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# Torsional Fixation of Girders in Cable Suspended Bridges

Fixation des tabliers des ponts suspendus ou à haubans contre la torsion

Torsionsfesthaltung von Versteifungsträgern in Hänge- oder Schrägseilbrücken

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## SUMMARY
A new concept for cable suspended bridge girder supports at main towers has been developed for a bridge under construction in Denmark. The girder is free to translate vertically under load without restraint, whereas torsional rotations are prevented. The system employs interconnected hydraulic cylinder pendulums in a passive circuit. The continuous elastic suspension of the continuous girder in suspension and cablestayed bridges provides an even sectional force distribution. The system also presents aesthetic advantages due to uninterrupted girder suspension through tower.

## RESUME
Pour un pont à haubans au Danemark, une nouvelle conception des appuis du tablier aux pylônes a été développée. Le tablier peut se déplacer librement dans le sens vertical sous l'effet de la charge, tandis que des mouvements de torsion sont exclus. Le système est conçu de pendules de cylindres hydrauliques dans un circuit passif. La suspension élastique continue du tablier dans un pont suspendu ou à haubans assure une distribution des contraintes sans discontinuité majeure. L'omission d'appuis fixes aux pylônes présente également un avantage esthétique dû à la suspension ininterrompue du tablier aux pylônes.

## ZUSAMMENFASSUNG
Ein neues Konzept für die Lagerung des Versteifungsträgers an den Pylonen von kabelunterstützten Brücken wurde für eine Brücke in Dänemark entwickelt. Der Träger kann zwangfreie lotrechte Translationen ausführen, während er gegen Torsionsdrehungen festgehalten ist. Das System arbeitet mit passiven druckverbundenen hydraulischen Zylinderpendeln. Die kontinuierliche elastische Aufhängung des Trägers in Hänge- und Schrägseilbrücken führt zu einem Ausgleich der Schnittkräfte. Das System hat mit der freien Führung des Trägers durch die Pylone auch ästhetische Vorteile.

## 1. INTRODUCTION

In cable-suspended bridges the girder is generally rigidly supported at the main towers as opposed to the otherwise flexible or elastic support provided by the suspension cables, hangers or stays. This principle generates an unfavourable moment distribution with concentration of sectional forces and local strengthening requirement close to the support at the towers. Such strengthening often complicates the fabrication of the girder and, therefore, affects cost unfavourably.

A moderate sectional force distribution is accomplished if the stiffening girder is elastically suspended in the cables only, with the girder free to move vertically under load. However, the girder must be restrained at the towers against torsional rotations to achieve the necessary rigidity for the comfort of the traffic, and, in particular, to assure sufficient aerodynamic stability.

A relatively simple restraint system satisfying these requirements has been developed for the Farø Bridges, presently under construction in Denmark and scheduled to be completed by mid 1985.

The $ 100 mio. bridge project consists of two continuous steel box girder superstructures, 1600 m and 1700 m long, respectively. One of the bridges comprises a cablestayed navigation span of 290 m with adjacent side spans of 120 m.

The bridge girder for both bridges has been designed as an aerodynamic closed single-cell all welded steel box girder with an orthotropic deck. The bridges are continuous from coast to coast and are corrosion protected internally by means of a dehumidification plant. Particular consideration was paid to rational and industrial fabrication of the approx. 23,000 t of steel and to the erection of the bridge girder in full span segments, each 80 m in length with weight of 600 t. The project is optimized with regard to initial construction cost and low maintenance cost over its design service life. Structural elements with less than 100 years life expectancy are easily replaceable, including cable stays.

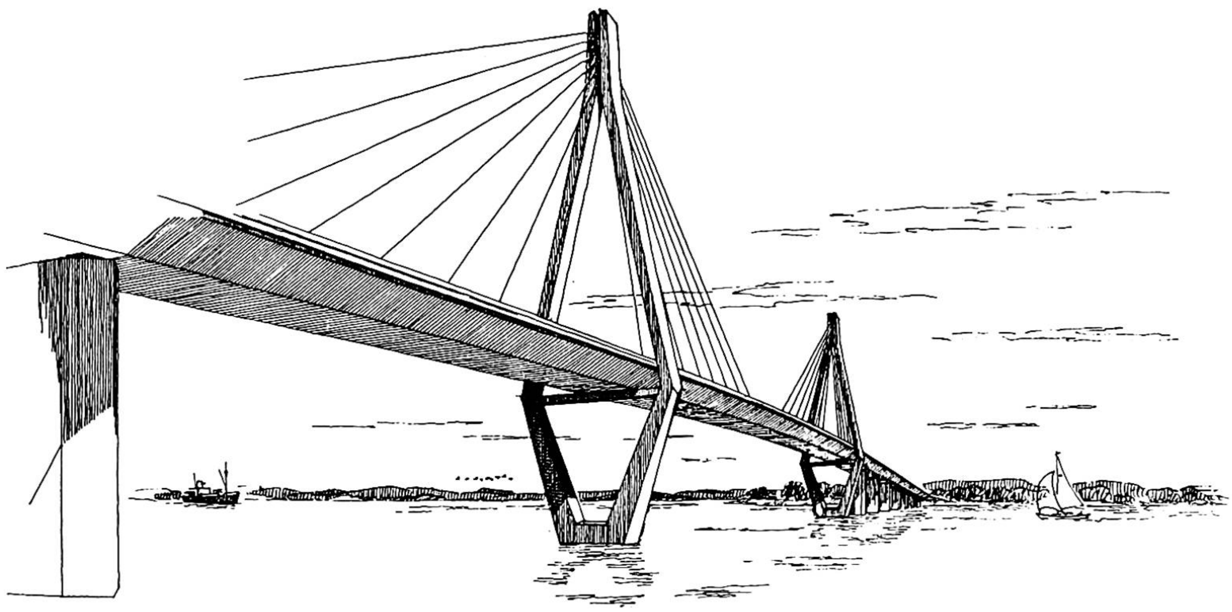
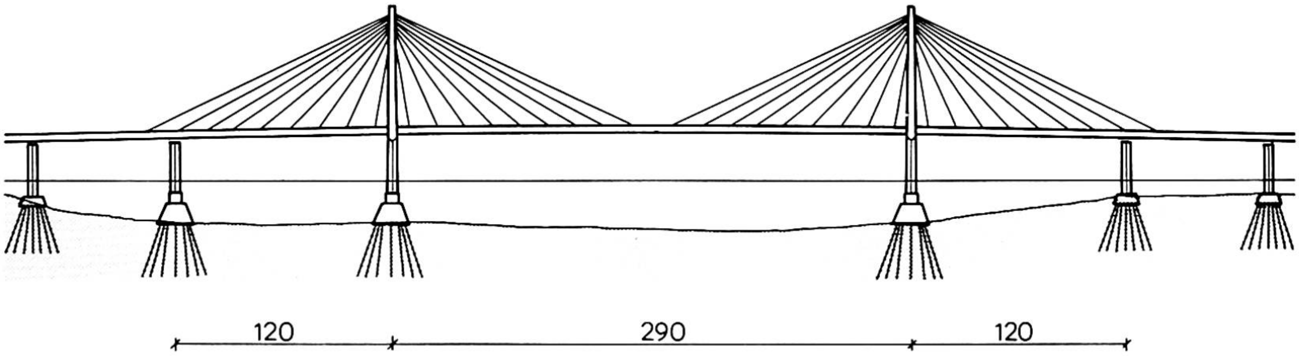


Fig. 1 Farø Bridges, Cable Suspended Section Perspective



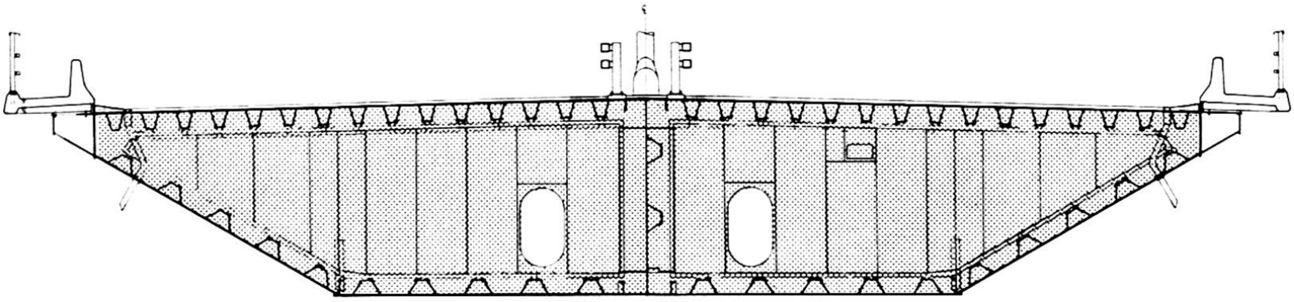



Fig. 2 Farø Bridges, Cable Suspended Section and Cross Section of Box Girder. The bridge carries a four-lane motorway.

The cablestayed bridge girder is suspended in concrete towers by means of a single multi-cable stay system with fan shape arranged in the median of the bridge.

The cross section is constant throughout the bridge, and vertical support is provided only by the cable stays between the anchor piers. The structural arrangement of supports and bearings at the towers is illustrated on figure 2. The support system may be divided into three distinct parts:

a) a torsional fixity of the girder, permitting vertical translations of the girder, but preventing torsional rotations;

b) a lateral support of the girder, preventing sidesway due to wind loads;

c) a longitudinal support at one of the bridge towers to absorb braking, mass- and bearing friction loads for the 1700 m long continuous girder. In order to eliminate an unfavourable horizontal restraint of the girder at the tower, inducing torsional moments in the tower, these bearings incorporate elastic supports.

The elastic suspension arrangement through the towers has the effect of equalizing the sectional forces in the stiffening girder such that, among others, the traffic induced positive and negative moments are readjusted to the same order of magnitude. Hence, redistribution of sectional forces at the towers will be unnecessary and all plate thicknesses in the continuous girder cross section can be maintained throughout the cablestayed spans.

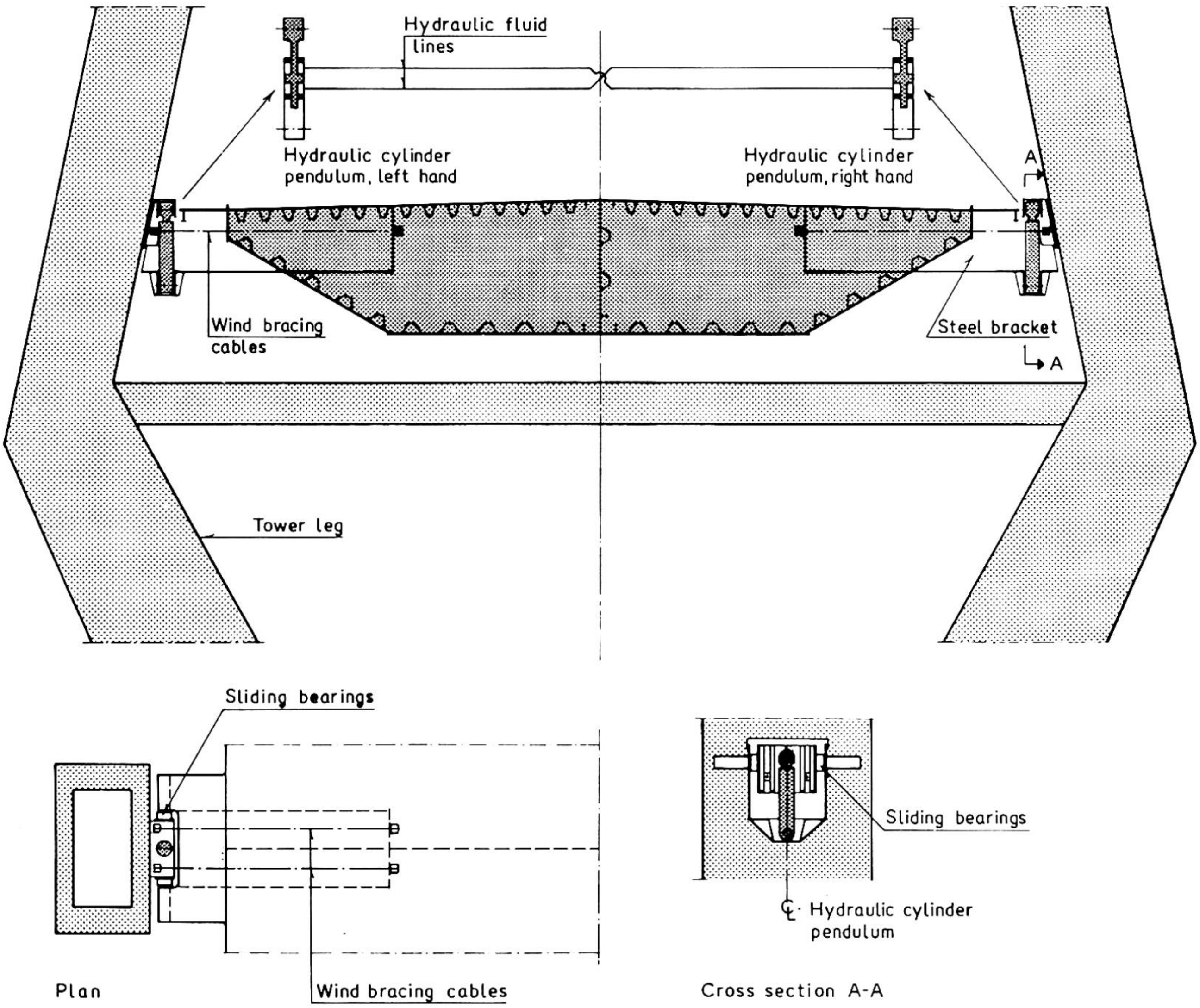



Fig. 3 Connection Arrangement between Tower and Box Girder.

## 2. TORSIONAL FIXITY OF THE GIRDER

The functional requirement a) has been solved by a system of hydraulic cylinders arranged close to tower legs.

Due to desired degrees of freedom of the girder, the hydraulic support cylinders have been arranged as pendulums, ref. figures 3 and 4.

The hydraulic cylinder pendulums are double-acting and are designed to work in a closed passive hydraulic system for maximum reliability. Thus, the hydraulic fluid pressure will develop exclusively due to forces from the girder due to traffic and wind loads.

The two chambers in each cylinder are connected cross-wise with corresponding chambers in the opposite cylinder. Same effective piston area in all pressure chambers is assured by throughgoing piston rod.

A vertical translation of the girder leads to hydraulic fluid movement from the lower chamber in one pendulum to the upper chamber in the opposite pendulum, and vise versa. The resistance being only the hydraulic fluid movement resistance in the fluid lines, which - as a by product - provides a favourable viscous damping. The girder is, thus, free to move in a vertical translation.

For pure torsion no fluid movement will take place and the girder will be torsionally fixed by the build-up of differential hydraulic pressure on the opposite sides of the pistons.

The hydraulic system is, of course, equipped with a feeding arrangement for hydraulic fluid and volume variations of fluid and chambers compensated for by pressure equializators. Furthermore, the system is ensured against excessive pressures by high-pressure safety valves.

In case of failure in the hydraulic system by leaking gaskets or other malfunction, the torsional rotation of the girder will be limited by mechanical stops in the hydraulic cylinders. Even if this emergency system is activated the maximum cross slope of the bridge girder will in no case exceed 10 o/oo.

During normal service load conditions, the forces exerted at the pendulum are expected to be rather low, only 15 to 25 percent of the ultimate capacity of the cylinders. Thus, high dependability and long durability is expected with low risk of failure.

The hydraulic suspension arrangement provides an excellent means for verification of torsional moments simply by hydraulic pressure registration. Pressure transducers are, therefore, incorporated and readings recorded by a datalogger system used for the overall instrumentation system for the cable-stayed bridge. Simultaneous readings of wind velocity and direction, as well as traffic loads and hydraulic pressures will enable the collection of additional information regarding bridge loads to compare with the actual design criteria used for this bridge and for future bridges.

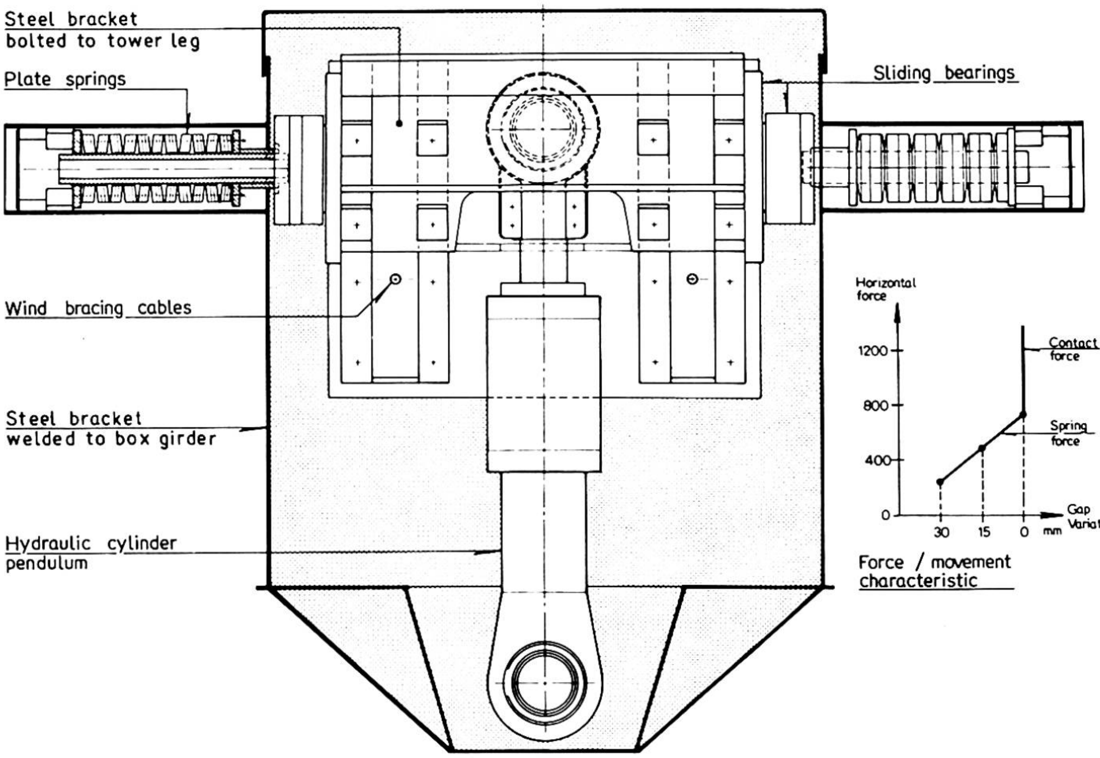



Fig. 4 Hydraulic Cylinder Pendulum and Longitudinal Support of Stiffening Girder. (View direction is indicated in Figure 3, Cross Section A).

## 3. LATERAL SUPPORT OF THE GIRDER

Lateral wind loads on the bridge girder will be transferred from the girder to the tower legs by means of wind bracing cables arranged so as to permit the relative movements between girder and tower without restraint. Cables will be moderately pretensioned to eliminate sag and lateral movement of the girder under wind load. The variation in pretension of the cable due to forced deflection by longitudinal and vertical girder movements will be small because of relatively small displacements compared to the length of the cable.

## 4. LONGITUDINAL SUPPORT OF THE GIRDER

The support of the girder lengthwise, refer figure 4, is arranged only at one of the two towers. This fixity is arranged by means of spherical bearings, movable in both directions on a vertical plane perpendicular to the bridge axis. A stack of plate springs between structure and bearing permits elastic support with elasticity of $\pm 15$ mm. The springs are slightly preloaded in order to ensure that the bearings in all situations are in positive compression. The elastic support prevents moment transfer to the pylon (torsion in the tower shaft). The characteristics of the plate springs are arranged as indicated in figure 4.

A fundamental consideration for the choice of this system is the extreme long continuity of the 1700 m girder without any intermediate expansion joints over. The girder, thus, has a very high mass for longitudinal movements. Although no permanent bearings are contemplated at the other tower,temporary bearings may be installed during maintenance operations.

## 5. STRUCTURAL CONFIGURATION

All three systems of girder supports are installed in welded steel brackets, bolted to the concrete towers at each leg and welded to the girder faces, respectively. The arrangement is illustrated on figure 3.

## 6. MAINTENANCE AND SERVICE

The support structures are arranged so as to provide visual checking possibilities. All components may be replaced without imposing any traffic restrictions. The functional behaviour as intended of the support structures will be monitored continuously by means of the previously mentioned instrumentation, providing amongst others remote indications. Instrumentation regarding supports at the towers will record:

a) Hydraulic fluid pressure variations in the hydraulic torsional support

b) Cross slope of the girder at the towers

c) Relative movements between girder and tower by mechanical indicators

d) Longitudinal forces by pressure transducer

The surveillance of the bridge will be commanded from a central facility with computer facilities, which will be arranged by the bridge authority close to the bridge.