golden Gate Bridge* and the *Result of Evaluation Findings for the Testing of Seismic Isolation and Energy*

Dissipating Devices, Highway Innovative Technology Evaluation Center (HITEC). These two extremely important testing programs have already become an informal standard of testing. The Chinese designers now have come to realize that it is imperative to use these test specifications as design requirements. Actually this is most tough job in China.
As a result, more and more Chinese engineers now can determine the difference between hydraulic buffers, Lock-up Devices and Fluid Viscous Dampers. Over the last few years, the utilization of dampers to protect bridges from vibration has successfully developed in China. For instance, since 2004, we have finished or will finish the installation of the Nanjing Yangtze 3rd bridge, the Jiangyin Yangtze bridge, the Sutong Yangtze bridge (the longest cable stayed bridge in the world), the Songhuajiang Longhua bridge, the Xihoumen and Jingtang bridges (an across sea bridge project linking Zhoushan Islands with the Mainland city of Ningbo, Zhejiang province), the Yuzui Yangtze River bridge and the Pengxi River bridge.
Now, almost all bridge designers and owners in China know that the dampers are extremely helpful in controlling the bridge vibration, mitigation of seismic and wind hazard, especially for the float system bridge – Cable stay bridge.

2. Bridges installed dampers on the Yangtze River and Across the Sea

So far 105 bridges have been built up or are still under construction over the Yangtze River. Among them 59 special large bridges are located from Shanghai to Yibing section of which 41 bridges have already been finished while 18 bridges still under construction until March 2008. Now an additional 15 bridges located at the lower reaches of the Yangtze River are to be built.

Nanjing 3rd Yangtze River bridge, Taylor Devices' dampers are not utilized for the main span of this 1000m cable stayed bridge. 54 sets of 1500kN dampers were installed at the approach bridge which connects the piers and the beams of the bridge. The dampers distribute and transfer the force to the more connected piers and also reduce the pier shear force during an earthquake.

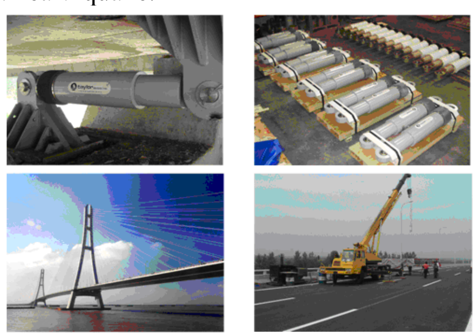

Fig. 1 Nanjing Yangtze river 3rd bridge and 54 dampers

Sutong Yangtze River bridge is the longest cable stayed bridge in the world. The main span is 1088 meters between the two towers. After repeated discussions with the designers, owners and Taylor's experts, the designers of the bridge finally decided to use the new huge dampers with displacement limitation in the dampers side.
In view of the fact that the extra load may cause the over displacement that will be harmful to the bridge and that needs to be limited, it was suggested that the end of the damper piston's traditional movement a displacement limiting device, which allows the dampers to have to spring for the final 100mm of travel with a peak force of 10000kN. The basic relationship of the damper becomes the following formula:

$$F=\begin{cases} CV^{\alpha} & D\le D_{max} \\ 0\sim F_{lim} & D>D_{max} \end{cases} \tag{2.1}$$

The following curve has shown the relationship of damper's displacement and force.

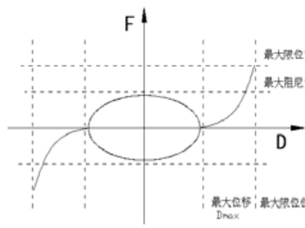

Fig. 2 Disp-Force Sutong Dampers

The traditional damper and limitation displacement devices combine in a big and a small cylinder but with only one piston. See the draft of Taylor Devices design.

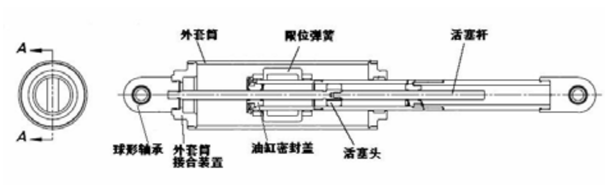

Fig.3 Draft of Sutong Dampers

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Fig.4 Sutong Bridge and dampers

Jiangyin Yangtzi River bridge, is the fifth longest suspension bridge in the world. The Jiangying bridge opened to traffic in 1999. But soon a serious damage was found at the expansion joint. The biggest unhealthy gap was found to be 8.1cm. The owner decided to retrofit the bridge. Four large stroke dampers were used to limit the longitudinal movement of the bridge. The dampers were installed in the February 2007. The performance of the bridge has been observed as "much better" than before the dampers were installed.

The China Highway Planning and Design Institute analyzed the structure under seismic, wind and traffic load conditions. Four dampers with 1000kN and large damper's stroke ±1000mm are useful in reducing the vibration. This is the first bridge retrofit project using damper devices in China.

Fig 5 Jiangyin Yangtze River Bridge and dampers

Next, we would like to discuss two across the sea bridges.

Xihoumen and Jingtang Bridges

One of the most famous across the sea projects in China is the Zhoushan Island-Mainland Linkage Construction Project located in the Zhejiang province. The highway and the several bridges will link Zhoushan Islands with Ningbo, a mainland city. The Xihoumen bridge with a main span of 1650 meters is the second longest suspension bridge in the world. Four of the longest stroke dampers (1000kN, ±1100mm) installed at the end of the girders of the bridge. An optimal analysis result of the best design parameters for the smallest resistant force is the velocity index α equal to 1.

Fig 6 Xihoumen and Jingtang Bridge and dampers

The Jingtang bridge is the second cable stay bridge with a main span of 800 meters in the Zhoushan Island-Mainland Linkage Construction Project. Both bridge eight dampers installed in the longitudinal direction of the bridge in September of 2008.
Although most dampers of the bridges are being used to control the longitudinal vibration for cable stayed bridges and suspension bridges so far, some bridges are quite different. For example, the Songhua River Longhua bridge with a reinforced concrete continuous beam is just a case in point. We shall install 16 Lock-Up Devices on the bridge. Another two direction control dampers (longitudinal and transverse) are designed to be installed on a circle highway around the city.
Other bridge applications have also been encountered in China. 8 dampers were installed on Bridge Inspection vehicles (maintenance travelers) to reduce the vibration of the vehicle. A TMD system with 8 Taylor's metal bellows dampers will be installed at the visiting tower in the middle of Hangzhou Bay Bridge.

3. Seismic Damage Inspection

After the Wenchuan earthquake we surveyed all of dampers installed in Chinese bridges and buildings. No damage was reported. As mentioned, the Pexihe Bridge located at Chongqin city, 500 kilometer from the epicenter of the Wenchuan earthquake. The bridge and dampers were stroking during the earthquake but the vibration was minimized by the dampers and no damage occurred.

4. Conclusions

The list in the following Table indicates the Chinese Bridge projects that have utilized or will utilize Taylor Devices dampers.

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Table 1 utilize or will utilize Taylor Devices dampers in China

Structural Types	Name of bridge	Damper Specification	Bridge information	Installation	Number
Continuous Beam Bridge	Jilin Songhua River Longhua Bridge	16 Lock-Up devices F=1800kN D=±140mm	7 Span R.C. Continuous Beam bridge, Max. Span 100m	May 2007	1
	Nanjing 3rd Yangtze river bridge	54 FVD F=1500kN, α=0.3 D=±150mm C=1000 kN/(m/s)$^{0.3}$	Approach RC bridge	Sept. 2005	2
Cable Stay bridge	Sutong Yangtze river Bridge	8 FVD with Disp. Limitation F=3025/10000kN α=0.4 D=±750/850mm C=3750kN/(m/s)$^{0.4}$	Main Span 1088m Two Towers	June 2007	3
	Jintang Bridge	4 FVD F=2750kN α=0.3 D=±350mm C=2500 kN/(m/s)$^{0.3}$	Main Span 620m Two Towers	2008	4
	Penxi River Bridge	4 FVD F=1600kN α=0.4 D=±200mm c=2600kN/(m/s)$^{0.4}$	Main Span 632m Two Towers	Oct. 2007	5
	Jiangjin Bridge	4 FVD F=1200kN α=0.5 D=±200mm c=2600kN/(m/s)^{05}	Main Span 436m Two Towers	. 2008	6
	Suramadu Bridge	4 FVD 限位阻尼器 F=2400kN α=0.4 D=±486mm c=2500kN/(m/s)^{04}	Main Span 445m Two Towers	. 2008	7
	Shangxi Xishenhe	4 FVD F=1500kN α=0.4 D=±300mm c=2000kN/(m/s)^{04}	Main Span Single Tower	. 2008	8
	Hubei Edong	4 FVD F=1000kN α=0.6 D=±600mm c=2500kN/(m/s)^{06}	Main Span 680m Two Towers	. 2008	9
	Meixi River Bridge	4 FVD F=1600kN α=0.4 D=±200mm c=2600kN/(m/s)$^{0.4}$	Main Span 632m Two Towers	Oct. 2007	10
Suspension Bridge	Jiangyin Bridge	4 FVD F=1000kN α=0.3 D=±1000mm C=1522kN/(m/s)$^{0.3}$	Main span 1385m Two Towers	Feb. 2007	11
	Xihoumen Bridge	4 FVD F=1000kN α= 1 D=±1100mm C=5000kN/(m/s)^{1}	Main span 1650m Two Towers	Dec. 2007	12
	Yuzui Yangtze river bridge	4 FVD F=1500kN α=0.3 D=±550mm C=1750kN/(m/s)0.3	Main span 616m Two Towers	2008	13
	Hangzhou East(1)	4FVD F=2000kN D=±300mm c=2000kN/(m/s)^{03}	Main span Two Towers 260m	2008	14
	Hangzhou East (2)	4FVD F=2000kN D=±300mm c=2000kN/(m/s)^{03}	Main span Two Towers 260m	2008	15
Others	Jiangyin Bridge	Total: 8FVD F=8.9 kN D= ± 25 mm	Inspection Vehicle	2008	16
	Hangzhou Bay Bridge Visit Tower	8 Metal Bellows dampers F= 20kN D=±250mm C = 60 kN(s/m)	TMD system	2009	17