

## VSL DAMPING SYSTEMS FOR STAY CABLES

### VSL 斜拉索阻尼系统



#### ASSESSMENT OF CABLE BEHAVIOUR

拉索运行状况评定

#### DESIGN AND FABRICATION

设计和制造

#### INSTALLATION AND TUNING

安装和调试

#### RETROFITTING

现有索上加（改）装

## VSL-SPECIALIST KNOW-HOW FOR CABLE-STAYED STRUCTURES

### VSL-关于斜拉桥结构的专业知识

Over 50 years of engineering experience

超过 50 年的工程实践经验

VSL's specialist construction systems have been used throughout the world since 1956 and have earned an excellent reputation for quality and reliability. This has made VSL a recognised leader in specialist construction methods and associated engineering works.

自 1956 年以来，VSL 的专业施工体系在全球范围内得以广泛应用，并以其高质量和高可靠性赢得了卓越的声誉。这使得 VSL 在专业施工方法和相关工程施工方面成为公认的领导者。

### A worldwide network

#### 全球市场分布

VSL provides solutions through its network of locally-based subsidiaries who have access to a strong common technical support structure. Its clients work with a local partner while benefiting from the constant development and evolution of VSL's technologies.

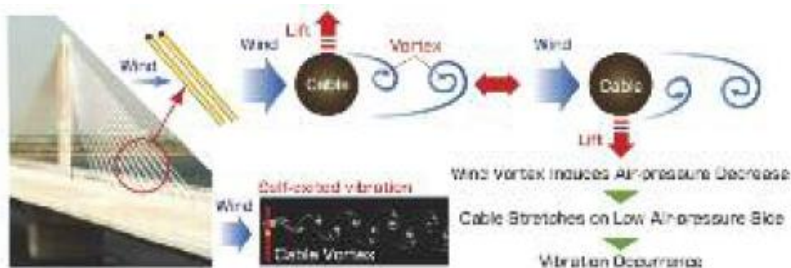
VSL 通过其位于世界各地的子公司来向当地市场提供解决方案，这些子公司拥有相同的强大技术支撑结构。客户与当地子公司合作时，将共同受益于 VSL 不断发展和革新的技术。

### Vibration phenomena

#### 振动现象

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:

如果不**进行**控制，**多种因素**各种作用**将**造成拉索**振动**，最终导致结构不稳定。斜拉索通常会因作用在拉索上的空气动力或是由于交通等动态力**作用在结构上**引起的锚具移位而**振动**。风力**导致的**振动可分为四类：

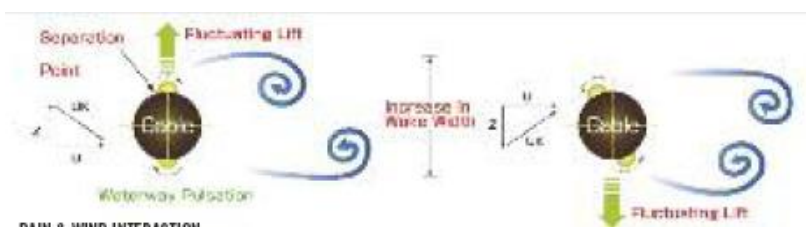


### VORTEX SHEDDING

#### 漩涡脱落

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

交替的不对称漩涡**脱落**产生了与风向垂直的**不对称**提升力，从而使拉索**产生**振动。



### RAIN & WIND INTERACTION

#### 风雨振

Water rivulets forming at the surface of the inclined cable modify its



## VSL Stay cable technology

### VSL 斜拉索技术

Stay cables are among the industry's most sophisticated technologies and so specialist expertise is the key to providing viable, economical and reliable solutions. VSL has become a world leader as stay cable contractor and offers an extensive range of services ranging from design assistance through cable supply and installation to full bridge construction packages. This makes VSL an invaluable partner for any bridge contractor or bridge owner, in particular when it comes to addressing the specific challenges of cable-stayed bridges.

斜拉索技术是行业中最先进的技术，因此专业技术是提供可行的、经济的和可靠的解决方案的关键。VSL 已成为世界领先的斜拉索承包商，并提供广泛的服务，从通过拉索供应和安装提供设计援助到完整的桥梁施工方案。这使得 VSL 成为桥梁承包商或桥梁业主的重要伙伴，特别是在解决斜拉桥的具体挑战方面。

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.

在斜拉索表面形成的水流能改变其空气动力特性，从而产生不对称的压力分布，因而使升力与实际风向垂直。气流的振动会引起升力的周期性变化，从而引起拉索的振动。这种情况通常会在风速相对较低时出现。



## WAKE GALLOPING

### 尾流驰振

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.

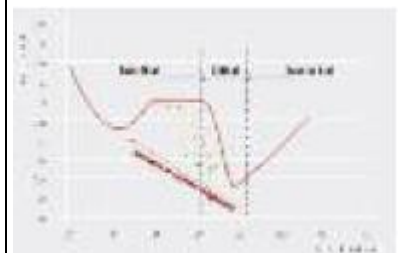
从上流障碍物（相邻拉索）分离的涡流在下游拉索的表面处引起压力差，导致垂直于风向的交替升力激励下游拉索引起振动。

## DRAG CRISIS

### 阻力激变

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.

拉索的阻力系数随风速的变化而变化。由于平行于风向的拉索的移动引起的相对风速的变化导致了



阻力系数的周期性波动，因此，阻力激励了与风向平行的拉索而引起振动。

## VSL SOLUTIONS FOR VIBRATION CONTROL

### VSL 振动控制解决措施

#### Modelling of vibration effects

##### 导致振动的因素模型

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.

今天由各国际机构发布的关于斜拉索的建议都要求对工程项目进行具体的动态因素进行评估。然而，动态激励作用机制是特别复杂的现象，对其进行可靠的预测也是极其困难的。VSL 使用的是行业内国际知名专家合作开发的分析工具。这些工具模拟拉索在组合激励效应下的反应，同时应用不同的稳定准则对振动风险和所需任何外加阻尼进行估计。

VSL can therefore assist the designer in assessing the risk of cable vibrations and can propose

#### Methods of controlling vibrations

##### 控制振动的方法

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:

现代的斜拉桥结构必须适应拉索上不断增加的振动情况。VSL 对这样情况的应对措施及相关装备如下：

#### Helical ribs

##### 螺旋线

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.

VSL SSI 2000 拉索的护套管配有双螺旋线。其形状和尺寸已在风洞试验中进行了优化和验证，可以有效控制风雨诱发的振动风险，同时最大限度地减少风阻力的增加。

#### Additional damping devices

##### 附加阻尼装置

The most versatile means of

#### VSL's services:

##### VSL 服务项目：

- Stability risk analysis
- 稳定性风险评估
- Proposal of mitigation measures, including provision of dampers
- 提议缓解措施，包括提供阻尼器
- Estimation of the behaviour of the damper-equipped cables, taking into account excitation by aerodynamic effects and structural coupling
- 考虑到气动效应和构造耦合作用造成的振动，对装备阻尼器的拉索的性能进行评估
- Design, fabrication, workshop testing, supply and installation of a choice of two different damping systems
- 两个不同的阻尼系统的设计、制造、车间检测、供应和安装
- 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)
- 在拉索安装期间或在拉索安装后，将两种不同类型的阻尼器完全集成到 VSL SSI 2000 拉索体

## 4 VSL DAMPING SYSTEMS FOR STAY CABLES

### 4 VSL 斜拉索阻尼系统

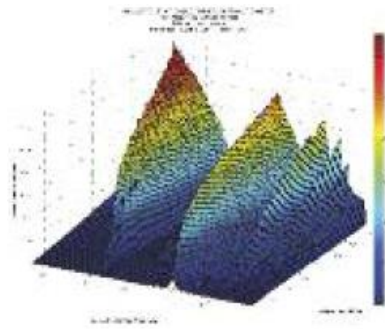
## CREATING SOLUTIONS TOGETHER

### 共同制定解决方案



suitable mitigation measures based on a modular approach.

因此，VSL 可以基于这些工具帮助设计人员评估拉索振动的风险，并提出合适的基于模块化方法的缓解措施。



Simulation of cable amplitudes for an undamped cable under parametric excitation

模拟在参数化激励下无阻尼拉索的振幅。

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 Gensui damper. This permits selection of the most appropriate damping behaviour to suit the characteristics of each individual cable. The VSL Gensui damper is further available in two grades, «Standard» and «High performance».

控制振动的最通用手段是通过安装附加阻尼装置来增加拉索的结构阻尼系数。VSL 提供两种类型的阻尼器：VSL 摩擦阻尼器和 VSL Gensui 橡胶阻尼器。这就允许根据每个独立拉索的特性和需要来选择最合适的阻尼运行情况，另外 VSL Gensui 橡胶阻尼器还有两种等级，“标准”和“高性能”。

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.

除了高效能之外，两种阻尼系统的共同特点是它们的适应性、耐用性和低维护成本，这些特点可通过减少活动部件的数量来实现。两种阻

#### 系中（改装）

- Retrofitting solutions for existing strand and parallel wire cables
- 改装是针对已有的钢绞线拉索和平行钢丝拉索的解决方案
- Fine-tuning of damping devices after installation to match the actual characteristics of cable and structure
- 安装后对阻尼装置进行精密调整，以适应拉索和结构的实际特性

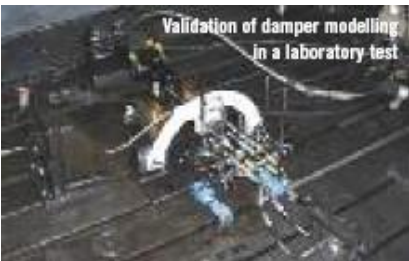
尼器相互补充，且考虑到斜拉索的特性、临界振动的类型和所需的性能，允许采取最合适的解决方案。可在同一结构上使用这两个系统。

## Testing

### 测试

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.

VSL 阻尼器的运行情况及计算的与实际的拉索振动的相关性已经在全尺寸试验中得到了验证。阻尼器的效果可通过测量使用和不使用阻尼器时拉索振动的振幅降低时间的不同来评估。



Validation of damper modeling in a laboratory test	在实验室试验中对减震器减振器建模进行验证
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The required additional damping ratio for each structure on a case-by-case basis and lies typically below 1%.

每个结构确定的所需附加阻尼比根据具体情况逐一确定，且通常低于 1%。

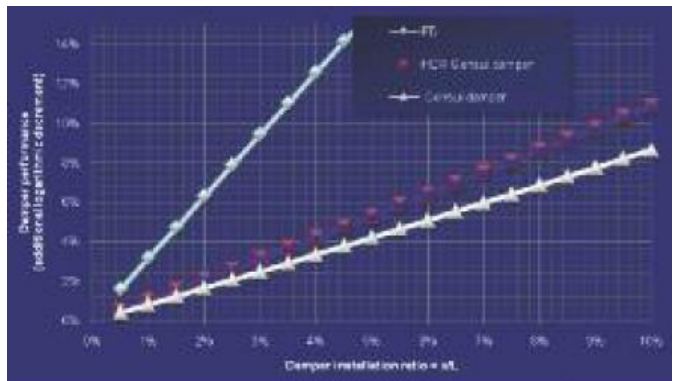
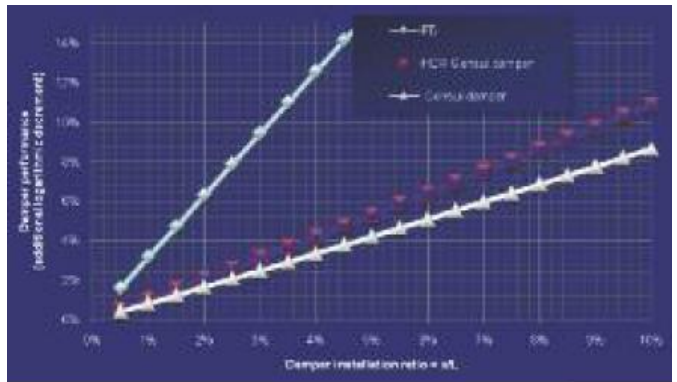
The achievable damping ratio can be

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  $x/L$ .

可达到的阻尼比可由方程  $x/L$  来确定，其中  $x$  是阻尼器安装位置到锚固点的距离而  $L$  拉索长度。上图可以用于根据可达到的  $x/L$  来选择合适的阻尼器类型。

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.

阻尼器通常安装于靠近桥面锚固的地方，以提高可操作性和美观性。在特殊情况下，可以在桥塔锚固附近安装阻尼器。



VSL DAMPERS-COMMON FEATURES WITH COMPLEMENTARY CHARACTERISTICS

VSL 阻尼器-共同特性与互补特性

Two systems cover the full range of requirements

两个系统涵盖了全部的需求

In general, VSL Friction dampers are more suitable for long cables, whereas VSL Gensui dampers are more suitable for short and medium length cables.

一般来说，VSL 摩擦摩擦更适合长拉索，而 VSL Gensui 橡胶则更适合短、中长度拉索。

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.

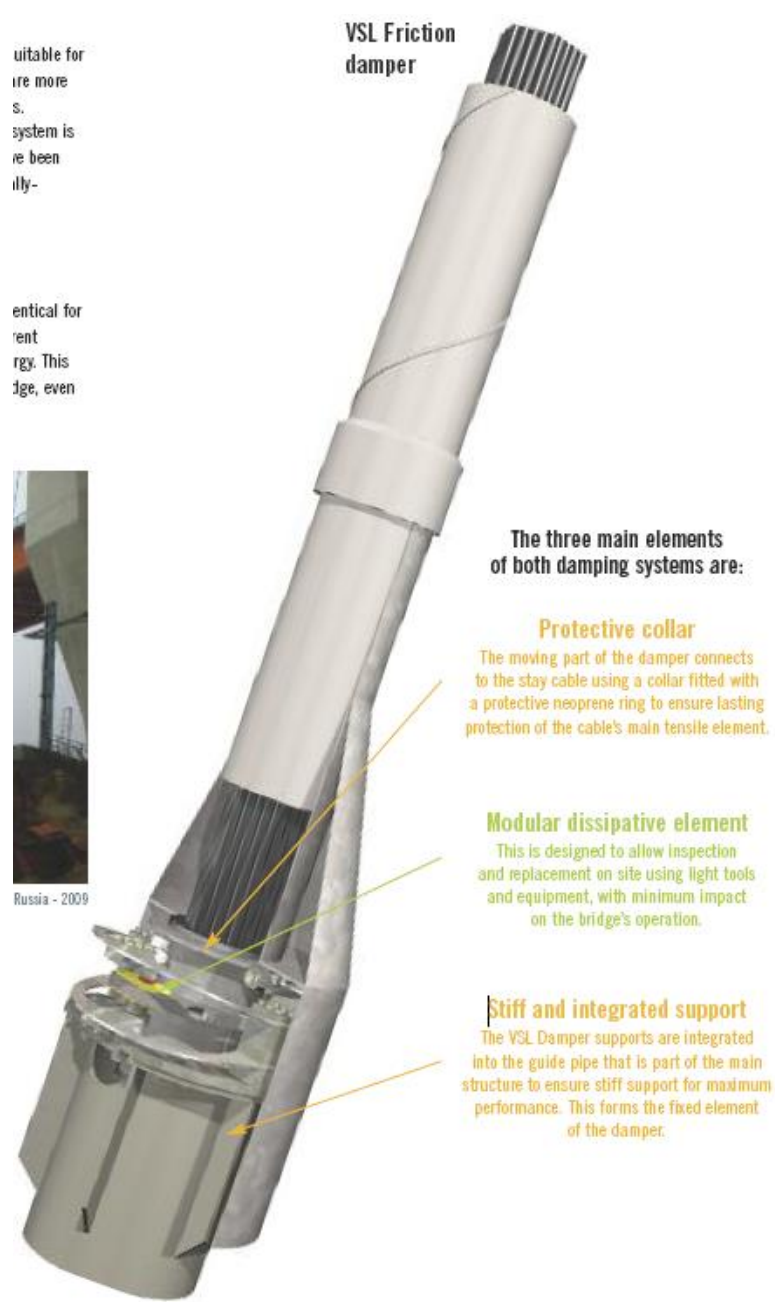
最适合的系统将由 VSL 使用先进的分析工具而做出的选择，这些工具是与国际知名专家合作开发的。

Two systems with the same external visual appearance

两个系统具有相同的外部视觉外观

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.

两个系统的外部部件和形状都是相同的，即使它们采用不同的方法来消耗振动能量。因此即使桥梁采



VSL Friction damper	VSL 摩擦阻尼器
The three main elements of both damping systems are:	两个阻尼系统的三要素是：
Protective collar	防护卡箍
The moving part of the damper	阻尼器的活动件用装有保护性氯

用两个阻尼系统也能保证桥梁外观的一致性。



Murom Bridge, Russia-2009

穆罗姆大桥，俄罗斯-2009

<p>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.</p>	<p>丁橡胶圈的<a href="#">卡箍</a>连接到斜拉索上，以确保长期保护拉索的主要负载部件。</p>
<p>Modular dissipative element</p> <p>This is designed to allow inspection and replacement on site using light tools and equipment, with minimum impact on the bridge's operation.</p>	<p>模块化耗能元件</p> <p>这种设计在尽量不影响桥梁运行的情况下可使用轻型工具和设备原地检查和/或更换阻尼器部件。</p>
<p>Stiff and integrated support</p> <p>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.</p>	<p>高刚度，一体化的支承结构</p> <p>VSL 阻尼器的支承结构被集成到作为主结构一部分的导管中，确保对最大性能的刚性支撑。这就构成了阻尼器的固定元件。</p>



VSL DAMPERS-COMMON FEATURES WITH COMPLEMENTARY CHARACTERISTICS

VSL 减震器减振器-共同特性与互补特性



Murom Bridge, Russia-2009

穆罗姆大桥，俄罗斯-2009

VSL damper	Gensui	VSL Gensui 橡胶阻尼器
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Accurate adaptation to meet requirements      Fully integrated for enhanced damping aesthetics

精确调整，满足阻尼减振要求

完全集成，增强美观性

The compact and highly-efficient nature of the

For both dampers, the dampers allows installation

heart of the damping system is made up of modular dissipative elements that are fully adaptable to all cable sizes.

对于两种体系的阻尼器，阻尼系统的内部由完全适用于所有拉索尺寸的模块化耗能元件组成。

For VSL Friction dampers, the performance can be fine-tuned once installed by adjusting the friction force without dismantling the damper.

对于 VSL 摩擦阻尼器，安装后可以通过调整摩擦力而不拆开阻尼器就能调整其性能。

For the VSL Gensui damper, the number of pads required is based on the dynamic characteristics of the cable.

VSL Gensui 橡胶阻尼器所需的橡胶垫数量取决于拉索的动态特性。

This allows easy adaptation to all cable sizes whether for a new installation or as part of a retrofitting solution.

这使得阻尼器可以轻松适应无论是新安装还是作为改装工作一部分的所有形式，规格和尺寸的拉索。

Highly efficient

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.

阻尼器具有紧凑和高效的特性，因此可在桥面锚固区附近安装阻尼器，在锚固处它们被完全整合到防撞管内部。这样就避免了对拉索的外观造成影响。由于其完全相同的隐蔽设计，这两种类型的阻尼都可以很容易地安装在同一结构上，而不会带来视觉上的冲突。

Easy maintenance

易于维护

The damper configurations provide easy access for inspection and maintenance operations and use a minimal number of moving parts.

阻尼器结构便于进行检查和维护操作，且使用了很少的活动部件。

All components can be dismantled and/or replaced on site using light tools and minimum impact on the bridge's operation.

所有部件都可以在尽量不影响桥梁运行的情况下使用轻型工具和设备在现场进行拆卸和/或更换。

Versatile

用途广泛

## 高效率

Several comparative tests on full-scale cables have demonstrated the exceptional efficiency of the dampers. Their measured performance has repeatedly exceeded the specified requirements, as well as exceeding that of other types of dampers.

全尺寸拉索的阻尼器几项比较性试验证明了 VSL 阻尼器的卓越效率。其测量性能多次超过规定要求，并超过其他类型阻尼器的性能。

## Very durable

### 持久耐用

Outstanding durability is achieved by movable parts and making use of dissipation mechanisms that employ stable solid materials instead of fluids.

其良好的耐久性是通过活动部件并利用使用稳定的固体材料代替流体的耗能结构来实现的。

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.

两种类型的阻尼器都经过了优化，可用作内部[减振器](#)，在 VSL SSI2000 防撞管内受到妥善保护，但如需要，也可以容易地适应于改装解决方案或用作外部[减振器](#)。它们都可连接到钢绞线拉索体系（PSS）或平行钢丝拉索体系（PWS）上。它们可安装在新的拉索结构上或改装现有的拉索结构。

THE VSL FRICTION DAMPER-HOW IT WORKS

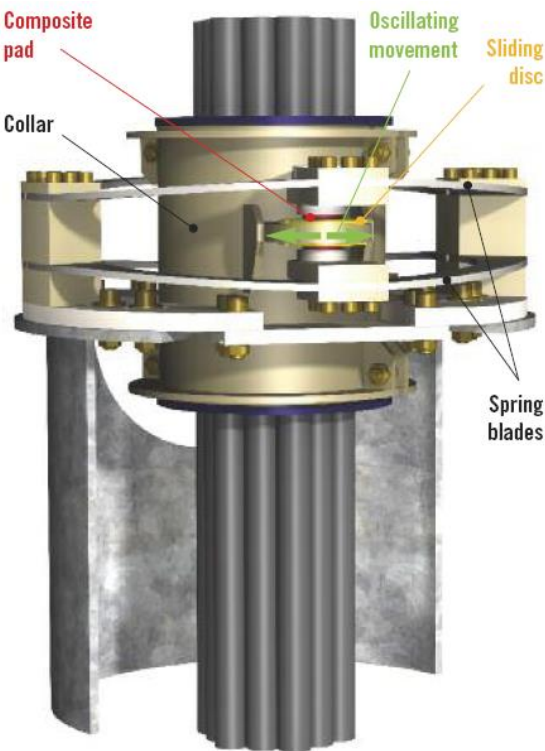
VSL 摩擦[减振器减振器](#)的工作原理

Dissipating energy through friction

通过摩擦消散能量

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.

VSL 摩擦阻尼器采用与盘式制动器相同的原理，通过两个摩擦元件之间产生的摩擦来消散能量。首先将一对[摩擦片](#)通过[卡箍](#)连接到拉索的索体上。每个摩擦片被二个摩擦件夹在中间，该摩擦件是由一对[弹簧片](#)支撑的专门开发的复合[垫](#)组成，且与预埋导管的外部结构相固定。



High performance and outstanding efficiency

高性能及高效率

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.

VSL 摩擦阻尼器在能实现其高性能，这与其安装位置到锚固区距离与拉索长度的相对比率有密切关系。

The required stiffness of the spring blades to generate the appropriate friction force depends on the dynamic characteristics of the cable.

弹簧片所需的高刚度以产生适当的摩擦力，这取决于拉索的动态特性。

This allows easy adaptation to all cable sizes, whether for a new installation or as part of a retrofitting solution.

结构上容易适应所有的规格的拉索，无论是新安装的

Composite pad	复合 <a href="#">摩擦垫</a>
Collar	<a href="#">卡箍</a>
Oscillating movement	振动
Sliding disc	<a href="#">摩擦片</a>
Spring blades	弹簧片



拉索或需要进行改进的拉索。

## Unaffected by temperature

### 不受温度影响

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.

阻尼器对温度变化的不敏感性使得 VSL 摩擦阻尼器在较大的温度范围内有着非常稳定的摩擦特性。但应确保控制好所选择的材料的性能,且在摩擦界面没有粘滑效应。



Friction damper installed prior to covering with anti-vandalism protection

摩擦阻尼器安装在防撞护罩之前

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.

在摩擦件开始相互移动之前,激活阻尼器时的作用力最初超过静摩擦力。

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 cablestayed structure.

交通和其他影响因素使斜拉结构产生较小的位移,这种无害的拉索振动不会使摩擦阻尼器的摩擦元件产生相对位移。

This is a very efficient method for preventing excessive wear of the friction surfaces without affecting the damper's performance.

这是一种非常有效的防止摩擦表面过度磨损而不影响阻尼减振性能的方法。

Inspections of installed dampers after several years of operation have clearly demonstrated this beneficial effect.

经过几年的运行,对安装的摩擦阻尼器的检查已经清楚地显示了这种有益的效果。

## THE VSL FRICTION DAMPER-HOW IT WORKS

### VSL 摩擦减振器减振器的工作原理

**Perfectly tuned for critical vibrations**

非常适合临界振动

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.

已经开发了各种理论方法来试图估计在靠近锚固处安装的装有阻尼器拉索的可实现的减振。

One result that is widely acknowledged shows the existence of a limitation, and can be expressed as (Kovacs 1982):

一个广泛认可的结果表明存在限制，可以表示为：（Kovacs 1982）

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

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

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

=阻尼器与最近锚固的距离, L=拉索净长度,  $\xi$  是附加减振比,  $\delta$  是对数衰减。

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

仅在需要时启动

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.

除了这种出色的性能，摩擦阻尼器的特性特别适合于斜拉索。静摩擦的初始效应防止在小振幅下启动阻尼器。这样可以防止阻尼器在不影响拉索性能情况下的小幅振动时产生不必要磨损，并且该情况是完全可以接受的，同时通过这些运动来保护锚固。然而，若拉索振动达到对拉索或阻尼器结构调节的临界水平时，VSL 摩擦阻尼器几乎可立即实现其最大性能。

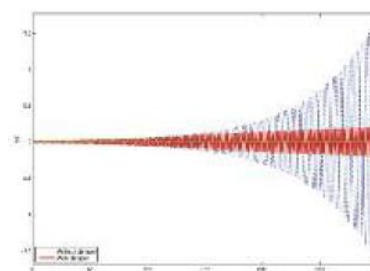
It achieves an extremely high damping ratio at these critical amplitudes and dissipates the cable's energy very efficiently to prevent any further excitation and

**Efficient at all vibration modes**

所有振动模式下都有效

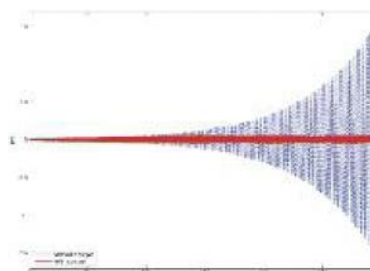
**First mode modal component**

第一种模式模态分量



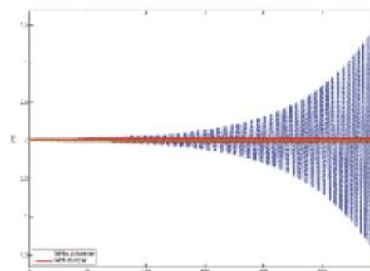
**Second mode modal component**

第二种模式模态分量



**Third mode modal component**

第三种模式模态分量



The example shows the calculated modal response of a specific stay cable susceptible to rain-wind induced vibrations resulting in instability over a

that these maximum ratios can be surpassed by certain dampers on individual modes of a modal analysis.

然而，该方法不考虑摩擦阻尼器的非线性。虽然它们有助于评估阻尼器系统的整体性能，但是在全尺寸试验中已经证明，在模态分析的单独模式下，某些阻尼器可超过这些最大比率。

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.

VSL 摩擦阻尼器是市场上减震比超过理论最大值的阻尼器之一。在测试中，第一种模式的效率达到了130%。第一种模式通常被认为是最关键的模式，因为它可以产生较大振幅，并且在本征频率接近结构频率的同时显著地影响用户的舒适度。这带来结构和拉索之间共振效应的风险，其可能是灾难性的。

ensure that the cable never typical 10min period. The same cable equipped with a VSL Friction damper does not experience instability over the solution for any cable, but in same period.

particular for long cables on structures with a high risk of parametric excitation.

它在这些临界振幅下实现了非常高的减振比，并且非常有效地消散了拉索的能量，以防止进一步共振，并确保拉索决不达到较大振幅。这些具体特性使得 VSL 摩擦阻尼器成为任何拉索的完美解决方案，特别是对于具有高参数化励振风险结构上的长拉索。

该示例显示了在典型的 10min 周期内，易受风雨影响的特定拉索的计算模态响应诱发的振动会导致产生不稳定性。配备 VSL 摩擦阻尼器的相同拉索在同一时期内不会出现不稳定性。



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

VSL 摩擦阻尼器：因其配  
有极少移动部件而经久耐  
用。



THE VSL FRICTION DAMPER-HOW IT WORKS

VSL 摩擦阻尼器的工作原理

Close to the anchorage:

靠近锚固:

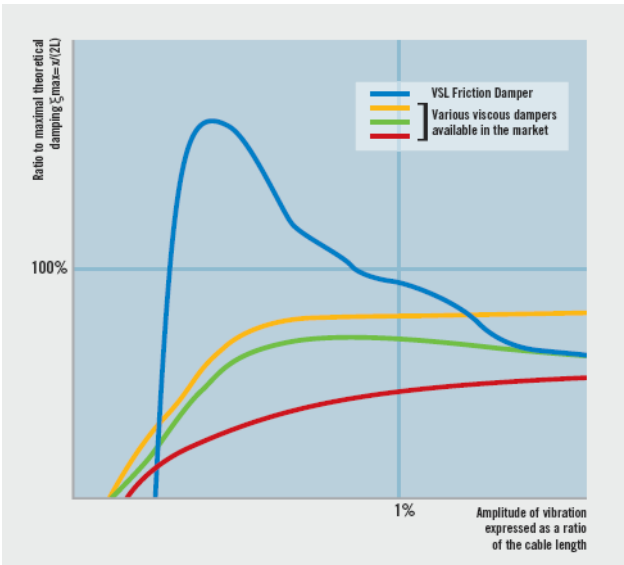
The low  $x/L$  ratio required by the VSL Friction damper and its compact body mean that it can be positioned close to the deck anchorage and easily integrated into the anti-vandalism protection near deck level. The result is an aesthetically-pleasing solution that does not compromise the performance. 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.

VSL 摩擦阻尼器因其紧凑型机身所需的低  $x/L$  比值意味着可以将其放置在靠近甲板锚固的位置，并且易于集成到靠近甲板水平的防破坏性防护上。这一种美观的解决方案，不会影响性能。在斜拉索的设计中，美学往往很重要，它们是地标建筑的主要特征。与需要大型安装架的外部阻尼器相比，使用 VSL 摩擦阻尼器作为内部阻尼器，为所有结构提供了视觉上令人信服解决方案。

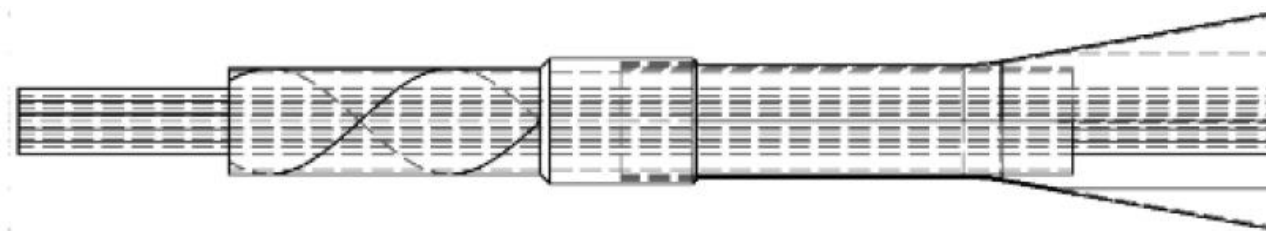


The damper is fully integrated into the anti-vandalism cover.

阻尼器完全集成到防破坏罩中。



Ratio to maximal theoretical damping $\xi_{\max}=x/(2L)$	最大理论减振比 $\xi_{\max}=x/(2L)$
VSL Friction Damper	VSL 摩擦阻尼器
Various viscous dampers available in the market	市场上有各种各样的粘滞阻尼器
Amplitude of vibration expressed as a ratio of the cable length	振动的振幅可通过拉索长度的比率来表达



WORKS

工作原理

Adjustable damping capacity

可调减震能力

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.

摩擦垫的接触力由弹簧片的弹性形变控制。改变叶片的刚度以调节每个装置的减震特性。

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.

在不拆卸阻尼器的情况下，在现场可以对阻尼器进行微调。通过对弹簧叶片复合摩擦垫突出程度的调整，可改变摩擦力的大小。用作摩擦件的材料因其作为最佳的能量耗散材料、具有稳定的摩擦特性和高耐用性而被选用。



Sucharskiego Bridge, Poland-2001

波兰-2001，Sucharskiego 大桥

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

VSL 摩擦阻尼器的指示尺寸，即为 VSL SSI 2000 斜拉索系统手册中的每个锚固的尺寸

type	L1 min DR*	L1 min DS*	L2**	Ø1**	Ø2 DR*	Ø2 DS*
类型	L1 最小 DR*	L1 最小 DS*				

6-12	1500	900	200	430	219.1 x 6.3	177.8 x 4.5
6-19	1750	1200	200	450	267 x 6.3	219.1 x 6.3
6-22	1900	1350	220	470	298.5 x 6.3	219.1 x 6.3
6-31	2100	1550	220	505	323.9 x 6.3	244.5 x 6.3
6-37	2300	1750	250	545	355.6 x 6.3	273 x 6.3
6-43	2550	2000	250	585	406.4 x 8.8	323.9 x 7.1
6-55	2650	2050	250	610	419 x 10	323.9 x 7.1
6-61	2850	2250	280	630	419 x 10	355.6 x 8
6-73	3050	2450	300	650	508 x 11	406.4 x 8.8
6-85	3150	2600	300	680	508 x 11	406.4 x 8.8
6-91	3400	2800	300	700	559 x 12.5	457 x 10
6-109	3550	3000	400	730	559 x 12.5	457 x 10
6-127	3950	3350	400	740	610 x 12.5	508 x 11

Dimensions noted in millimetres.

尺寸的单位为 mm。

Other sizes available on request.

其它尺寸阻尼器可按需供应。

For larger sizes please contact your local VSL representative.

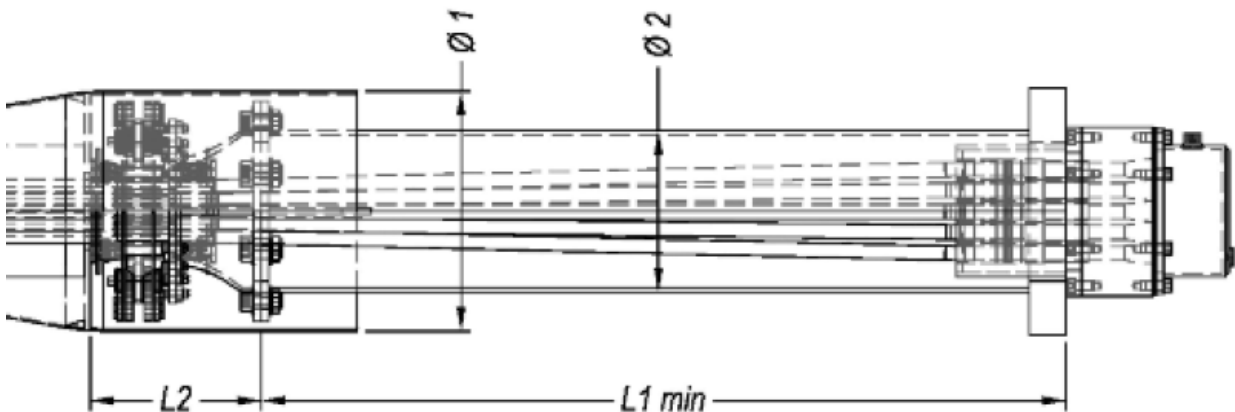
更大尺寸阻尼器请联系当地 VSL 代理商。

\*DR refers to the use of adjustable anchorage at the damper location level, while DS refers to the use of fixed anchorage.

\*DR 是指在阻尼器位置上使用可调锚具，而 DS 则是指使用固定端锚固。

\*\*These dimensions are given for indication only. They must be adapted according to specificities of the project.

\*\*这些尺寸仅供参考它们必须根据项目的具体情况加以调整。





THE VSL GENSUI DAMPER-HOW IT WORKS

VSL GENSUI 橡胶阻尼器的工作原理

Shear deformation of high damping rubber

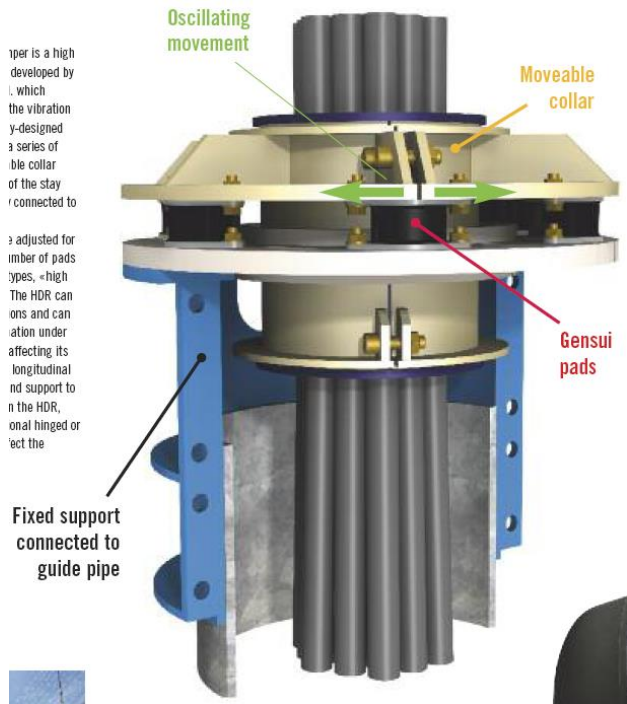
高减震橡胶的剪切形变

The heart of the VSL Gensui damper is a high damping rubber (HDR) material developed by Sumitomo Rubber Industries Ltd. 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.

VSL Gensui 橡胶阻尼器的核心是采用由住友橡胶工业有限公司开发的高减震橡胶（HDR）材料，其通过特殊设计的橡胶垫的剪切形变消散振动动能。每个阻尼器都由一系列的减振橡胶垫组成，这些橡胶垫安装在固定在拉索上的支架和连接在预埋导管上的固定支架之间。

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.

通过改变减振橡胶垫的数量并在“高性能”和“标准”两种减振橡胶垫类型之间选择，可以调整每个结构阻尼器的特性。HDR 可以承受大的剪切形变，并且还可以在拉伸或压缩的情况下适应显著的形变而不影响其减震性能。允许将拉索和支架之间的纵向移动完全容纳在 HDR 内，这避免了对减震比的额外铰链造成影响或对滑动接口的需要。



Fixed support connected to guide pipe	固定支架连接到预埋导管
Oscillating movement	振动运动
Moveable collar	可移动卡箍
Gensui pads	Gensui 减振橡胶垫



Incheon Bridge, Korea-2009

仁川大桥，韩国-2009

## Durability without maintenance

### 耐久，无需维护

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.

高减震橡胶垫具有较长的设计寿命和良好的抗疲劳性能。加速老化试验证明其具有60年的预期寿命，并且在疲劳测试期间，减震橡胶垫已经保持了1000万次荷载循环。

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.

阻尼器在其使用寿命期间仅需要最小程度上的维护。这将允许在需要的时候，将阻尼器安装在在桥塔上。即使桥塔上的维修通道是困难的、昂贵的。



## THE VSL GENSUI DAMPER-HOW IT WORKS

### VSL GENSUI 橡胶阻尼器的工作原理

#### Independent of vibration mode and amplitude

##### 独立的振动模式和振幅

The behaviour of the VSL Gensui 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 Gensui damper largely independent of the vibration mode and the amplitude. The time-displacement curves recorded from full-scale tests clearly illustrate this behaviour.

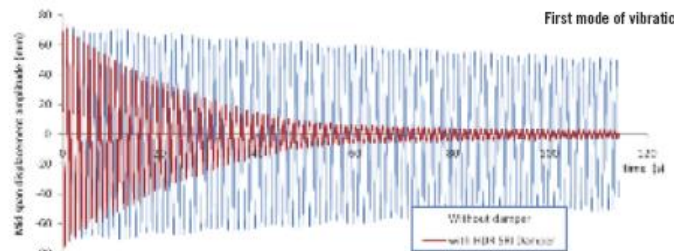
VSL Gensui 橡胶阻尼器的运行状况可模拟为一个组合装置，该装置由弹簧、摩擦构件和全部包含在 HDR 橡胶垫中的粘性元件组成。这使 VSL Gensui 橡胶阻尼器的减震性能与振动模式和振幅无关。通过全尺寸实验，时间位移曲线清楚地记录了阻尼器的运行状况。

#### Time-displacement curves as recorded during VSL Gensui damper testing

##### VSL Gensui 橡胶阻尼器实验期间记录的时间位移曲线

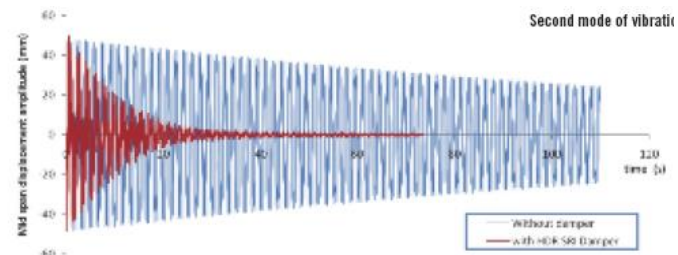
##### First mode of vibration

##### 第一种振动模式



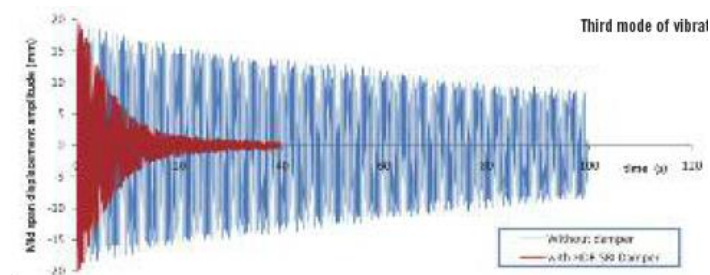
##### Second mode of vibration

##### 第二种振动模式



##### Third mode of vibration

##### 第三种振动模式





The VSL Gensui damper performs best on short to medium length stay cables or where compact solutions are required.

在使用短至中长斜拉索或需要紧凑型解决方案时，VSL Gensui 橡胶阻尼器的性能最佳。



THE VSL GENSUI DAMPER-HOW IT WORKS

VSL GENSUI 橡胶阻尼器的工作原理

Full-scale test results

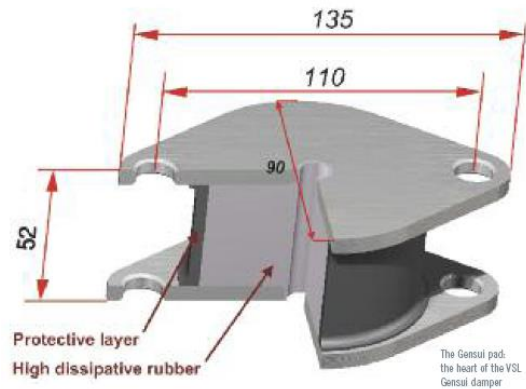
全尺寸试验结果

As well as laboratory testing, numerous full-scale in-situ tests have been carried out to assess the VSL Gensui damper's performance and the characteristics of the HDR component under varying environmental conditions.

为评估 VSL Gensui 橡胶阻尼器的性能，以及 HDR 组件在不同环境条件下的特性。除实验室测试之外，还进行了许多现场全尺寸实验。

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.

在实验室测试中，减振橡胶垫已受到疲劳荷载的影响，必须承受 10Mio 的荷载循环。为了评估它们的耐久性，已进行了加速老化试验，其中预期寿命已超过 60 年，其机械性能没有劣化。

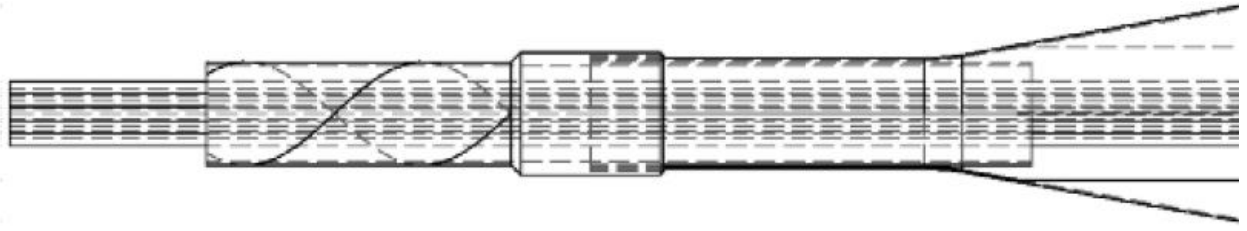


Protective layer	保护层
High dissipative rubber	高耗能橡胶
The Gensui pad: the heart of the VSL Gensui damper	Gensui <a href="#">减振橡胶垫</a> <a href="#">衬垫</a> : VSL Gensui 橡胶阻尼器的关键部件



Megami Chashi, Japan-2006

Megami Chashi, 日本-2006



The VSL Gensui damper can also be mounted as an external damper if required for special retrofitting applications.

如需特殊改装应用，VSL Gensui 橡胶阻尼器也可安装为外部[减振器](#)。

WORKS

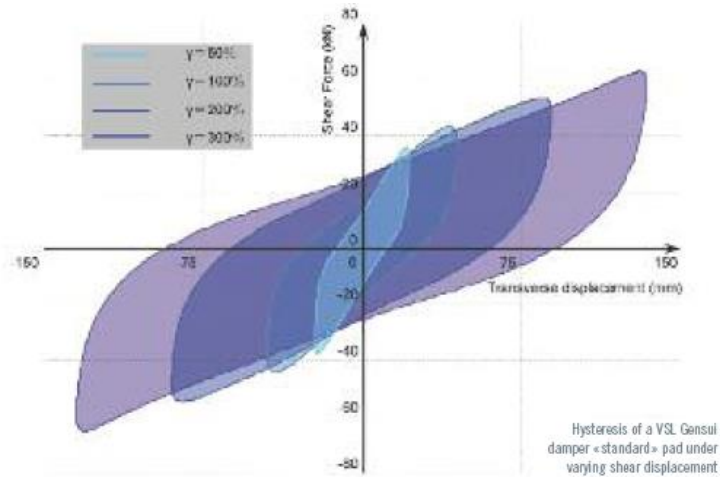
工作原理

Highly deformable

高度可形变

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.

阻尼器的橡胶减振垫（HDR），包括橡胶垫（HDR）和安装板之间的连接，已设计为可适应较大形变，而无损坏。每个切变周期的耗散能量随着形变的增加而增加。最大允许的形变量大大超过在阻尼器中发生的实际运动。这会导致非常高的耐久性和耐疲劳性。



Hysteresis of a VSL Gensui damper «standard» pad under varying shear displacement

不同的切变位移下的 VSL Gensui 减震器减振器《标准》衬垫的迟滞现象



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

VSL Gensui 橡胶阻尼器的尺寸，即为 VSL SSI 2000 斜拉索系统手册中的锚固的尺寸

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类型	L1 最小 DR*	L1 最小 DS*				

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6-109	3550	3000	290	600	559 x 12.5	457 x 10
6-127	3950	3350	300	620	610 x 12.5	508 x 11

Dimensions noted in millimetres.

尺寸的单位为 mm。

Other sizes available on request.

其它尺寸阻尼器可按需供应。

For larger sizes please contact your local VSL representative.

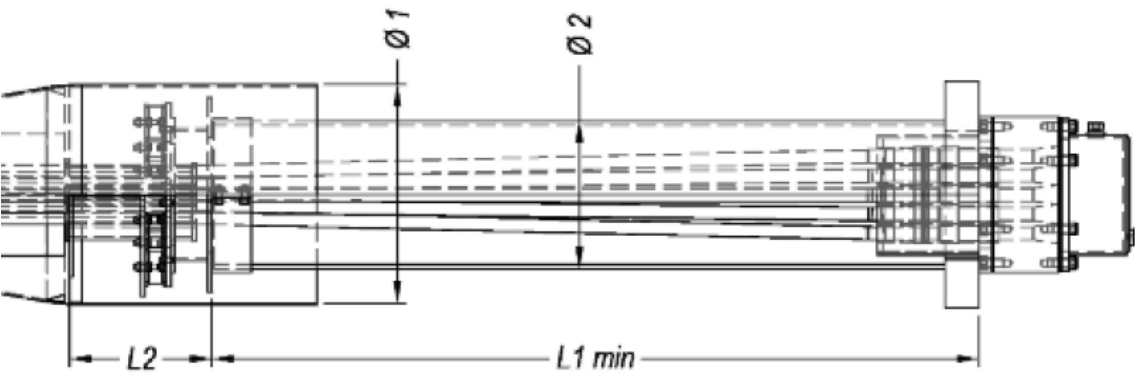
更大尺寸阻尼器请联系当地 VSL 代理商。

\*DR refers to the use of adjustable anchorage at the damper location level, while DS refers to the use of fixed anchorage.

\*DR 是指在阻尼器附近位置上使用可调接锚具，而 DS 则是指使用固定端锚具。

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L1 min	L1 最小
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APPLICATIONS



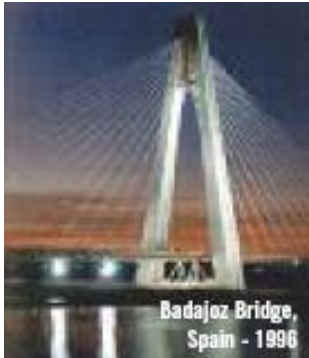
Puente La Unidad, Mexico-2003	Puente La Unidad , 墨西哥-2003
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Uddevalla Bridge, Sweden-1998	乌德瓦拉大桥, 瑞典-1998
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Puente La Unidad, Mexico-2003	Puente La Unidad , 墨西哥-2003
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Badajoz Bridge, Spain-1996	巴达霍斯大桥, 西班牙-1996
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Canada Line Pier Bridge, Canada-2008	加拿大线码头桥, 加拿大-2008
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30 VSL DAMPING SYSTEMS FOR STAY CABLES

30 VSL 斜拉索阻尼系统

CREATING SOLUTIONS TOGETHER

共同制定解决方案



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## VSL-guided by a strong QSE culture

### VSL 由强大的 QSE 文化引导

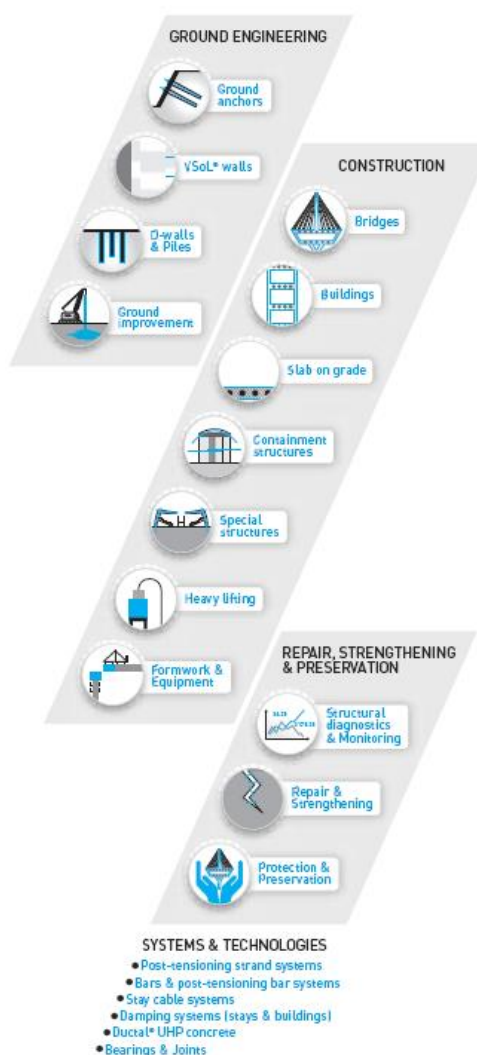
VSL's leading position is based on a rigorous and committed quality culture. The QSE (Quality, Safety, Environment) policy represents a major focus for every service provided. Local teams ensure co-ordination of actions, encourage sharing of experience and promote best practices, with the aim of continuously 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.

VSL 的领先地位是基于严谨和坚定的品质文化。QSE（质量、安全、环境）政策代表着每项提供的服务的重点。本地团队确保协调行动，鼓励分享经验并促进最佳实践，以不断提高绩效。在 VSL 的文化中，员工对公司的竞争力和繁荣至关重要。VSL 致力于将客户满意度和人员安全保持在最高水平。

## Changing the way we do business

### 改变我们的经营方式

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



[www.vsl.com](http://www.vsl.com)

GROUND ENGINEERING	地基工程
Ground anchors	地锚
VSoL® walls	VSoL® 挡土墙

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VSL DAMPING SYSTEMS FOR STAY CABLES 31

斜拉索 VSL 阻尼系统 31

energy as well as the production of less pollution and waste.

对于 VSL，可持续发展意味着在其业务的经济盈利能力与其社会和环境的影响之间，在其发展模式取得平衡。这一承诺已经正式化为 VSL 可持续发展计划，该计划的重点是安全性，使用更少的稀缺材料和更少的能源，以及减少生产污染和浪费。



## Creating sustainable solutions with VSL Dampers

### 使用 VSL 阻尼器创建可持续解决方案

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.

VSL 设计，制造和安装的阻尼器系统是非常耐用的系统。此外，它们减振的功能降低了在拉索和桥梁的材料疲劳的风险，从而降低了在结构使用寿命期间对维护和更换的需要。它们为提高结构的寿命做出了重要贡献。

D-walls & Piles	D-墙和桩
Ground improvement	地基加固
CONSTRUCTION	建筑
Bridges	桥梁
Buildings	建筑物
Slab on grade	斜坡板
Containment structures	外壳结构
Special structures	特殊结构
Heavy lifting	重载提升
Formwork & Equipment	模板与设备
REPAIR, STRENGTHENING & PRESERVATION	维修、加固与保存
Structural diagnostics & Monitoring	结构诊断与监测
Repair & Strengthening	维修与加固
Protection & Preservation	保护与保存
SYSTEMS & TECHNOLOGIES	系统与技术
Post-tensioning strand systems	后张绞线系统
Bars & post-tensioning bar systems	钢筋及后张钢筋系统
Stay cable systems	斜拉索系统

Damping systems (stays & buildings)	减震系统（拉锁与建筑物）
Ductal® UHP concrete	Ductal® UHP 混凝土
Bearings & Joints	桥梁支撑与接头

## VSL LOCATIONS

### VSL 的位置

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