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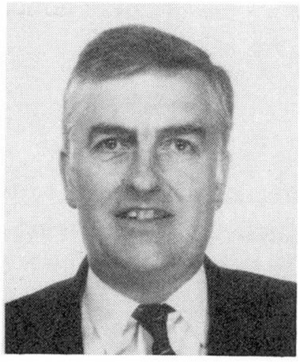
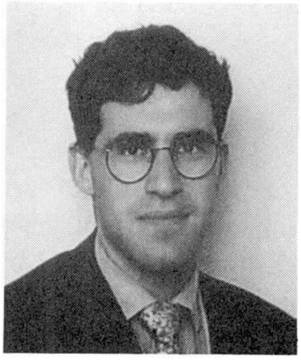
Wind Vibrations and Damping Systems for Stay Cables





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Summary

The large-amplitude cable vibrations which have occurred in several major cable-stayed bridges remind us that the dynamics of cable structures are fundamental to their design. During the last past years several research programs have been performed and significant progresses have been made. The dynamic behaviour of the cables themselves have been considered together with the calculation of the dampening characteristics of the cables and the additional measures which are used to limit the amplitude vibrations. Several devices have been developed, installed and tested. An excellent correlation with the theoretical assumptions has been achieved.

1. Introduction

The main sources of cable vibrations are, on one hand, the wind which creates periodic or irregular lift and drag forces and on the other hand, the movements of the cable attachments on the pylon and on the deck due to the action of traffic loads or of the wind on the structure itself.

Several research programs and analyses have been carried out on this subject (References : [1], [2], [4] and [5]).

2. Vibrations phenomena

2.1 Vortex shedding

This movement is due to oscillating pressures in the wake of the cable. To have a vortex shedding exciting a stay cable, the frequency shall coincide with one of the natural frequencies of the stay cable since this type of vibration follows the *von Karman* law : $N = C\ V / D$ (V = wind speed / D = duct diameter / C varies from 0.16 to 0.22). This is possible but as the stay cable fundamental frequency is comprised between 2 and 0.5 Hz, the coincidence will always take

place on high harmonics. Also several studies give a limit to the amplitude of the vibrations which can reach a cylinder subject to vortex shedding. This amplitude is close to 40 % of the diameter of the cylinder.
Consequently vortex shedding can excite stay cables with high frequencies but low amplitudes. These vibrations are likely to generate fatigue at the anchorage zones but are little noticeable for the bare eye.

2.2 Galloping

Galloping oscillations are movements of large amplitude in a direction transverse to the wind. They are related to the modification of the transverse force coefficient with the wind angle of incidence. The angle change is originated by the movement of the stay cable which creates a change in the apparent angle of incidence. Sometimes interaction between cables can initiate what is called wake galloping.

2.3 Rain and wind vibrations

This phenomenon has been observed several times (References : [3], [5] and [6]). During rainy days a water rivulet can be formed on the surface of the sheath ; a wind (6 to 12 m/s speed) showing an angle with the cable vertical plane between 20 to 60 degrees may create such vibrations which could be considered as a particular galloping.

2.4 Effort of the structure vibrations

Cable vibrations can also be caused by dynamic forces acting on other parts of the structure (deck and pylon). The intrinsic structural damping of the stay cable is so low that a small movement of the deck and/or pylon suffices for creating a large movement of the stay cable.
Recent studies show that the amplitude of the movement of the stay cable can be up to 30 to 100 times the amplitude of the movement of deck and/or pylon but that the amplitudes can't increase with no limits.
Experience shows that risks are limited in case the fundamental frequency of the deck is close to that of the stay cable, the amplitude of the vibrations being small. To the contrary risks become high when the stay cable fundamental frequency is close to the double of the fundamental of the deck.

3. Damping characteristics of a stay cable

3.1 Damping factor definition

If $\mathbf{a}_{n+1}$ and $\mathbf{a}_n$ represent two consecutive amplitudes of vibration of a system left free to vibrate without any external excitation, $\mathbf{l}_n\ (\mathbf{a}_{n+1}\ /\ \mathbf{a}_n)$ is the « logarithmic decrement » or the damping ratio.

β, the damping factor, is defined as $\beta = 1 / 2\pi\ l_n\ (a_{n+1}\ /\ a_n)$.

Stay	Natural damping factor β
- Grouted stay	0.08 to 0.13 %
- Locked coil	0.15 to 0.3 %
- HDPE duct with galvanized strands and filled with wax	0.1 to 0.18 %
-HDPE duct with individually protected Freyssinet strands	0.12 to 0.20 % *

* The damping factor β may be written **$\beta = -6 \times 10^{-4} \times L + 0.24$ (L** = length of the stay cable in m).

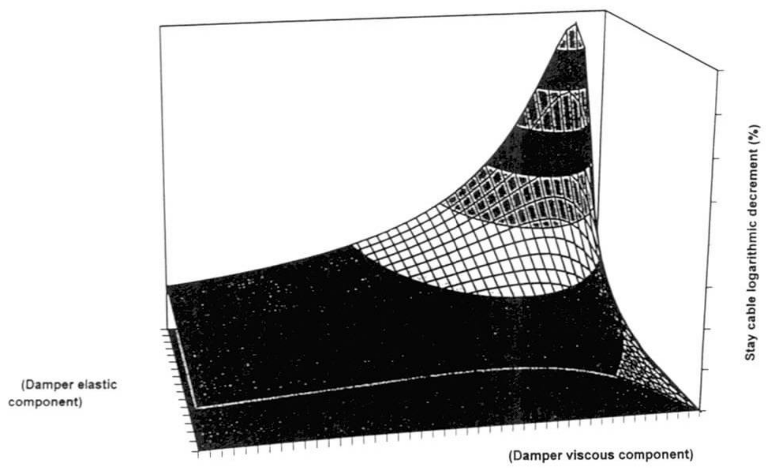
3.2 Measurement of the damping factor

When the stay vibrates under any excitation, its damping effect results from the energy dissipation within the stay itself or thanks to specific dampers where the energy is consumed by friction or by lamination of a confined material. Using an accelerometer and an automatic recording system, the damping characteristics of any stay cable can be obtained. In the same manner it is possible to predict with accuracy the effect the installation of a damper with given characteristics will have on the damping factor. The numerical models which are used are confirmed by experiments on site.

3.3 Prediction of the damping factor

A detailed calculation model has been developed to evaluate the β factor provided by the various types of damping systems. A universal damping curve has been established allowing an accurate tuning of the damper. This curve permits to predict the behaviour of each stay cable in the wind.

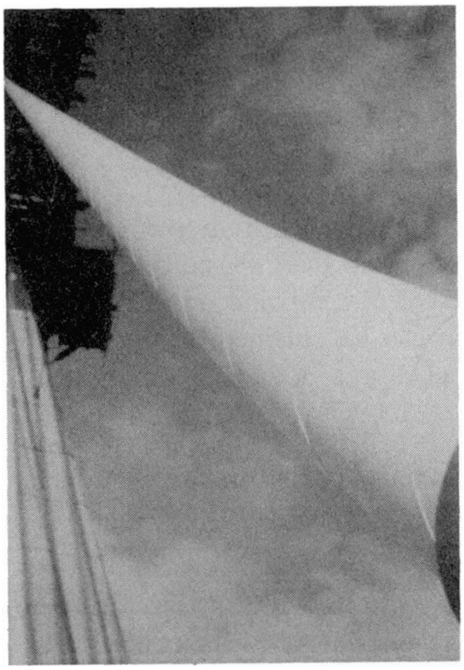
Freyssinet surface for dimensioning of a damper with an elastic component

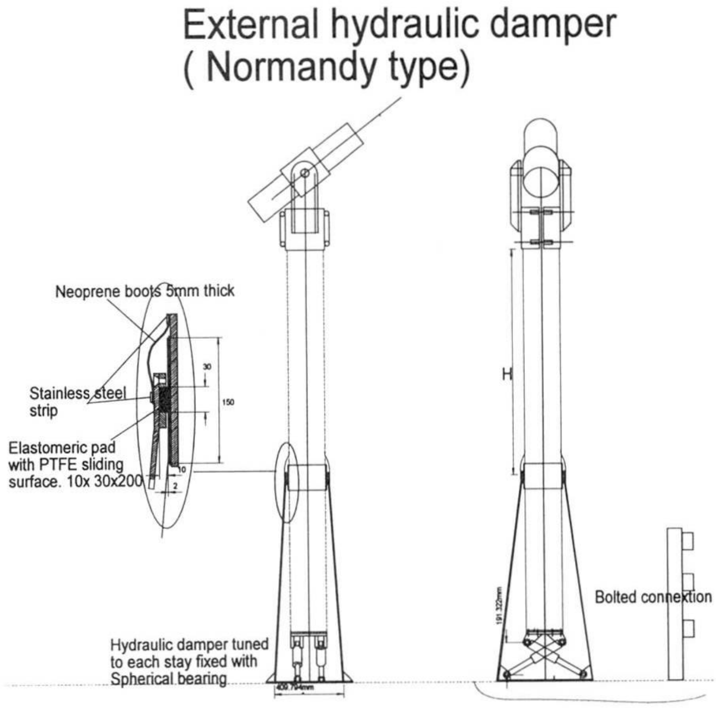


4. Range of available technologies

4.1 Circular duct with helical ribs

Several approaches have been made in JAPAN with longitudinal ribs or artificial roughness created on the duct [6]. The system which has been developed for the Normandie Bridge incorporates a double helical rib on the HDPE duct (patented). Extensive testing programmes were carried out in both laboratories : at the CSTB (NANTES), 1992-1993, for the Normandie Bridge and at the Danish Maritime Institute in 1997. This system keeps the stay cable stable by preventing the apparition of the water rivulet under certain wind conditions ; it does not increase the drag factor of the cable while maintaining the required aesthetical appearance of the stays.





4.2 Damping ropes

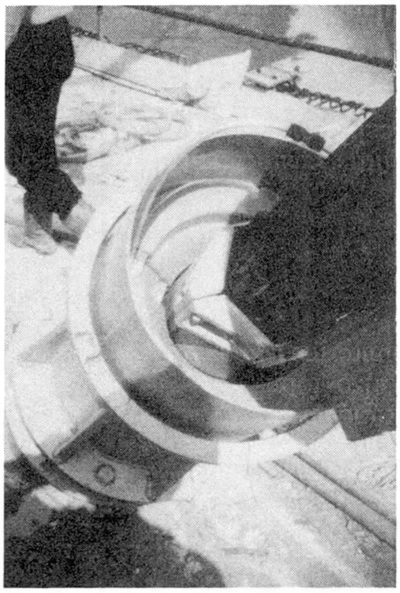
The natural frequency of the stays can be modified by means of transversal cables connected to them. This solution which is effective although expensive and delicate to install has been used for some large bridges. It is recommended when the vibration frequencies of the deck or pylon are close to the frequencies of the stay cables. For the Normandie Bridge , the main vibration period for vertical bending would have been of the same magnitude as the vibration period of the longer cables, 4.5 seconds. The cross ropes reduce the periods of the cables to 1.25 second and less (Ref. [4]). Four ropes connect all cables in each plane of stays. Their tension was selected to avoid slackening effects. They consist of a bundle of stainless steel wire ropes fully embedded in HDPE and other dampening plastic material. They went through a testing programme for fatigue and damping capacity. A steel collar provides the fixation of the ropes on each stay and facilities for any orientation.

4.3 External Hydraulic Damper (EHD)

This damper is specifically designed to each project. The damping capacity can be tuned to obtain the required logarithmic decrement. However it requires a regular maintenance and it is not always meeting the aesthetics objective of the designer.

4.4 Internal Elastomeric Damper (IED)

A cast piece of special rubber with high damping characteristics and a specially designed shape is placed between the stay cable and the guide tube (deck and pylon). If the damping characteristics need to be increased, viscous oil can be placed in a special chamber. This is a very compact system with virtually no maintenance. It can provide sufficient damping for cables as long as 150 m (500'). This damper is completely invisible from the deck. It must be remembered that sometimes the word « damper » is used improperly to designate an annular sleeve generally made of normal elastomer placed around the stay cable near its extremities. The support of this sleeve is connected to the structure. This device can be effective to « dampen » the bending stresses at the anchorage but not at all the cable vibrations. It should rather be called an elastic support or guide.



Internal Elastomeric Damper

4.5 Internal Hydraulic Damper (IHD)

This system is very convenient for cables longer than 150 m. Used in parallel with the IED, it increases the damping characteristics of the whole system. It has the same advantage : not visible and nearly no maintenance.

5. Conclusion

Several tests have been conducted on various cable-stayed bridges with different mechanical concept, stiffness and materials. This has permitted to validate the vibration calculation model and to establish a universal damping curve. A damping ratio, a logarithmic decrement, in the order of 3 to 4 % is sufficient to provide in most cases a satisfactory behaviour of the cable stays.

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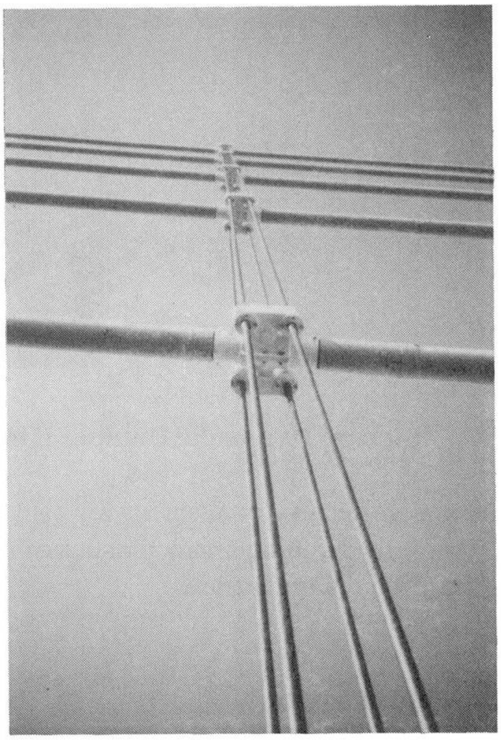

Normandie Bridge : Damping ropes and hydraulic dampers