Vibration phenomena
Various effects can lead to excitation of the cable and eventually to instability of the structure if the vibrations are not controlled. Stay cables are generally excited by aerodynamic forces acting on the cable, or by anchorage displacements caused by the action on the structure of dynamic forces such as traffic. Wind excitations can be categorised in four families:

VORTEX SHEDDING
Alternating asymmetrical vortex detachment induces a lift force perpendicular to the direction of the wind and hence vibrations of the cable.

RAIN & WIND INTERACTION
Water rivulets forming at the surface of the inclined cable modify its aerodynamic profile resulting in an asymmetrical pressure distribution and hence a lift force perpendicular to the virtual wind velocity. Oscillation of the rivulet results in cyclic changes to the lift force and hence oscillation of the cable. This occurs typically at relatively low wind velocities.

WAKE GALLOPING
Vortices detached from upstream obstacle (adjacent cable) induce a pressure differential at the surface of the downstream cable resulting in an alternating lift force perpendicular to the wind direction exciting the downstream cable.

DRAG CRISIS
The drag coefficient of the cable varies with the relative wind velocity. Variations of the relative wind velocity due to movement of the cable parallel to the wind direction induce cyclic fluctuations of the drag coefficient and hence the drag force exciting cable vibrations parallel to the wind direction.
VSL SOLUTIONS FOR VIBRATION CONTROL

Modelling of vibration effects
Today’s recommendations for stay cables issued by the various international bodies require a project-specific assessment of the dynamic effects. However, the mechanisms of dynamic excitation are particularly complex phenomena and their reliable prediction is difficult. VSL uses analytical tools that have been developed in collaboration with internationally-renowned experts in the field. These tools simulate the cable’s response under combined excitation effects while applying different stability criteria that allow estimation of the vibration risks and any additional damping required.

VSL can therefore assist the designer in assessing the risk of cable vibrations and can propose suitable mitigation measures based on a modular approach.

Methods of controlling vibrations
Modern cable-stayed structures have to accommodate increased dynamic demands on their cables. VSL’s response to this requirement includes use of the following devices:

Helical ribs
The stay pipes of the VSL SSI 2000 cable are supplied with helical ribs. Their shape and dimensions have been optimised and validated in wind tunnel tests for effective control of the risk of rain-wind induced vibrations while minimising the increase in wind drag.

Additional damping devices
The most versatile means of controlling vibrations is to increase the structural damping ratio of the cable by installing additional damping devices. VSL offers two types of dampers: the VSL Friction damper and the VSL VE damper. This permits selection of the most appropriate damping behaviour to suit the characteristics of each individual cable. The VSL VE damper is further available in two grades, «Standard» and «High performance».

In addition to their high efficiency, the common qualities of both damping systems are their adaptability, their great durability and their low maintenance costs, achieved by minimising the number of moveable parts. The two dampers complement each other and allow implementation of the most appropriate solution, taking account of the characteristics of the stay cables, the types of critical vibrations and the required performance. Both systems can be used on the same structure.

VSL’s services:
- Stability risk analysis
- Proposal of mitigation measures, including provision of dampers
- Estimation of the behaviour of the damper-equipped cables, taking into account excitation by aerodynamic effects and structural coupling
- Design, fabrication, workshop testing, supply and installation of a choice of two different damping systems
- Full integration of two different damper types into the VSL SSI 2000 system either at the time of installation or for installation at a later stage (retrofitting)
- Retrofitting solutions for existing strand and parallel wire cables
- Fine-tuning of damping devices after installation to match the actual characteristics of cable and structure

Testing
The behaviour of VSL Dampers and the correlation of calculated and actual cable oscillations have been verified in several full-scale tests. The effectiveness of the damper can be assessed by measuring the cable acceleration over time and comparing the results with and without the damper.

The required additional damping ratio is defined for each structure on a case-by-case basis and lies typically below 1%. The achievable damping ratio can be defined as a function of x/L, where x is the position of the damper from the anchorage relative to the cable length L. The graph above can be used to select the appropriate damper type depending on the achievable x/L. The damper is typically located close to the deck anchorage for improved accessibility and aesthetics. For special cases, an additional damper can be provided near the pylon anchorage.
Two systems cover the full range of requirements

In general, VSL Friction dampers are more suitable for long cables, whereas VSL VE dampers are more suitable for short and medium length cables. The final selection of the most appropriate system is made by VSL using analytical tools that have been developed in collaboration with internationally-renowned experts in the field.

Two systems with the same external visual appearance

The external components and shapes are identical for both systems, even though they adopt different approaches to dissipating the vibration energy. This allows a consistent appearance along a bridge, even where both systems are required.

Protective collar

The moving part of the damper connects to the stay cable using a collar fitted with a protective neoprene ring to ensure lasting protection of the cable’s main tensile element.

Modular dissipative element

This is designed to allow inspection and replacement on site using light tools and equipment, with minimum impact on the bridge’s operation.

Stiff and integrated support

The VSL Damper supports are integrated into the guide pipe that is part of the main structure to ensure stiff support for maximum performance. This forms the fixed element of the damper.
TH COMPLEMENTARY CHARACTERISTICS

Fully integrated for enhanced aesthetics
The compact and highly-efficient nature of the dampers allows installation close to the deck anchorage, where they are fully integrated into the anti-vandalism pipe. This avoids them affecting the visual appearance of the stay cable. Thanks to their identical cover designs, both types of damper can be installed easily on the same structure without introducing visual differences.

Easy maintenance
The damper configurations provide easy access for inspection and maintenance operations and use a minimal number of moving parts. All components can be dismantled and/or replaced on site using light tools and equipment, with minimum impact on the bridge’s operation.

Versatile
Both damper types are optimised for use as internal dampers, fully protected inside the VSL SSI 2000 anti-vandalism pipe, but they can also easily be adapted for retrofitting solutions or use as external dampers if required. They can be attached to both parallel strand systems (PSS) or parallel wire systems (PWS). They can be fitted on new structures or retrofitted to existing ones.
THE VSL FRICTION DAMPER – HOW IT

Dissipating energy through friction
The VSL Friction damper applies the same principles used in disc brakes, dissipating the energy through friction generated between two friction partners. The first is a pair of sliding discs which is connected via a collar to the tensile member of the stay. It is sandwiched by the second partner, which consists of a specially developed composite pad supported by a pair of spring blades that are connected to the external structure of the guide pipe.

High performance and outstanding efficiency
The VSL Friction damper provides high performance for critical cases or where the damper has to be placed close to the deck anchorage relative to the overall length of the cable.

Unaffected by temperature
The damper’s insensitivity to temperature changes results in friction characteristics that are very stable throughout a wide temperature range. The chosen materials ensure well-controlled behaviour with no stick-slip effect at the friction interface.

The force acting on the damper when it is activated has initially to exceed the static friction before the friction partners start moving relative to each other.

There is no movement of the damper arising from the non-critical continuous vibration of the cable with the small displacements that traffic and other effects cause on every cable-stayed structure.

This is a very efficient method for preventing excessive wear of the friction surfaces without affecting the damper’s performance. Inspections of installed dampers after several years of operation have clearly demonstrated this beneficial effect.
Perfectly tuned for critical vibrations
Various theoretical approaches have been developed in an attempt to estimate the achievable damping of a stay cable equipped with a damper installed near one anchorage. One result that is widely acknowledged shows the existence of a limitation, and can be expressed as (Kovacs 1982):

$$\xi_{\text{max}} = \frac{x}{2L} \quad \text{or} \quad \delta_{\text{max}} = \frac{\pi x}{L}$$

with $x$ = damper distance to the closest anchorage, $L$ = cable free length, $\xi$ is the additional damping ratio and $\delta$ is the logarithmic decrement.

However this approach does not consider the non-linearity of the friction damper. While they help to assess the overall performance of a damper system, it has been demonstrated in full-scale tests that these maximum ratios can be surpassed by certain dampers on individual modes of a modal analysis.

The VSL Friction damper is one of the few dampers in the market that has achieved damping ratios exceeding the theoretical maximum values above. It has achieved an efficiency of 130% on the first mode during testing. The first mode is often considered the most critical mode as it can result in large amplitudes and hence significantly affects the comfort of the user at the same time as having an Eigen frequency close to that of the structure. This brings the risk of coupling effects between the structure and cable, which could prove catastrophic.

Activated only when needed
In addition to this outstanding performance, the damper’s characteristics are particularly suited to stay cables. The initial effect of static friction prevents activation of the damper under small amplitudes. This prevents unnecessary wear on the damper under vibrations that do not affect the cable’s performance and that are considered perfectly acceptable while protecting at the same time the anchorage by filtering these movements. However, the VSL Friction damper achieves its maximum performance almost immediately once the cable vibration has reached a level that is critical for the cable or the structure to which the damper has been tuned.

It achieves an extremely high damping ratio at these critical amplitudes and dissipates the cable’s energy very efficiently to prevent any further excitation and ensure that the cable never reaches large amplitudes. These specific characteristics make the VSL Friction damper the perfect solution for any cable, but in particular for long cables on structures with a high risk of parametric excitation.

Efficient at all vibration modes

The VSL Friction damper: durable thanks to its few moving parts

The example shows the calculated modal response of a specific stay cable susceptible to rain-wind induced vibrations resulting in instability over a typical 10min period. The same cable equipped with a VSL Friction damper does not experience instability over the same period.
THE VSL FRICTION DAMPER – HOW IT

**Close to the anchorage:**
The low x/L ratio required by the VSL Friction damper and its compact body mean that it can be positioned close to the deck anchorage and easily integrated into the anti-vandalism protection near deck level. The result is an aesthetically-pleasing solution that does not compromise the performance. Aesthetics are often important in the design of stay cables where they are the dominating feature of landmark structures. Compared with external dampers which require large mounting frames, the use of the VSL Friction damper as an internal damper provides a visually-convincing solution for any structure.

Based on the high performance measured during several full-scale tests, the VSL Friction damper can be considered amongst the most efficient passive damping devices for mitigation of stay cable vibration (Cable Dynamic Symposium Vienna 2007, proceedings, Behavior Comparison of Cable Dampers by Full-Scale Experiment, S.S. Ahn, J.H. Park, S.H. Lee, C.M. Park). Performances have surpassed 100% of the theoretical maximum damping that can be provided by a passive damping system to a stay cable.
Adjustable damping capacity
The contact force of the pads is controlled by elastic deformation of the spring blades. Varying the stiffness of the blades allows adjustment of the damping characteristics for each installation.

Further fine-tuning on site is carried out without dismantling the damper. The friction force is varied through adjustment of the protrusion of the composite pads from the spring blades. The materials used as friction partners have been selected for optimum energy dissipation, stable friction behaviour and high durability.

Indicative dimensions of the VSL Friction dampers, for each anchorage size in the VSL SSI 2000 stay cable system brochure

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<tr>
<th>type</th>
<th>L1 min DR*</th>
<th>L1 min DS*</th>
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Dimensions noted in millimetres.
Other sizes available on request.
For larger sizes please contact your local VSL representative.

* DR refers to the use of adjustable anchorage at the damper location level, while DS refers to the use of fixed anchorage.
** These dimensions are given for indication only. They must be adapted according to specificities of the project.
THE VSL VE DAMPER – HOW IT WORKS

Shear deformation of high damping rubber
The heart of the VSL VE Damper is a high damping rubber material which dissipates the kinetic energy of the vibration by shear deformation of specially-designed pads. Each damper consists of a series of pads mounted between a moveable collar attached to the tensile element of the stay cable and a fixed support rigidly connected to the guide pipe. The damper’s characteristics are adjusted for each structure by varying the number of pads and choosing between two pad types, «high performance» and «standard». The HDR can withstand large shear deformations and can also cater for significant deformation under tension or compression without affecting its damping properties. This allows longitudinal movements between the cable and support to be accommodated entirely within the HDR, which avoids the need for additional hinged or sliding interfaces that would affect the damping ratio.

Durability without maintenance
The high-damping rubber pads have a long design life and excellent fatigue resistance. Accelerated ageing tests have demonstrated a life expectancy of 60 years and the pads have sustained 10 million load cycles during fatigue testing. The damper requires only minimal maintenance during its operating life: this allows it to be placed if necessary even at the pylon, where maintenance access is difficult and expensive.
Independent of vibration mode and amplitude

The behaviour of the VSL VE damper can be modelled as a combined device consisting of a spring, a friction member and a viscous element all contained in the HDR pad. This makes the damping performance of the VSL VE damper largely independent of the vibration mode and the amplitude. The time-displacement curves recorded from full-scale tests clearly illustrate this behaviour.

Time-displacement curves as recorded during VSL VE damper testing

The VSL VE damper performs best on short to medium length stay cables or where compact solutions are required.
Full-scale test results
As well as laboratory testing, numerous full-scale in-situ tests have been carried out to assess the VSL VE damper’s performance and the characteristics of the HDR component under varying environmental conditions. The pads have been subjected in laboratory tests to fatigue loading where they had to sustain 10Mio load cycles. To assess their durability, accelerated ageing tests have been carried out, from which a life expectancy has been derived that is in excess of 60 years without deterioration of the mechanical properties.
**Highly deformable**

The damper pads, including the interface between the HDR and the mounting plates, have been designed to accommodate large deformations without damage. The dissipated energy per shear cycle even increases with increasing deformation. The maximum permissible deformation is considerably in excess of the actual movements occurring in the damper. This results in very high durability and fatigue resistance.

![Hysteresis of a VSL VE damper](image)

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APPLICATIONS

Puente La Unidad, Mexico - 2003

Uddevalla Bridge, Sweden - 1998

Neva Bridge, Russia - 2006

Badajoz Bridge, Spain - 1998

Canada Line Pier Bridge, Canada - 2008
VSL – guided by a strong QSE culture

VSL’s leading position is based on a rigorous and committed quality culture. The QSE (Quality, Safety, Environment) policy represents a major focus for every service provided. Local teams ensure co-ordination of actions, encourage sharing of experience and promote best practices, with the aim of continuously improving performance. In VSL’s culture, employees are vitally important to the competitiveness and prosperity of the company. VSL is committed to maintaining the highest levels of client satisfaction and personnel safety.

Changing the way we do business

For VSL, sustainable development means striking a balance in its development model between the economic profitability of its businesses and their social and environmental impacts. This commitment has been formalised into the VSL Sustainable Development programme, which focuses on safety together with the use of fewer scarce materials and less energy as well as the production of less pollution and waste.

Creating sustainable solutions with VSL Dampers

VSL’s Dampers have been designed and constructed as very durable systems. Moreover, their function in mitigating vibration reduces the risk of material fatigue in the stays and in the bridge, which in turn reduces the need for maintenance and replacement during the service life of the structure. They make a vital contribution to increasing the life expectancy of the structures where they are installed.