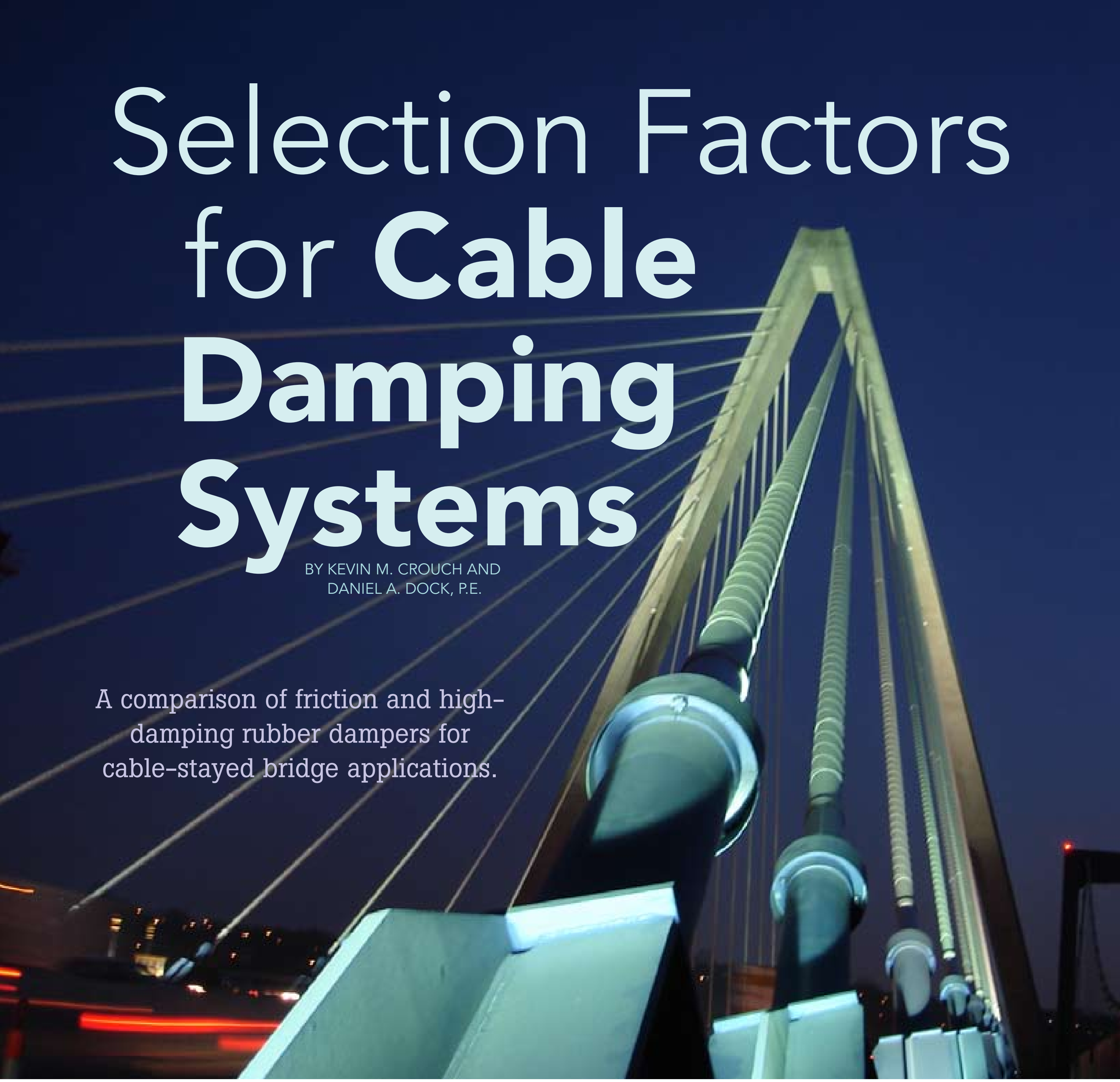

Selection Factors for **Cable Damping Systems**

BY KEVIN M. CROUCH AND
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A comparison of friction and high-damping rubber dampers for cable-stayed bridge applications.

THE REQUIREMENTS FOR INCREASED DURABILITY of cable-stayed bridges now make the 100-year bridge the norm. A key factor in providing long-life is a strategy for controlling the complex problem of cable vibrations due to wind and aeroelastic instabilities.

This article examines the features of two vibration damping systems and factors to consider when choosing a damping system in the design of a cable-stayed bridge. Friction dampers typically are more suitable for longer cables and those with more demanding damping requirements. Once active, they protect the cable by providing damping across all modes of vibration and any axis. With no moving parts, high-damping rubber (HDR) dampers are ideal for cable-stayed bridges with short to medium cable lengths or cables with moderate damping requirements. The article concludes with three examples of recent installations.

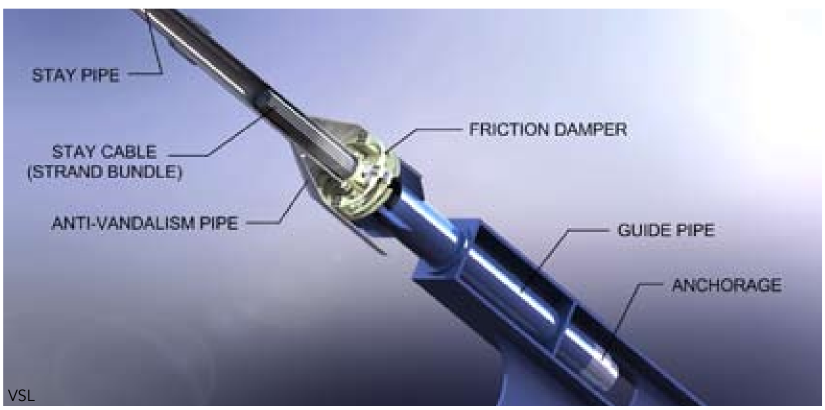
Increasing Popularity of Cable-Stayed Bridges

Cable-stayed bridges have been constructed all over the world in recent years. Combining a steel superstructure with current stay cable technology has enabled the construction of main spans in excess of 3,300 ft. Examples include the Stonecutters Bridge in Hong Kong and the Sutong Bridge in Jiangsu Province, China. The recently opened John James Audubon Bridge near Baton Rouge, La., currently is the longest cable-stayed main span in the western hemisphere at 1,583 ft. With many more planned projects on the horizon, the cable-stayed bridge appears to be well-positioned for future construction.

Given the up-front investment required to build a cable-stayed structure, it is understandable why owners want these bridges to provide a 100-year service. Many factors contribute

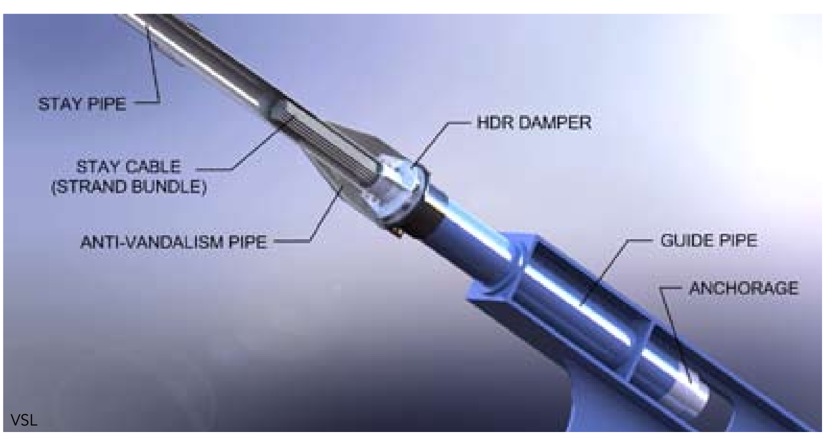
to this extended life expectancy, including improved corrosion protection measures and the ability to replace individual strands or even entire cables without closing a bridge to traffic. Another important aspect of ensuring a long life involves improvements in controlling the complex problem of cable vibrations due to wind and aeroelastic instabilities. A number of different solutions have been developed to address this concern, most notably stay-cable dampers.

◂ With its relatively short stay cables, the Christopher S. Bond Bridge spanning the Missouri River near Kansas City, Mo., was a good application for HDR dampers.



▴ Components of a friction damper assembly.

▾ Components of a hard-damping rubber (HDR) damper assembly.



Why Are Dampers Needed?

Stay cables are prone to a number of different types of vibration. The U.S. Federal Highway Administration's document *Wind-Induced Vibration of Stay Cables* (Publication No. FHWA-HRT-05-083) names at least eight different types of cable excitation. The most common one with the potential to generate large cable amplitudes is known as Rain-Wind Induced Vibration (RWIV), though other types of excitation can also affect particular bridges. RWIV typically occurs during a rain event with moderate wind speeds (in general 18 to 33 mph). Stay cables have a small amount of intrinsic damping, but in many situations this is not enough to control the excitation from various phenomena. A number of solutions have been developed to provide additional damping, including cross-ties, stay pipe surface treatments (such as helical ribs or dimples), external dampers (like piston-type viscous dampers), and internal dampers.

Though driver comfort is perhaps the most prominent reason for controlling stay cable vibration, durability is also a significant concern that dampers can address. Dampers contribute to long-term bridge life primarily through keeping steel protection elements, such as guide pipes and anchorage components, from experiencing repetitive large movements and loads. Large vibrations can damage the connections of these elements, as was observed on the Fred Hartman Bridge near Houston. Repeated cable excitation on that bridge led to broken welds at the base of the deck guide pipes.

On most cable-stayed bridge projects, a qualified engineering consultant performs a wind study to determine the level of additional damping recommended for each stay cable on the bridge. These recommendations

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The long stay cables of the newly opened John J. Audubon Bridge in Louisiana are benefitting from the use of friction dampers.

are then used to develop project specifications, which in turn lead to the use of specific damping systems on a bridge. Certain types of dampers are more appropriate for specific applications, so it is important to understand a project's needs before proposing a solution.

Two Distinct Damping Solutions

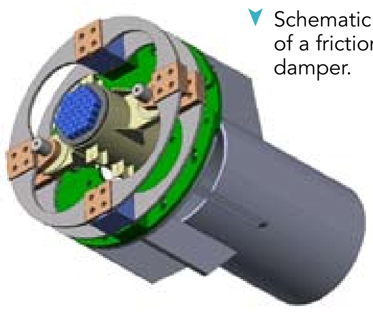
In the 1990s, two very effective damping solutions were developed to address the problem of stay cable vibration. The first, the friction damper, was created by Imre Kovacs and patented by VSL International. This solution was first applied in 1996 on the Puente Real (Badajoz) Bridge in Spain. In essence, the friction damper functions similarly to disc brakes on an automobile. Spring blades connected to a bridge's guide pipe provide a clamping force on a collar attached to an individual stay cable. At a particular amplitude, the force from the cable's vibration overcomes the friction between the contacting parts in the two assemblies, at which point the damper activates. The system then works quickly and efficiently, dissipating energy in order to return the cable to a low-vibration state. Because of their shape and non-linear behavior, friction dampers can provide damping across all modes of vibration and any axis. During periods of vibration with very small amplitudes, the damper remains inactive and functions like a guide deviator. This minimizes the wear on the damper and allows it to transfer the force from these small vibrations to the guide pipe rather than the cable anchorage.

Another damping system was developed in Japan by Sumitomo Rubber Industries. This solution, consisting of multiple HDR pads, was introduced on the Odawara Blueway Bridge in 1994. The rubber pads, which somewhat resemble a hockey puck, connect a stay cable to its corresponding guide pipe, dissipating energy and transferring vibration forces to the pipe rather than the cable anchorage. Unlike the friction damper, the HDR assembly is always active. However, because the system includes no moving parts, it is highly resistant to wear.

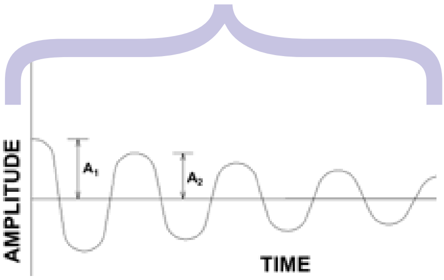
The unique features of each system make it important to evaluate which is more appropriate for a particular use. For instance, friction dampers are generally more suitable for longer cables, while HDR systems function best for shorter and medium-length stays.

In general terms, the further away a damper is from the anchorage, the more damping it can achieve. However, the flexibility of the damper support, which is usually the guide pipe, must also be considered, as a flexible support will reduce the effectiveness of a damper. Because of their higher effi-

Schematic view of a friction damper.



Close-up view of a friction damper.



Basics of Stay-Cable Damping

Stay-cable damping requirements are typically expressed with one of two values: percent of critical damping, or the percentage of logarithmic decrement. The percentage of logarithmic decrement (log dec) represents the natural logarithm of a ratio between two successive vibration amplitudes, expressed as a percentage. In the chart shown above, the percentage of log dec (δ) would be expressed as:

$$\delta = l_n \frac{A_1}{A_2}$$

Critical damping refers to the damping level needed to bring the cable to rest in one cycle without experiencing further vibration. The damping ratio (ξ) is typically expressed in terms of a percentage of this amount. The damping ratio can be related to the percentage of log dec with the following equation:

$$\xi \approx \frac{\delta}{2\pi}$$

Stay cables are long, flexible members and thus cannot achieve critical damping. Attempts at providing a completely rigid damper would simply create a node on the cable, while supplying an excessively soft damper would allow too much movement and thus forfeit the damper's effectiveness. Analysis confirmed by testing has been used to determine the highest damping level possible for a stay cable. For a cable with a passive damper attached at a particular point, the maximum achievable damping under free vibration can be expressed as:

$$\delta = \pi \frac{\Delta x}{L}$$

where δ is the damping expressed in the percentage of log dec, Δx is the damper position measured from the closest end of the cable, and L is the cable length.

The Luling Bridge, also known as the Hale Boggs Memorial Bridge, is getting new cable stays with a mix of both HDR and friction dampers.

ciency, friction dampers typically can provide the same level of damping as HDR dampers at a position closer to the cable anchorage. However, friction dampers usually require a larger diameter anti-vandalism cone than HDR dampers to allow for the larger movement associated with the system. The additional size of the components may need to be considered in situations with tight clearances. The two damping systems also can be mixed on a single bridge, with one system used on certain cables and the other on the remaining cables, or even combined on an individual cable, as is being done on the Luling project.

The Two Solutions Applied

The John James Audubon Bridge spans the Mississippi River between New Roads and St. Francisville, La. Early in the design-build process, a wind engineering study indicated that varying levels of damping were needed for individual cables. The maximum was 0.59% critical damping. Given the cable lengths (maximum length of approximately 830 ft) and damping requirements, a friction damper was chosen for this application. At the present time, friction dampers have been installed successfully on all cables, and the bridge was opened to traffic in May 2011.

The Christopher S. Bond Bridge spanning the Missouri River is part of the kcICON project in Kansas City, Mo. As with the Audubon Bridge, a wind engineering study was performed early in the design-build process and the recommendations from the report became the basis for the required damping on the job. Two primary factors led to the selection of HDR dampers for the bridge. First, the shorter cable lengths, which had a maximum length of approximately 530 ft, and lower damping levels (the maximum cable required 0.38% critical damping) allowed the use of the rubber dampers. In addition, the diamond shape of the pylon combined with above-deck steel anchorage assemblies permitted smaller anti-vandalism cones in order to avoid possible clearance issues with truck traffic on the bridge. The bridge was opened to traffic in September 2010, complete with HDR damping systems in place.

The Luling Bridge, also known as the Hale Boggs Memorial Bridge, was originally constructed in the early 1980s near New Orleans. A lengthy investigation initiated by the Louisiana Department of Transportation and Development in the early 2000s uncovered concerns with the existing stay cables, leading to the first stay cable replacement project in the United States. As part of this project, the issue of cable vibration was addressed; the original cables had not been equipped with dampers. The project specifications required 0.95% critical damping for all cables. After much discussion, both friction and HDR dampers were selected for the project. The cable replacement is currently under way; dampers have been installed on one quadrant of the bridge, and the remaining systems will be installed as construction progresses. Project completion is anticipated for 2012.

These examples demonstrate the utility and flexibility of the friction damper and the HDR damper. Though different in many ways, both types of dampers function well under the appropriate circumstances. As the number of cable-stayed bridges continues to increase, these damping systems will certainly assist in maintaining the long-term durability of these bridges. MSC