



Structural Protection Systems

## MAURER Stay Cable Dampers



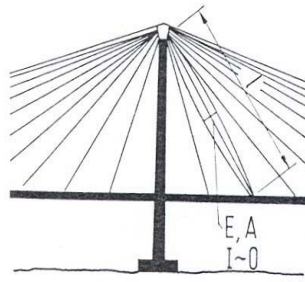
**MAURER SÖHNE**  
Innovations in steel



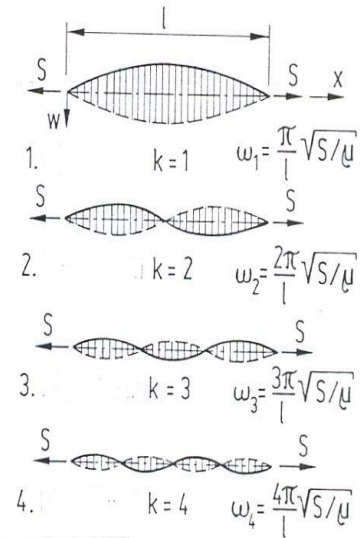
Since 1876

## Vibration of Stay Cables

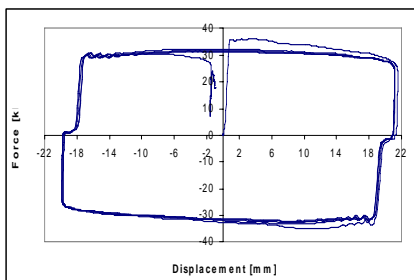
Rain in combination with wind can cause considerable vibrations in stay cables. In unfavourable circumstances, the magnitude of the vibrations of the stay cables can endanger the total bridge structure, in particular when the vibrations match the natural frequency of the bridge structure. But as a minimum, undesired vibrations may lead to fatigue problems, reducing the design life of stay cables, and also shortening the maintenance interval.



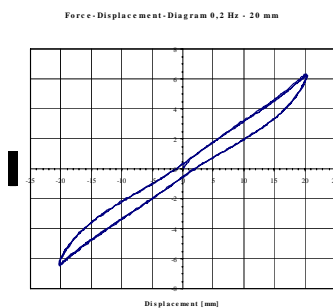
The first 4 modal shapes of vibrating stay cables and their natural frequencies



Modes of vibrations of stay cables, and their natural frequencies



Hysteresis of a viscous damper (above) and an elastomeric damper (below), illustrating the superior energy dissipation capacity of viscous dampers.



### What can be done about undesired vibrations?

Simply speaking, when required, a so called cable vibration damper shall be attached to the stay cable, to reduce the amplitudes of the vibration to a tolerable level. Instead of the term "damping", a more scientific term "energy dissipation" can be used. A damper dissipates the (undesired) energy which is introduced into the structural system. The source of such undesired energy can be in earth quake, or, like in this case, in a combination of rain and wind that excites a stay cable to vibrations that might be dangerous for the structural system

Energy dissipation means that a certain response force which is created by the damper has to perform a certain displacement, and the product of force and displacement is the energy that will be dissipated. The force could be a friction force (as we have it in the friction dampers) or a shear force (which is the case in elastomeric dampers), or a viscous response force (viscous dampers).

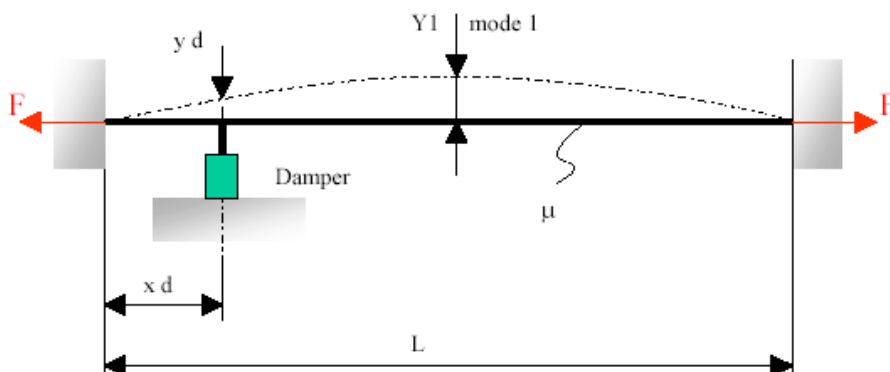
The energy dissipation capacity per cycle is expressed in the hysteresis of the damper. The bigger the area that a hysteresis comprises, the better is its energy dissipation capacity.

### What is the tolerable level of an amplitude?

According to the FIB Bulletin 30/2005, pp.21, the maximum amplitude of a vibrating cable shall be kept below  $1/1700$  of its length. Should the amplitude  $Y_1$  of the (undamped) cable exceed  $L/1700$ , a cable damper has to be devised.

### Fatigue of the cable

Next to the reduction of vibrations of big amplitudes, another motivation for the installation of dampers is the reduction of small vibrations, which can result in an early ageing of the material at the anchor head caused by big curvatures. Great care has to be taken that these curvatures are not shifted to the location of the damper.



Principle sketch of a cable of length  $L$  that vibrates in the 1<sup>st</sup> mode. Distance of the cable damper from the edge is  $x_d$ , where a cable amplitude  $y_d$  prevails. Maximum amplitude in the centre is  $Y_1$ . Tension force in the cable is  $F$ , mass of the cable per meter is  $\mu$ .



*Example of an externally arranged viscous cable damper (Eiland Bridge, Kampen, NL).*

### **What kinds of cable dampers are available ?**

All cable dampers have in common that they are attached to the stay cable close to their end, at the level of the bridge deck. At that location they will enact some force onto the vibrating cable, thus reducing the amplitude of the vibration. Cable dampers can be arranged internally, that is within the protection tube, or externally. Internal cable dampers are usually cheaper than the external ones, and will not affect the aesthetics of the bridge, and they may offer also more safety against vandalism or other external impacts. However, due to their relative "closeness" to the stay cable their response force capacity is limited, and so is their damping capacity that such internal stay cable dampers can introduce into the system. This is why internal cable dampers have usually a limited scope of application, like in foot bridges, where the length of the stay cables is limited, and the damping requirement can be met with such internal dampers.



*External elastomeric cable damper installed at Forchheim Bridge*

### **Why can't we use a conventional damper ?**

Such shock absorbers are certainly cheaper than the tailor made cable dampers. However, their design response force will not match the requirement of the response force of cable dampers which can reach a magnitude of 40 kN or more.

Due to the fact that the optimum damping coefficient that is to be set is different in each case, an individually adjusted type with preset properties would be required, when using vehicle shock-dampers. In regard to delivery date, costs, consulting, dimensions, design of connections, installation, removal and inspection possibilities this is only difficult to accomplish. Long-term behaviour of such vehicle shock-absorbers in regard to leakage, heat transfer and effectiveness is also difficult to judge (and to guarantee). Further, they are no maintenance-free elements.

### **The elastomeric cable damper**

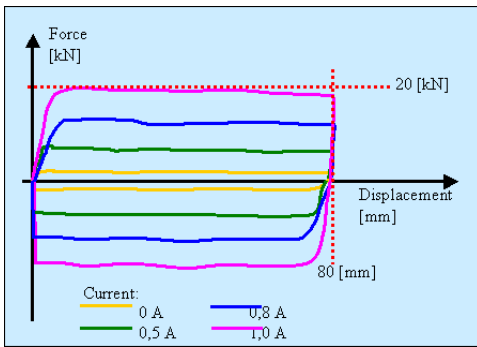
Such a damper works by shear deformation of the high damping elastomer. Elastomeric cable dampers display a relatively weak damping characteristic, which mirrors the relatively low damping characteristics of the elastomer. Elastomeric cable dampers may be useful for pedestrian bridges where the stay cables are relatively short. Their biggest advantage is their low price, and in the same time their weak technical performance is their biggest draw back.

### **The friction damper**

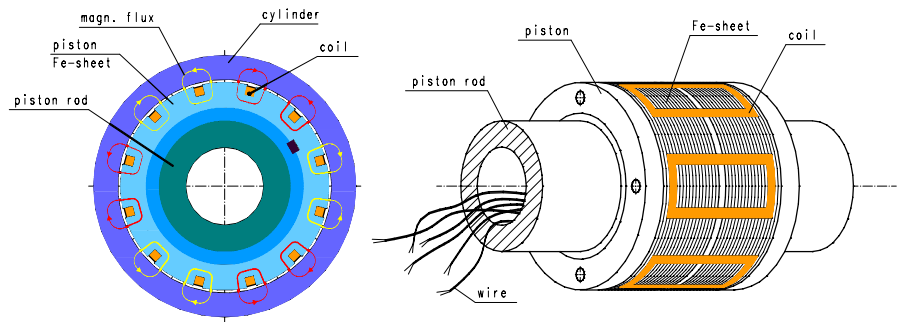
A friction damper dissipates energy by means of friction forces that perform a displacement which corresponds to the amplitude of the stay cable at that location. Friction dampers can employ a sufficiently high damping ratio, however their functionality is limited to a relatively narrow range where there is the maximum requirement for damping. Below and above this range, a friction damper will not be very effective.



*Internal elastomeric Cable Damper in the test rig, showing the shear deformation*



*Hysteresis of an adaptive magneto-rheological damper at different currents*



*Principle sketch depicting the arrangement of the coils around the piston, for designing a semiactive magneto-rheological (MR) damper*

### Adaptive Cable Dampers (ACDs)

As its name implies, an adaptive linear viscous damper can adapt its response force to the modal shapes of the vibrating cable, thus making sure that always optimum damping is enacted. The damper thus adapts to the existing situation on site, taking into account the specific parameters that make the cables vibrate, and tunes itself optimally to the situation by way of a certain algorithm. Maurer Magneto-Rheological Dampers (MRDs) can be considered to be a member of the family of adaptive cable dampers. MRDs behave under a constant current in a very good approximation like a friction damper. This means that the electrical current has to be regulated such that the damper force behaves in a way that the MR damper always works in its best location (which is the optimum described as Range 2 as explained in the section about friction dampers). In this best location the MR damper puts the maximum possible damping into the cable. This means that the MRD force must be controlled proportional to the vibration amplitude at the location of the MRD.

### Optimum Damping

In order to damp a certain vibration, that is a certain mode (most often the 1<sup>st</sup> mode), we can imagine that there is a certain force acting on the cables with the objective to reduce the amplitudes.

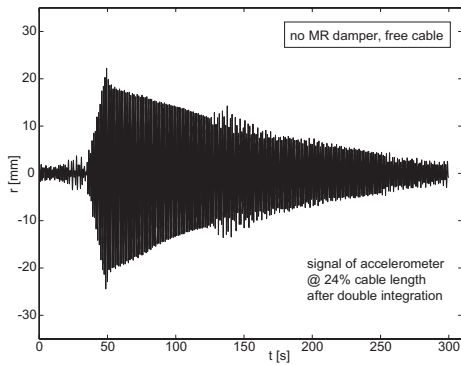
If this force is too weak, it does not create enough "resistance" to the vibrations, and so the vibrations will not decay in the optimum way. In the other extreme, should this force be too strong, at the location of the damper there will be no movement of the cable. The damper clamps the cable, and no energy will be dissipated. Since this point now turns to a node, the length of the cable that can now freely vibrate is reduced by the length where the damper clamps, and the cable in its reduced length can again be excited to vibrations.

In between there is a certain force that reduces the vibrations, i.e. the amplitudes of the cable in an optimum way. This state is called the optimum damping. Each modal shape has its own state of optimum damping, and the optimum response force of the cable damper may vary for each modal shape that has to be damped.

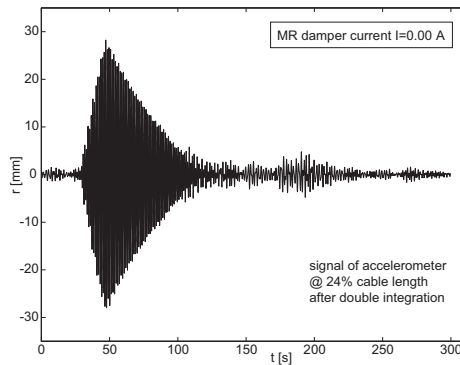


In contrast to a conventional friction damper: the controlled MRD prevents clamping (which is 1<sup>st</sup> priority), and by way of an approximately optimum control algorithm the controlled MRD damps the cable in an optimum way. In any case, the damping effect is superior to the one of a conventional friction damper. Because, when the damper is "off", the coupling between cable and bridge deck is relatively weak and thus vibrations of the deck cannot excite vibrations in the cable, which consequently reduces the cable's exposure to fatigue.

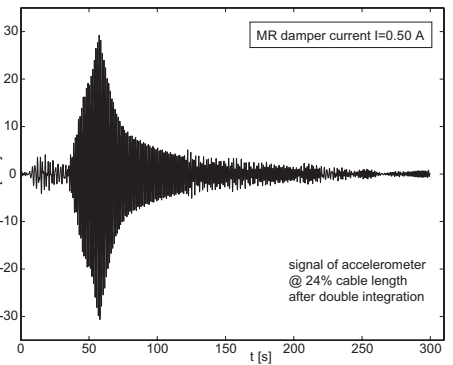
*Adaptive Cable Damper (Eiland Bridge, Kampen, NL)*



*Decay of vibrations of an undamped cable, i.e. no cable damper attached*



*Minimum decay of vibrations, when the attached adaptive Cable damper is in its base friction, i.e. no current.  $I = 0$ , „off-mode“.*



*Optimum damping of an adaptive cable damper: fast decay of vibrations. Damper is switched on,  $I = 0.5 \text{ A}$ .*

### Decay Curves

The effect of an adaptive magneto-rheological cable damper can be seen from the 3 figures above, which were taken from measurements at the Ijssel Bridge near Kampen, NL that were conducted by EMPA in Switzerland.

The figures depict the decay of the amplitudes of a stay cable over the time, after the stay cable was excited by means of a rope in its natural frequency. Left depicts the decay of the undamped cable, that is without a cable damper. The effect of an inactive cable damper can be taken from the central figure. Inactive hereby refers to the state when the magneto-rheological damper is "switched off", that is the current is 0. This state which is also called the passive mode provides the minimum damping effect of an MR damper. The right figure above represents the state of optimum damping,

### Special Features of Maurer's Adaptive Cable Damper

Maurer has designed the adaptive cable damper (ACD) on the principle of the magneto-rheological (MR) fluid damper. The fluid displays the characteristics that its shear strength can be varied under the influence of a magnetic field. Within the damper, coils are arranged which by way of electronic control can create a magnetic field.

The higher the electrical current, the stronger the magnetic field, and the higher the damper force (see Fig. 9). The force of an MR damper has a lower and an upper limit:

- The lower limit is set by the base friction at 0 Ampere current and by the friction at the sealing
- The upper limit is set by the maximum current

At a constant current, in good approximation the damper force follows the Coulomb Friction, this means the force is independent from the velocity of vibration. Due to the effect of base friction, an MR damper already employs a damping effect when the electric current is switched off, or when there is a power break down.



*Evaluating the performance of a Maurer adaptive cable damper (ACD) in the test rig of the EMPA located in Dubendorf, Switzerland.*

### Power Supply of an adaptive magneto-rheological damper

The current that is required to control the magnetic field in the damper takes a low energy supply. Should no fixed power supply be available, solar panels might suffice to provide the necessary energy. In the said example of the Ijssel Bridge near Kampen, NL, the power consumption is 21 mA when in passive mode, and 220 mA when in active mode. This demonstrates that solar panels might very well suffice.



## Reference Projects



### *Bridge Dubrovnik / Croatia*

*Response Force variable from 1 – 40 kN  
Stroke  $\pm 80$  mm  
Supply of 20 adaptive cable dampers (ACDs)*



### *Eilandbrug Kampen / Netherlands*

*Test installation of MAURER Adaptive Cable Damper:  
Response Force variable from 1 – 40 kN,  
Stroke  $\pm 60$  mm  
Length of damped cable = 163 m.*



### *Sutong Bridge / China*

*MAURER ACD,  
Response Force variable from 1 – 50 kN,  
Stroke  $\pm 65$  mm  
Supply of a total of 200 cable dampers,  
both of type ACD and passive linear  
viscous dampers.  
Longest cable to be damped is 588 m.*



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