Active Tendon Actuators for Cable-Stayed Bridge

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Abstract

Improvements in materials led to the construction of progressively longer, structurally more efficient and slender bridges. But consequently, structures are more and more flexible. Deck and cable vibrations have become a major issue in cable-stayed bridge design. Their increasing span length makes them more sensitive to flutter instability as well as to wind and live load induced vibrations. It is a difficult problem to assess because of the highly non-linear behaviour of cables with sag. Avoiding significant levels of wind excited oscillations, resulting in levels of vibration, and in the worst case in flutter instability is a new challenge for the designers. In the long term there is a potential for serious fatigue damage. In the short term, excessive levels of vibration hamper the traffic and bother the end-user comfort.

To minimise vibrations, passive damping devices for stay-cables have already been developed and used. The dashpot damper delays the appearance of vibrations, but only until a certain level of excitation. As regards elements of cable-tie systems, although used on actual bridges, their long-term behaviour to fatigue has still to be proved. But these damping devices mitigate only the cable vibrations, not the structure vibrations. Tuned Mass Dampers have also been studied in order to reduce structure vibrations. Their efficiency is limited by the geometrical constraints of the deck cross-section. In addition, all these passive devices are tuned on theoretical simulation results, which can be partly far away from the real world, and fit only with previous predefined scenarios. Finally, these devices do not take into account the ageing of the structure components, and consequently the variation in time of the structure behaviour.

The present work concerns the development of Active Tendon Actuators for use in cable-stayed bridge in the framework of the ACE research project partly funded by the EC Brite-EuRam programme. The aim is for the active tendon actuators to increase the structural damping in order to mitigate vibrations. The application of active actuators to flutter control has already been considered theoretically and application to active damping has been studied with more or less success. The proposed technology uses an alternative control strategy developed by Université Libre de Bruxelles, partner of the ACE project. The control strategy is based on a force sensor collocated with the active tendon actuator. The technique has a strong physical support and the effectiveness has been confirmed by simulations and demonstrated experimentally on a small-scale laboratory mock-up.

The project aims to:

a) improve the understanding of the induced vibrations of cable-supported structures;
b) develop an appropriate software package capable of analysing the behaviour of cable-supported structures;

c) develop an active system to control induced vibrations of cable-supported structures;
d) develop the appropriate actuators; and
e) validate the active control system with a large scale mock-up and measurements of existing structures.

The main critical points of the project are outlined here. This concerns the following issues:

- the active control strategy having been validated on a small scale mock-up, extensions to more complex structures are investigated on a small scale mock-up and on a large scale mock-up.
- as regards the large scale mock-up and also real structures, the key element is the actuator. Two solutions will be explored and tested.
- the design of the active control system requires important improvements of the current structural dynamic algorithms.
- an experimental on a large scale cable stayed bridge mock-up will be carried out to validate the active control system and the structural dynamic algorithms.
- experimental measurements on existing structures will also be used.
- a technical and economic comparison of this method of upgrading with other techniques will also carried out.

Funding under the EC Brite-EuRam programme (Contract N°BRPR-CT97-0402) is gratefully acknowledged. The author as co-ordinator of the ACE project gratefully acknowledge the contributions of the other partners of the Consortium: Defence Evaluation and Research Agency (UK), Newlands Technology Ltd (UK), Johs.Holt A.S (NO), Mannesmann Rexroth (DE), VSL (FR), Technische Universität Dresden (DE), Université Libre de Bruxelles (BE) and the Joint Research Centre of EC.

Stay Adjustment: From Design Perspective to On Site Practice

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Abstract

Stay adjustment is a major topic in cable stayed bridge construction. As a matter of fact, this issue, which directly controls the stress distribution in the structure as well as the final geometry, concerns both analyses during detailed design and tensioning procedures during erection on site.

Experience shows that there exist a great variety of approaches for characterizing stay adjustment at design level and for performing the related adjustment operations on site.

The purpose of this paper is to re-visit the subject of stay adjustment, from both a theoretical and a practical perspective. Some concepts are presented, which enable one to tackle this problem efficiently, while taking into account technological constrains.

1. Review of Current Practice

From the designer's perspective, stay adjustment traditionally consists in specifying:
- either, the value of the stressing force applied to each stay at given phases of the construction,
- or, more recently, the unstressed cable length l_0.

Using software programs, which allow simulating stage by stage construction, the designer seeks stay adjustment specifications such that stresses in the structure remain allowable, both during erection and service stages, and such that pylon and deck positions at bridge completion are satisfactory.

Very often, the values of the tensioning force or the unstressed cable length l_0 taken as input of the computational model are then directly used as the adjustment instructions for on site operations. In case of very flexible structures, the tensioning force is replaced by the geometric deflection it produces.

The apparent advantage of this approach is that operations follow very precisely the erection stages planed by the designer, with as consequence an actual state of the structure being very closed to the model prediction.

However, the following issues must be raised:

- the tension applied to a stay when installing it does not characterize intrinsically its adjustment; as a matter of fact, the action of the stay on the structure depends on the temporary erection loads, such as the actual weight of the formwork, the presence of a crane or heavy coils on the deck, etc. some of which are hardly possible to predict.

- the set of tension values at a given state is not an accurate description of the stay adjustment. Practical examples have shown that re-tensioning the stay system to compensate for creep effects can produce a vertical displacement of the midspan section of 0.60m whereas the increase of tension values is only 3%, i.e. hardly more than the measuring precision.

- the actual loading conditions may differ from their theoretical counterparts (stay and structure temperatures). These discrepancies must be taken into account in the adjustment procedure on site.

Using the unstressed cable length l_0 to describe stay adjustment represents a significant improvement from the theoretical standpoint, as it makes it possible to determine the structural state at a given stage, without having to consider the cumulative effects of all elementary actions during erection history. Indeed, the unstressed cable length constitutes an intrinsic description of the adjustment of the stay.

However, l_0 is a parameter that can be successfully used on site to adjust stays, only if cable marking and anchorage positioning can be achieved very accurately. In a workshop, prefabricated stays can be cut at length with a tolerance of about 0.01m per 100m of cable length, but the tolerances are far higher when placing anchorages in a formwork.

2. The Reference Tension Concept

The reference tension notion was introduced as a parameter representing intrinsically stay preloading and aimed both at designers and site engineers responsible with stay adjustment operations.

The reference tension of a stay is defined as the force at tensioning anchorage which would exist, if the structure deformations were frozen, i.e. if the structure was forced to coincide with its theoretical geometry, called the reference geometry (generally the one defined by the drawings). The value of the reference tension does not depend either on the anchorage location tolerance or the temporary loads on the bridge; therefore, it represents the appropriate parameter to describe numerically stay adjustment.

The principle of stay adjustment procedure using the reference tension consists of the following steps:

1. Determine the target value of the reference tension to be reached at the end of tensioning operation, using the relevant data extracted from the design model,
2. Evaluate by survey the anchorage displacements and deduce the tension to apply to the strands in order to impose to the stay a given fraction of the target reference tension,
3. Measure the actual stay tension and the related values of the anchorage displacements; then deduce the elongation to apply to the stay to reach the target value of the reference tension,
4. Perform a check by evaluating the actual value of the reference tension through simultaneous measurements of stay tension and anchorage displacements.

Damping Characteristics of Carbon Fiber Composite Cables for Application in Cable-Stayed Bridges

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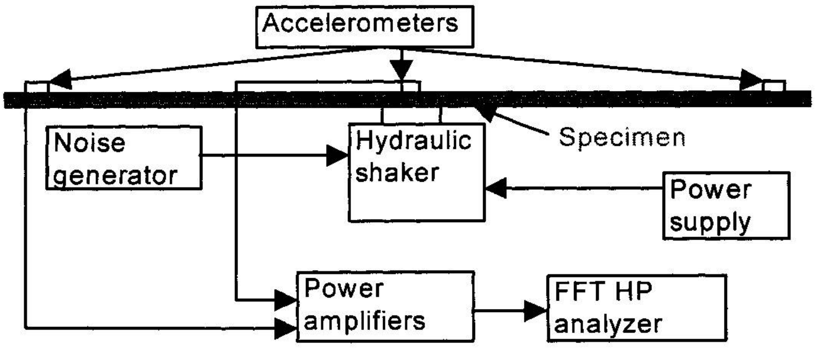
Abstract

The paper presents the results of experimental and analytical studies on the loss factor of CFRP and prestressing steel tendons when subjected to out of-plane loading. Damping characteristics are then estimated from the loss factor. Aluminum samples were first used as control specimens to calibrate the accuracy of the setup. Several CFRP tendons with different lengths and diameters were subjected to forced vibrations using a hydraulic shaker to apply white noise (up to 20Khz) on the double cantilever system. Accelerations were measured using "piezoelectric accelerometers" and the data is obtained through a fast fourier transform (FTT) analyzer. The setup of the experiment is shown in the given schematic.



Schematic of the test apparatus for measurement of response of double cantilever specimens.

The results are presented as graphs expressing the relation between the loss factor, length, and the eignvalues of different mode shapes. Similar tests have been performed also on steel strands, which are commonly used as cables for CSB. The results are presented as graphs expressing the relation between the loss factor, length, and the eign values of different mode shapes (fig.1). Analysis of the experimental results is performed using both the half power band width, and the resonance dwell technique to obtain the loss factor of the specimens at different frequencies, the shape function, and the relation between loss factor and the ratio between acceleration at the cantilever tip to the support movement.

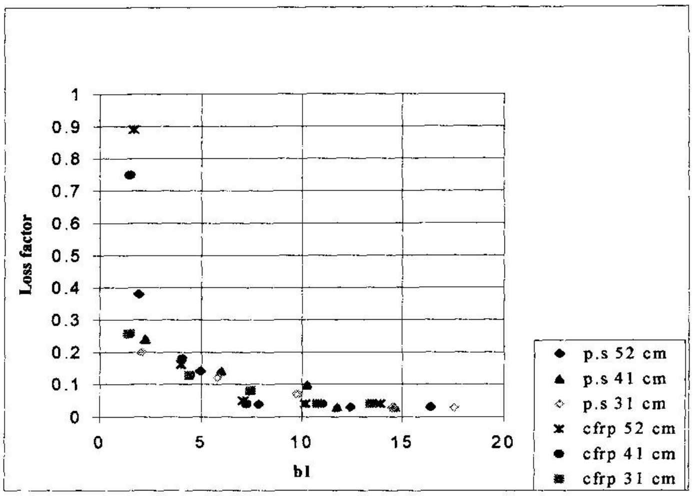


Fig. 1: Loss factor for 12.5mm diameter CFRP and prestressing steel Specimens.

The results of the experiments are used in calculating the damping ratio of CFRP and prestressing steel cables with different length (table 1), which shall be used afterwards in the computer analysis of different CSB cables subjected to different cases of loading (wind,..etc.). Axial damping and fatigue characteristics for CFRP tendons are currently tested and results may be available in the near future.

Material	Horizontal Projection (metres)	Cable length (metres)	Sag ratio	Strain energy ratio	Damping ratio
Steel	330	465	0.0026	0.01	.005μ
	440	622	0.0035	0.02	.01μ
	660	933	0.005	0.05	.025μ
CFRP	330	465	0.001	0.002	.001μ
	440	622	0.0015	0.004	.002μ
	660	933	0.0022	0.01	.005μ

Table 1: Damping ratio for CFRP and PS cables as a function of loss factor.

Development of New Stay Cable Dampers

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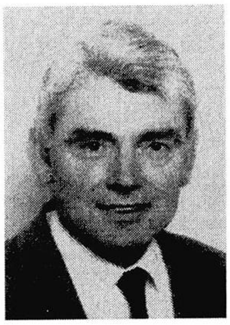

Abstract

Presentation of the different steps of analysis and the results of this analysis : the development of new stay-cable-anchorage dampers, and particularly the new damping system that will be installed on the stay cables of UDDEVALLA Bridge.

1 Review of the different damping systems used on bridges

Cable vibration on cable stayed bridges is known since several years, but it is only recently that this problem is becoming more and more critical, perhaps due to the increasing span lengths of the bridges and the reducing of the dead load of the decks.
Engineers developed some damping devices and we will review the different systems with a particular point on the three following items :

- Installation of a damping system on an existing bridge
- The fatigue of the damping systems
- Cost of the maintenance

2 Definition of the criteria and specifications of a damping system

We will dress the list of criteria and specifications that will have to be considered by the designer of a damping system.
Some damping systems are composed of mechanical or hydraulic components. These components are generally submitted to small movements and small loads, but with a high level of frequencies and can thus have a total displacement of several tens of kilometers per year. So according to the present experience, the fatigue criteria will perhaps be the most important criteria.

We have also to consider the maintenance cost that could be several times the initial cost of the damping system within a very short period compared to the duration life of the stay cable. The beauty, architecture and the highness of the cable-stayed bridges are very important parameters. So the aesthetic is today one of the most important specification imposed by the client to the designer of a damping system.

3 A new development : the friction damper

The paper will present the development of a new friction damper, designed by D. KOVACS and developed in collaboration with VSL for a future installation on the UDDEVALLA Bridge. One year ago, a new friction damper has been tested to reduce the critical vibrations observed on some stay-cables. According to this first experience, a new generation of friction dampers will be installed on UDDEVALLA Bridge.

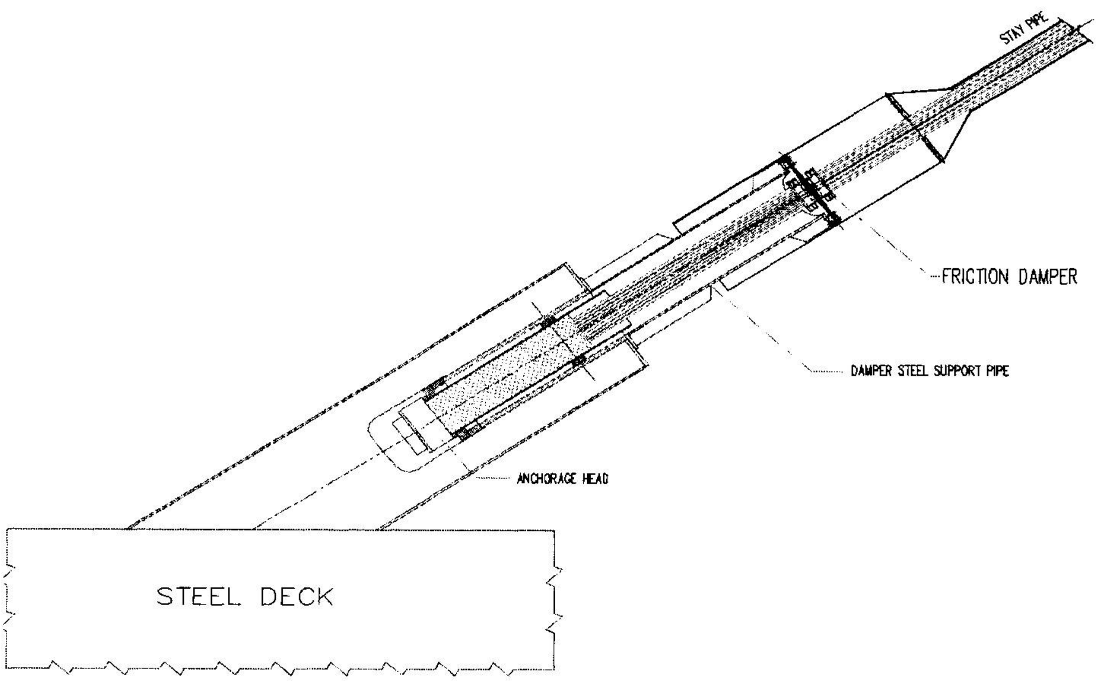

Figure 1. Installation of friction damper on UDDEVALLA Bridge

4 Conclusions

Researchers have to work, to have a better understanding of cable vibrations. Dampers characteristics have to be optimized. For the future, designers are working on a new generation of damper : the active control damping system.

Fatigue Reliability Evaluation of Cables in Cable-Stayed Bridges. Case Study: the Sama de Langreo Bridge.

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Abstract

The current methods for the verification of the Cable Fatigue Limit State in cable-stayed road bridges are usually very conservative. An accurate and reasonably procedure for the evaluation of such Limit State from a probabilistic point of view based on structural reliability theory is presented in this paper.

A general fatigue resistance model for cables made up of "n" parallel elements (wires or strands) and a procedure for the prediction of traffic load effects in cables based on numerical simulations are proposed. The combination of resistance and loads effects may lead to estimate the damage due to fatigue in probabilistic terms.

Although the present work is focused on fatigue due to traffic loads, the general procedure can also be applied for railway traffic, wind effects or other variable loads. The method could also be used for other structural elements (anchorages, etc) which fatigue strength could be described with a fatigue limit.

The basic work is applied to a real case study: the Sama de Langreo Bridge in Spain (Figure 1), to illustrate the possibilities of the proposed methods. Experimental data has been collected to estimate the relevant statistical parameters for the steel cable fatigue resistance model. The stress amplitudes due to traffic have been obtained from numerical simulations using real traffic data (Figure 2). The simulations lead to calculate the fatigue failure probabilities for different traffic situations. The final results confirm very low failure probabilities in comparison with other Limit States.

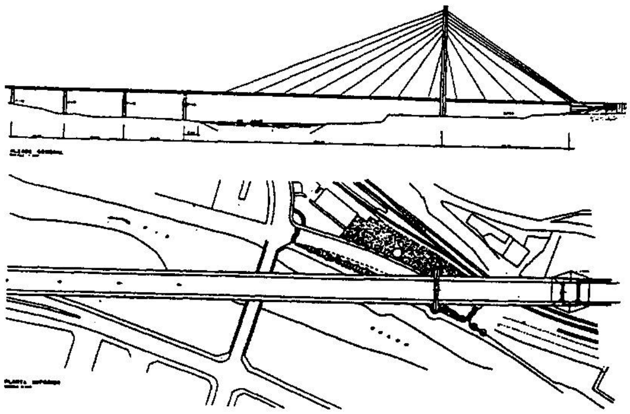

Figure 1. Sama de Langreo Bridge in Spain. Elevation

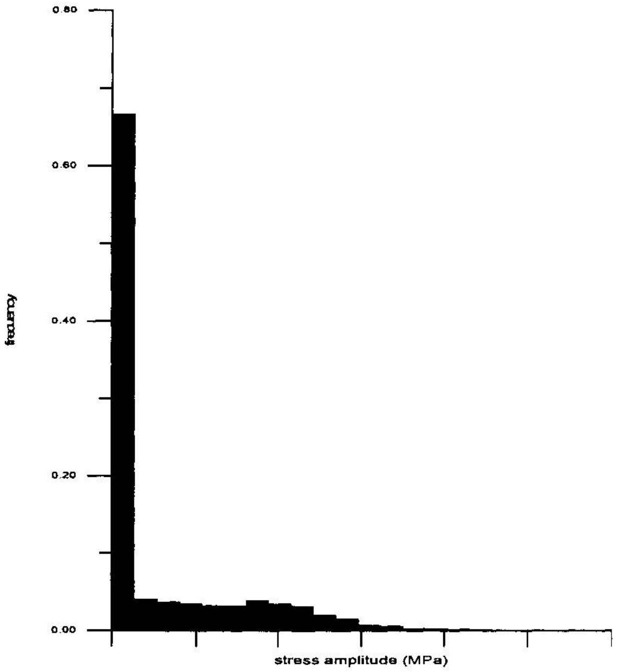

Figure 2. Stress spectra in a cable-stay of the Sama de Langreo Bridge under traffic loads, coming from numerical simulations

Although the present work is focused on fatigue due to traffic loads, the general procedure can also be applied for railway traffic, wind effects or other variable loads. The method could also be used for other structural elements (anchorages, etc) which fatigue strength could be described with a fatigue limit.

As conclusions, more investigation should be done to estimate fatigue strength of cables and cable-anchorages. More statistical data of fatigue parameters is required, in particular, for the fatigue limit. Strategic testing methods may be developed to obtain this information because of significant economical and safety implications. On the other hand, fatigue design traffic loads could be obtained or updated with the proposed procedure.

The Super High Damping Rubber Damper on the Stay-Cables of Meiko East Bridge

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Abstract

1. Introduction

The Meiko East Bridge is one of the three cable stayed bridges to across the Ise Bay in Japan. The bridge has 700m in total length and center span length of 410m. The parallel wire strand coated with polyethylene tubes, is used to the cable. In Japan, since the rain vibration was recognized at Meiko West Bridge-1, in 1984, the rain vibration had been often observed in some stay cabled bridges. Therefore the countermeasure for rain vibration was required in Meiko East Bridge.

The damping countermeasure and also consideration for aesthetics point of view were required for this bridge. As the countermeasure, the cable damping device using SDR(Super Damping Rubber) that can be installed inside of a waterproof cover at the top of anchor pipe, was adopted. This paper gives an outline of the damping device and experimental results of the cable in Meiko East Bridge.

2. Outline of the Damping Device

This damping device is installed inside of a waterproof cover at the top of anchor pipe. One side of the SDR is connected to an anchor pipe and the other side to a cable. When the cable is excited, a relative displacement occurs between an anchor pipe and the cable, and SDR is distorted. SDR can absorb the vibration energy of a cable due to this shear distortion. This device is useful for all radial vibrations of a cable. Figure 1 shows the structure of the device.

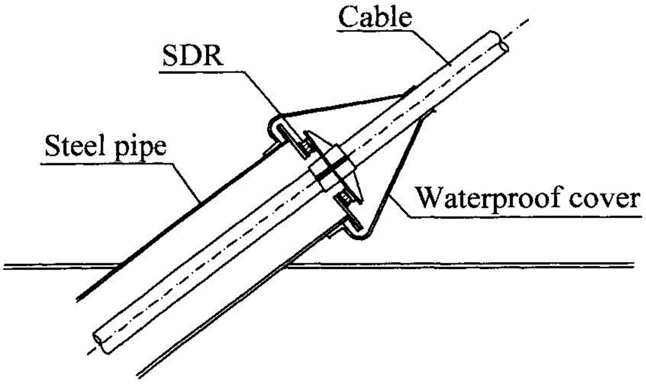

Fig.1 Cable Damping Device using SDR

The SDR used in the damping device has been developed to achieve the high damping properties. It has greater damping characteristic than HDR(High Damping Rubber) used for a seismic bearing of the bridge.

3. Confirmation of the Cable Damping

An additional damping decrement by the device was confirmed by experiments. The objective cables are two upper row cables. These cables were excited by using exciter. As a result, damping decrement of these cables were obtained from free vibration wave shape. Figure 2 shows typical examples of experimental results. The damping decrement of a cable without a device is 0.005-0.010. The average of damping decrement of a cable with the device is 0.033-0.045. The damping decrement of the other cable is 0.042-0.046. These damping exceed calculated value.

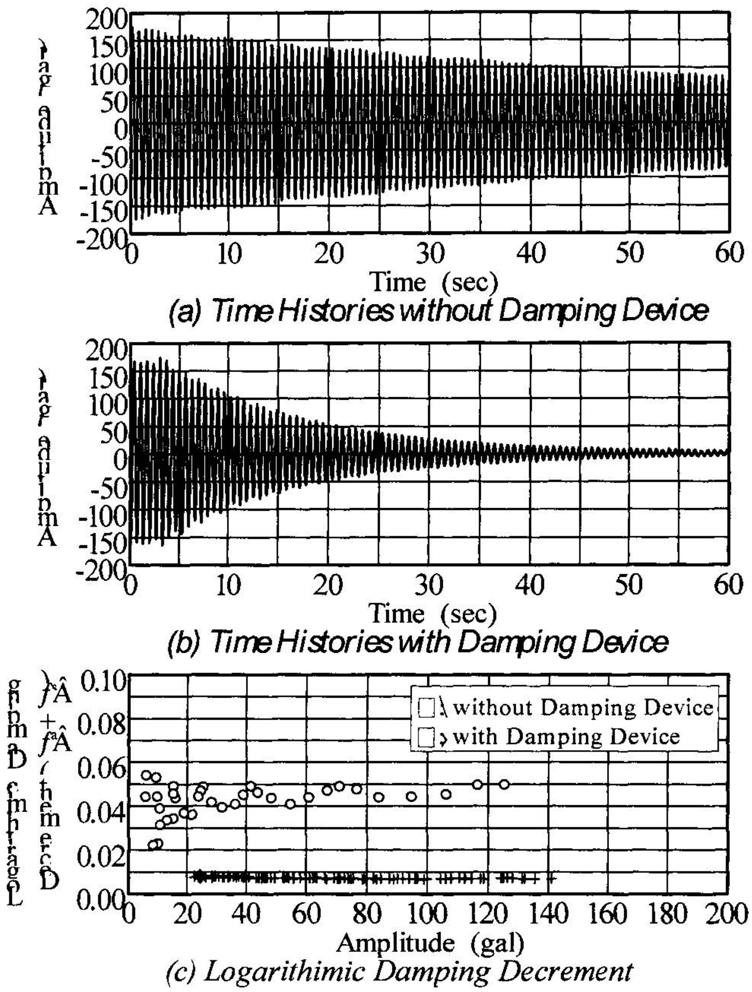

Fig.2 Typical Time Histories and Logarithmic Damping Decrement of C26N-Cable (3rd Mode)

Assuming the standards of Scruton's number required in order to prevent the rain vibration is 60, the required damping decrement of the cable is 0.018 in Meiko East Bridge. The damping obtained through the experiment exceeds required damping.

4. Conclusion

In this paper, we described the abstract of a cable damping device using SDR(Super Damping Rubber) that was adopted to Meiko East Bridge and estimated the damping by calculation, and confirmed through the field experiment. Experimental results exceed calculated value, and the validity was confirmed. As a result, the damping devices were installed at all cables except some lower row cables. Since completion in April, 1998, wind induced vibration has not been observed. This device is able to keep the original design around the bridge owing to be closed by waterproof cover.

Corrosion Protection of Locked Coil Ropes at Road Bridges

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Abstract

1. Introduction – Rope Bridges in Germany

In the course of federal motorways, major roads and some city roads in Germany there are about 40 big road bridges which have high strength cables. All but one bridges have locked coil ropes, one bridge has parallel wire strands. Most bridges are cable stayed bridges, some bridges are suspension bridges, at two bridges there are under-guyings. Closely packed bundled single ropes are called as cables.

2. Locked Coil Ropes

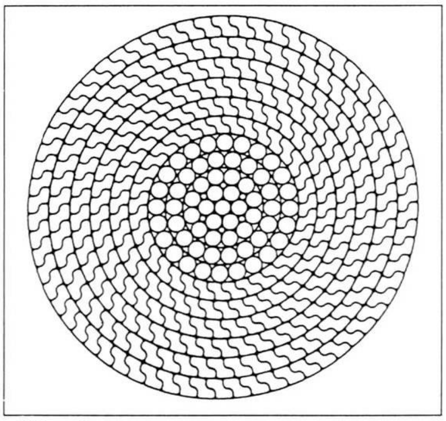

Fig. 1:
Locked coil rope – cross section

Locked coil ropes inside consist of round wires and outside of several layers of Z-wires which tighten the inner structure by their shape and order, see Fig. 1. They have the advantage that a wire takes load after two lay lengths if it is broken. This behaviour is got by pressing this wire into the structure of the rope through contraction of the rope caused by the spiral structure. At parallel wire strands a broken wire is lost for the strength over the whole length of the cable. Furthermore locked coil ropes have the advantage that they can be designed in a more slender way than parallel wire strands and that by the locked type the inner structure of the rope is mechanically tightened and therefore much better protected against corrosion attack. But it seems that they have the disadvantage that they are more expensive than parallel wire strands having the same strength. Regarding the rope mechanics it has to be considered that they have a lower modulus of elasticity than parallel wire strands by reasons of the spiral structure.

In the beginning (about 1959 – 1965) the single wires were not galvanized. Later on only the outer wires were galvanized, and since the end of the seventies all wires are galvanized. The galvanizing alone is not a sufficient corrosion protection. Therefore an outer corrosion protection is necessary in the form of a coating, consisting of several coats.
Beside some exceptions red lead was and is used as blocking agent which is filled in the inner of the rope during the fabrication of the single layers. The aim is that by the blocking agent an easy gliding is possible between the single wires (lubricating) and that the single wires are protected against corrosion. As these characteristics must be available over the whole life time the blocking agent has to fulfil high requirements of the lubricating, the corrosion protection and the durability. The anchoring of a rope is normally done by the embedding of the wires in a cast corpus consisting of a zinc alloy and by wedging the wires against each other in the socket.

3. Rules

Standards were drafted and introduced in the responsibility of the German Ministry of Transport to avoid mistakes at this member sensitive and important for safety and to have a basis for the invitation to bid for rope works. By this a high level of quality at the fabrication of the rope and the capability for inspection under traffic is to be ensured. The maintenance is also dealt with in detail. Additional to the regulations in the standards requirements to the rope or cable (rope bundle) and to the corrosion protection are formulated to fulfil the expectations to the life time: It is counted on that the existing bridges reach 80 to 100 years supposed that the heaviness of the traffic does not grow strongly and that no other life time diminishing influences occur which are not determined by the structure itself. For the structure itself a regular test of the stability is necessary in any case. The rope is not understood as a working part, but modern structures allow the changing of single ropes in an emergency case.

4. Maintenance of the ropes

At the construction works in the responsibility of the road administration in Germany the German standard DIN 1076 is used. A main inspection has to be done every 6 years and between after 3 years a simple inspection. For the main inspection at bridges with ropes and cables in Germany a Bridge rope inspection machine was developed. It is a kind of cable railway with whom a driving of the ropes and cables is possible without loading the tensile elements themselves. For the inspection of ropes for wire fractures the magnetic inductive test is used.

5. Investigations of Ropes

By the BASt investigations were carried out with the aim to get information about the mechanical situation for bridges ropes in the structure. Beside that investigations were done about the climatic effects by exposure tests. At a chemical laboratory the chemistry of the blocking agent itself was investigated. In particular the water absorption was important. Temperature measures were also carried out at ropes where the temperatures were measured on and under the corrosion protection coating.

6. Conclusion

The locked coil rope in bridge structures presents itself as a robust, durable and easy-care member if the requirements of the above mentioned regulations are fulfilled which can be inspected easily, too. Single wire breaks of the outer layer possibly appearing are not critical and can be seen at the surface.

Experimental Analysis of the Active Tendon Control of a Large-Scale Cable-Stayed Bridge Mock-up.

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Abstract

Recent improvements in materials led to the construction of progressively longer, structurally more efficient slender bridges. But consequently, structures are more and more flexible. Deck and cable vibrations have become a major issue, particularly in cable-stayed bridge design. The present work concerns the laboratory testing of an active tendon control system for use in a cable-stayed structure. The aim of the active control system is to upgrade the damping of the structure and consequently to mitigate the induced vibration of the stay cables. The study will include an experimental evaluation to be carried out on a large-scale cable-stayed bridge. The proposed design and testing of the mock-up is outlined here.

The bridge mock-up is a cable stayed cantilever beam. The deck, about 30 metres long (which is the maximum dimension allowed in the test laboratory), is mainly composed of two H-beams whose axes are spaced 3.0 meters apart. They are appropriately linked to provide to the whole structure with sufficient transverse stiffness and each H-beam is fixed to a Reaction Wall. The vibration excitation source is anchored at the free end of the deck. Four pairs of parallel stay cables support the deck and a couple of secondary tie-cables are inserted in order to study the control of transverse vibrations of the stay-cables. To give to the stay cables enough sag and consequently reduce their free vibration frequencies, they are heavily overloaded with split steel cylinders in order to increase their average mass.

The mock-up will be subjected to forcing functions to improve the understanding of induced vibrations, to validate the numerical tools for prediction of dynamic behavior of cables, to verify the capability of the active control system to mitigate the effects of induced vibrations, as well as to evaluate in detail the performances and the reliability of the whole implementation. This mock-up is a unique large-scale cable-stayed bridge to improve knowledge in stay cable dynamics. While substantial progress has been made in the study of components of active damping systems, little attention has been paid to the overall performance of the system applied to a realistic structure. The structural control system consists of a number of important components such as sensors, controllers, actuators, and power generators that must be part of an integrated system. Moreover, a number of implementation-aspects must be addressed such as intermittent and fail-safe operations, integrated safety, reliability and maintenance. These issues require experimental verification under realistic conditions.

Special care will be assigned to the selection of the most appropriate dynamic testing techniques and to the selection of the transducers, including their conditioning electronics. The tests will be repeated with different loading conditions to provide the reliable data necessary for the validation of a numerical model that includes the structural dynamics, the control system and the actuator dynamics. The deliverables will help the various industrial involved in cable-supported structures to better understand the behaviour of the structures when exposed to vibrations induced by wind, live load, or seismic phenomena.

Forced vibrations in the mock-up will be obtained by means of an electro-hydraulic exciter operating in a frequency sweep excitation manner. This kind of excitation, where the input force can be perfectly monitored and measured, is the most suitable to perform experimental modal analysis. Impulse and free-vibration tests will also be performed.

Measurement equipment will include instrumentation consisting of inductive and laser displacement transducers, accelerometers, strain gauges, and force transducers. To measure tendon vibrations other techniques will be considered such as line-scan camera and laser scanning systems.

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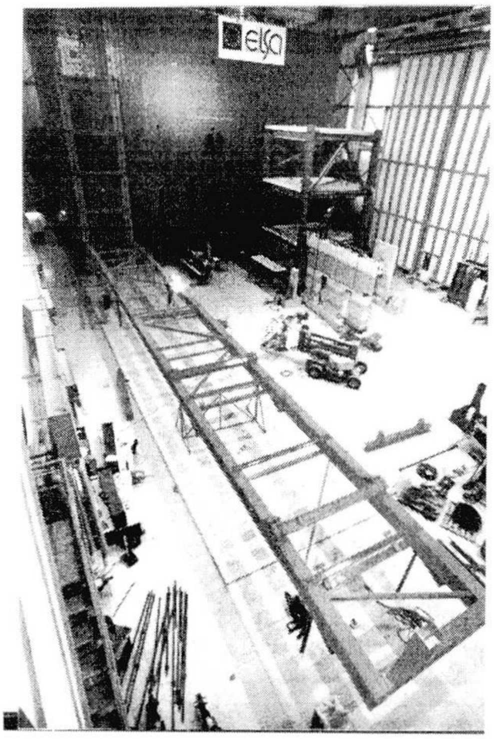

Large scale cable-stayed bridge mock-up in construction at the JRC - ELSA Laboratory.

Vibration Control of Stay Cables

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Abstract

During the recent past years several analyses have been conducted dealing with the vibration characteristics of stay cables. The fundamental theories as well as the fundamental behaviour of various types of cables have been developed. At the same time, various remedies and vibration control devices were proposed by contractors and suppliers.

This paper reviews the previously used systems and presents the up-to-date technology which is available today. It covers the streamline sheath coping with the rain and wind vibration phenomena, the internal or external hydraulic dampers, the visco-elastic dampers and the damping cross ropes. Calculations of the damping system characteristics, prediction and measurement of the damping ratio are presented.

1. Introduction

Cable vibrations can be excited by dynamic wind forces acting directly on the cable itself or by the movements of the cable attachments on the pylon or on the deck due to the action of traffic loads or of the wind itself. Four different sources of vibrations are considered in the analysis :

- parametric excitation by the movements of the pylons and the deck ;
- rain and wind vibration ;
- low wind dry vortex ;
- galloping.

2. Damping technologies

2.1 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.

2.2 External hydraulic damper

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.

2.3 Internal visco-elastic damper (IED) and Internal hydraulic damper (IHD)

This damper is completely invisible from the deck since it is located inside the steel guide pipe of the stay cable.

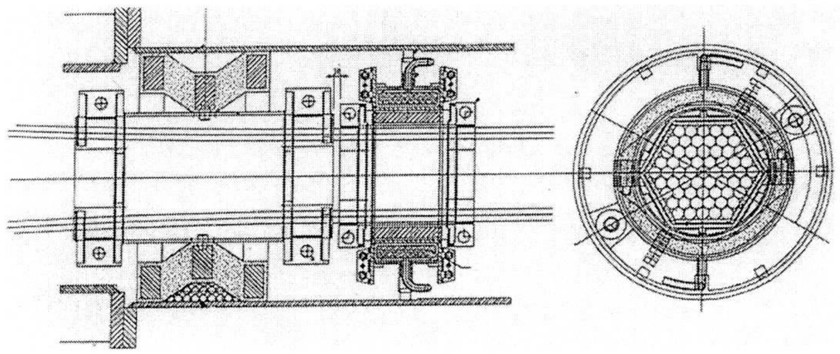
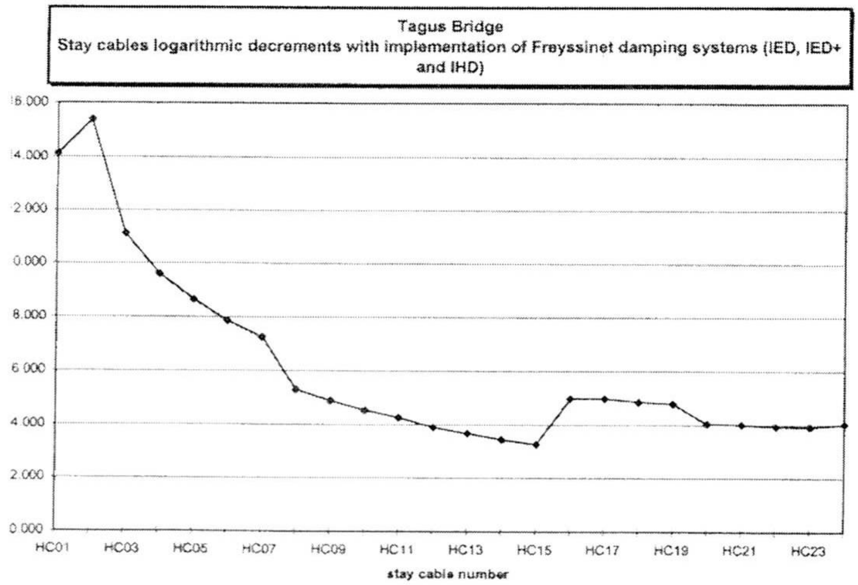


Figure 1

3. Vibration control

Calculation models have been developed to evaluate the logarithmic decrement δ provided by the various types of damping systems. A universal damping surface has been established allowing an accurate tuning of the damper.



Tagus bridge Lisbon (Portugal)

Active Tendon Control of Cable-Stayed Bridges: Control strategy and Actuator Design

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Abstract

This paper is part of a trilogy describing the Brite-Euram project "ACE". The first part of the paper describes the control strategy for active damping of cable structures with an active tendon collocated with a force sensor. The main analytical results for predicting the closed-loop poles are summarized and the procedure for selecting the number and the location of the active tendons is outlined. The second part of the paper describes a laboratory experiment with a small size mock-up representative of a cable-stayed bridge during its construction phase (Fig.1). The control of the parametric vibration of passive cables due to deck vibration is demonstrated. Finally, the third part of the paper outlines the conceptual design of an hydraulic actuator for industrial applications.

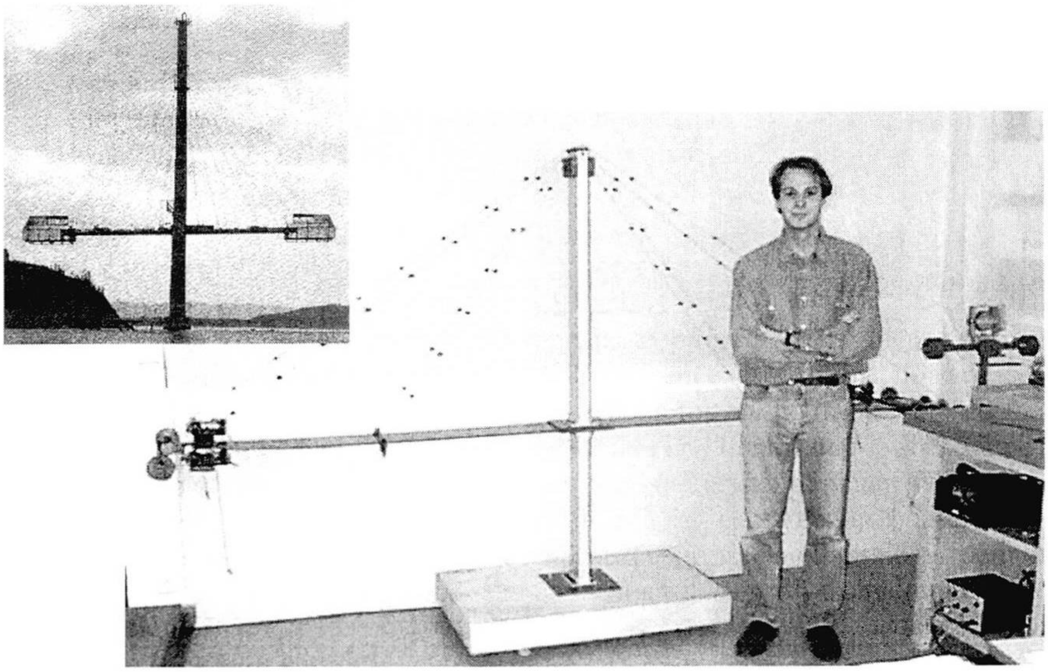

Fig.1: Experimental set-up for the cable-stayed bridge (the small picture shows the Skarnsund bridge –Norway– in its construction phase)

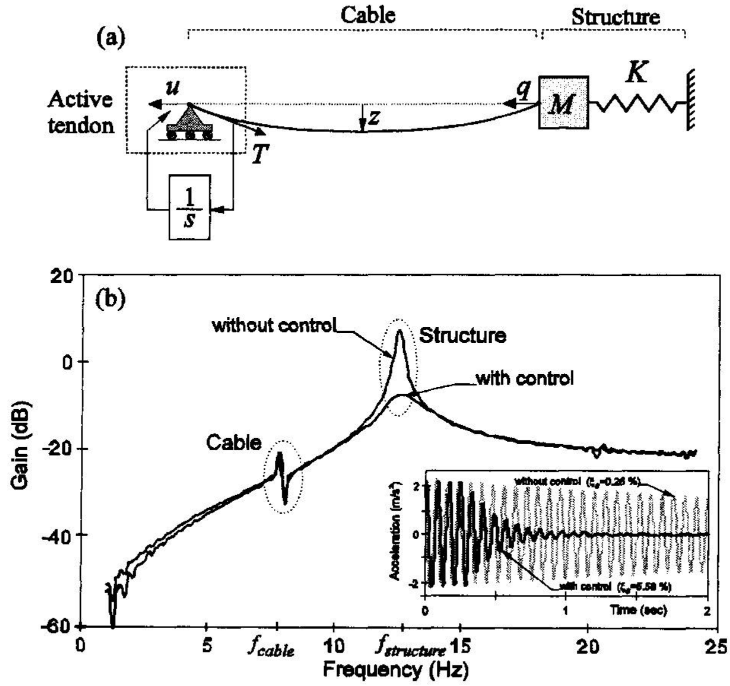

Fig.2: Active damping of cable structures

CFRP-Tendons - Development and Testing

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Abstract

CFRP (Carbon Fibre Reinforced Plastics), developed for the aerospace and aircraft industry, are increasingly becoming an interesting material for civil engineering. Especially the strength and stiffness in relation to weight makes them an ideal material for cable-stayed bridges.
The aim of a common research project, sponsored by the Bavarian Ministry of Economy, Traffic and Technology and conducted by the Technische Universität München (Lehrstuhl für Massivbau) and DSI (DYWIDAG Systems International), was to develop a CFRP-tendon.
Since 1983 stay cable specimens and anchoring systems have been tested at the Technische Universität München. With the testing machine (figure 1) it is possible to apply forces up to 19000 kN in dynamic and static tests.

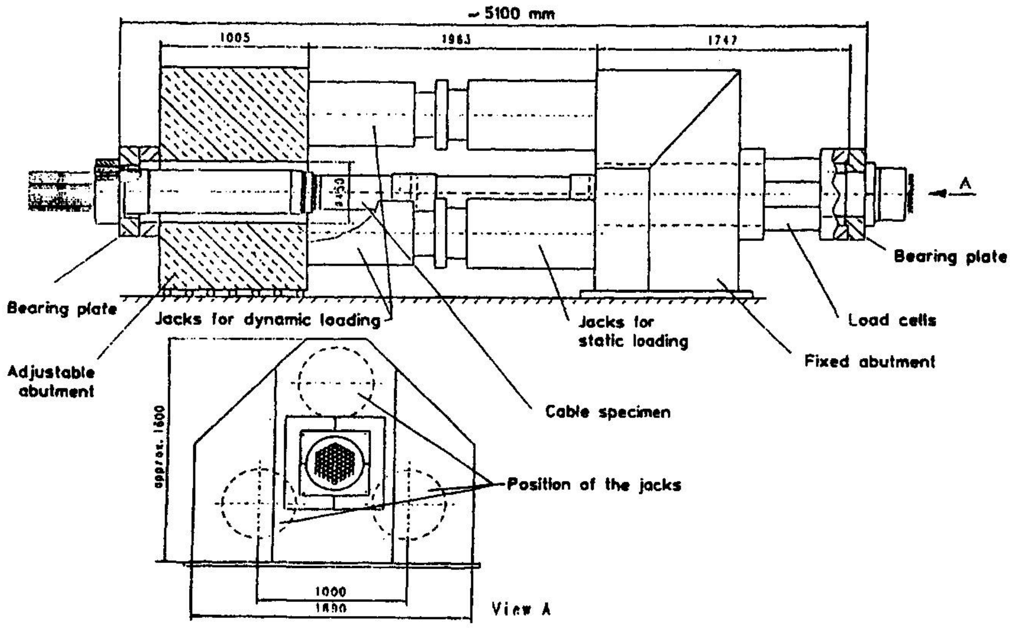

Figure 1: Stay cable testing equipment at the Technische Universität München

This paper deals with the development and the testing of this CFRP-tendon. The major problem are the anchorage systems where high forces have to be applied to the cable specimen. A FEM calculation verified by tests builds up the foundation for a practical anchorage system. The constant development led to the anchorage system for 91 CFRP wires, which was tested under dynamic (according to the PTI recommendations for stay cables) and subsequent static load in 1998.

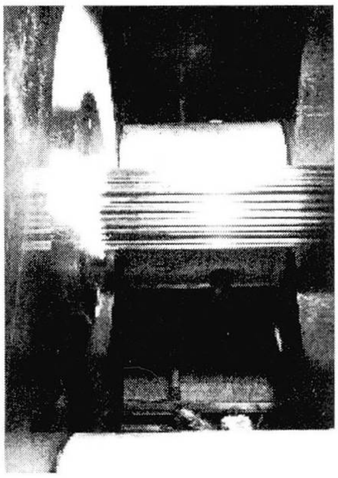

Figure 2:
Anchorage before the ultimate strength test

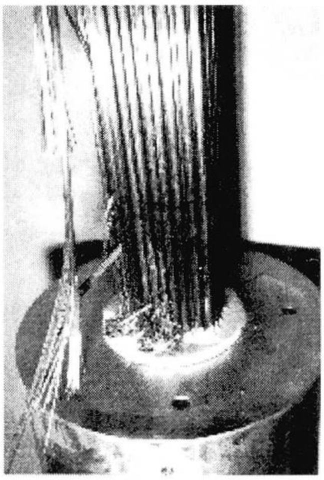

Figure 3:
Wire fracture at the anchorage

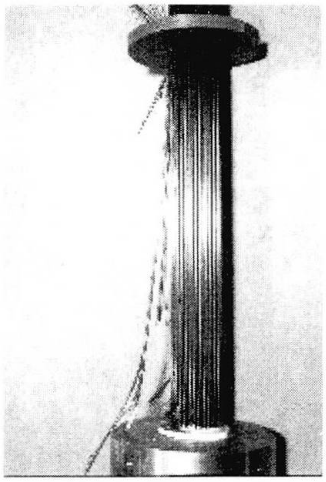

Figure 4:
part of the free length of the specimen

During the fatigue test no wire fracture occurred in the free length or in the anchorage of the cable specimen. The displacement of the adjustable abutment (anchor block) at maximum load increased due to the application of two million load cycles by 1.10 mm. This elongation was mainly caused by the pull-out of the potting material from both steel hulls. The stay cable showed very good dynamic properties as expected from CFRP. After the fatigue test was completed the static load test was performed. The cable was loaded up to a load of 3600 kN. The ultimate load of a single CFRP-wire was 50 kN. Corresponding to these value the ultimate load of the cable is equivalent to 78% of the theoretical ultimate strength. The specific elongation of the whole cable specimen corresponding to this load was about 1,9 %. The test was stopped after six wire fractures of which the first occurred at a load of 3500 kN. Due to the type of material the wires failed in the linear elastic region of the stress elongation line. The cable specimen broke wire by wire not as suspected with a sudden fracture of the whole cable specimen. Figure 2 shows the specimen at the anchorage before the ultimate strength test. The wire fractures are shown in figure 3 and 4.