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Limitation of Deformations of Long Span Suspension Bridges

Limitation des déformations des ponts suspendus de grande portée

Deformationsbegrenzung bei weitgespannten Hängebrücken

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SUMMARY
The paper concerns arrangements for limitation of deformations for long span suspension bridges. Reference is made among others to the simple establishment of a horizontal fixation of the main cables at mid span through the stiffening girder and to the possibilities for utilization of hydraulic devices, which can easily be adapted to different tasks for stabilization and damping of cable and girder systems.

RÉSUMÉ
L'article traite des mesures à envisager pour la limitation des déformations des ponts suspendus de longue portée. Entre autres il est fait référence à l'établissement simple d'une fixation horizontale des câbles principaux de la travée principale au tablier rigide et aux possibilités d'utiliser des disponsitifs hydrauliques, qui peuvent facilement être adaptés aux différents besoins de stabilisation et d'amortissement des système de câbles ou de tablier.

ZUSAMMENFASSUNG
Der Artikel beschreibt Massnahmen zur Deformationsbegrenzung bei weitgespannten Hängebrücken. Es wird u.a. auf die einfache Etablierung einer horizontalen Stabilisierung der Tragkabel im Hauptfach durch den Versteifungsträger hingewiesen, sowie auf die Möglichkeit, hydraulische Anordnungen, welche sich gut verschiedenen Aufgaben anpassen, für Stabilisierung und Dämpfung der Kabel- und Trägersysteme zu verwenden.

1. INTRODUCTION

During recent years the effort to realize fixed connections across wide and deep waterways has been intensified (Honshu-Shikoku, Store Bælt. Messine Strait, Gibraltar etc.) and the projects comprises suspension bridges with free spans between 1500 and 3000 m for both road- and railway traffic. Free spans of 3 to 4 kilometers are considered to be realistic with present day technology and construction practice.

Earth anchored bridges are characterized by the so-called "deflection effect", by which the system is stabilized for increasing permanent loads, and in this respect deviates considerably from other statical bridge systems. For increasing span lengths and permanent loads the deflection effect gives an additional stiffness, which makes suspension bridge systems especially adequate to carry heavy loads including heavy railway traffic. However, long span suspension bridges are - regardless of increased stiffness through increased cable tension - characterized by considerable deflections, which for bridges with heavy railway traffic requires special precautions in order to fulfil the restrictive demands to the rail profile and the deformations.

In connection with feasibility studies for long span suspension bridges for e.g. the Store Bælt and Gibraltar crossings, the possibilities of increasing the structural stiffness globally and locally have been analysed systematically, partly by modifications of cables and girder, by which unacceptable deformations - often due to asymmetric loads - are suppressed systematically.

Essential aspects in the studies were that bending moments in the bridge girder from variable loads are relatively small due to the dominating stiffness of the suspension cables and so the girder consequently has a great unused capacity to carry longitudinal loads; furthermore present day hydraulic systems are very reliable and they can advantageously be used in bridges either as passive or active elements for load carrying or damping purposes.

2. CABLE ARRANGEMENT

The suspension system and the free spans are normally arranged due to topographical and navigational reasons and eventually geotechnical conditions. The main or the navigational span dominates the bridge structure and the position of the free span can normally be varied only within close limits. It is often possible, however, especially for the side spans, to improve the global system stiffness by suitable modifications of the cable system.

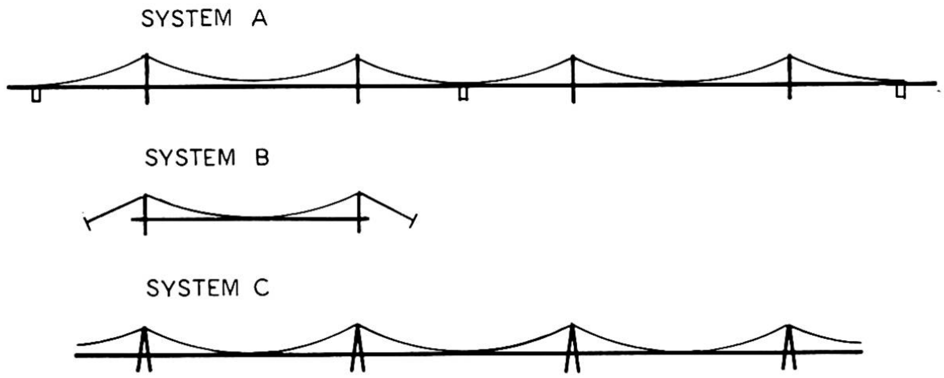


Fig. 1: Suspension Systems.

In conventional three span suspension bridges with flexible pylons, cf. figure 1.A a great deal of the flexibility in the main span is due to cable deformations in the side spans. Shortening of the side spans or the use of straight cables to the anchorages cf. figure 1. System B will imply a significant reduction of the deformations in the main span.

Optimal conditions are achieved in the untraditional single span suspension system, where unbalanced horizonatal forces from variable loads are carried by stiff pylons obtained by a triangular configuration in the longitudinal direction. Fig. 1. System C shows a multispan suspension system made of single span systems in mutual balance for permanent loads.

This system will for long distances over deep water and made with very long spans, be attractive in comparison with series of three span bridges - e.g. the Bisan Seto and San Francisco-Oakland bridge - shown in figure 1. System A., because anchorages in deep water are costly and implies increased navigational risks. The multispan system is one of the preferred solutions in the Gibraltar crossing studies presented in another paper at the IABSE Congress in Helsinki 1988 (1).

The required transfer of unbalanced cable forces from traffic at top of pylons means that the ratio between traffic load and dead weight should be low in order to obtain a suitable economic pylon structure. As increased span width decreases the mentioned loading ratio considerable this system will be favourable for very long spans - in particular for rail traffic as the weight and length of a train are constant regardless of the span length.

In figure 2 an example of the total loads on the pylon are given for various spans of a road bridge. The increasing stabilization for increasing span lengths is clear. In addition to the sag ratio of L/8 an extremely low sag ratio of L/12, which implies a large progressively increasing cable weight, is shown.

Pylons of this type requires naturally a very large and robust basis. Consideration of ship collision, current and eventually earthquakes, requiring very massive and resistant substructures, normally coincides with the requirements of the triangular pylon structures.

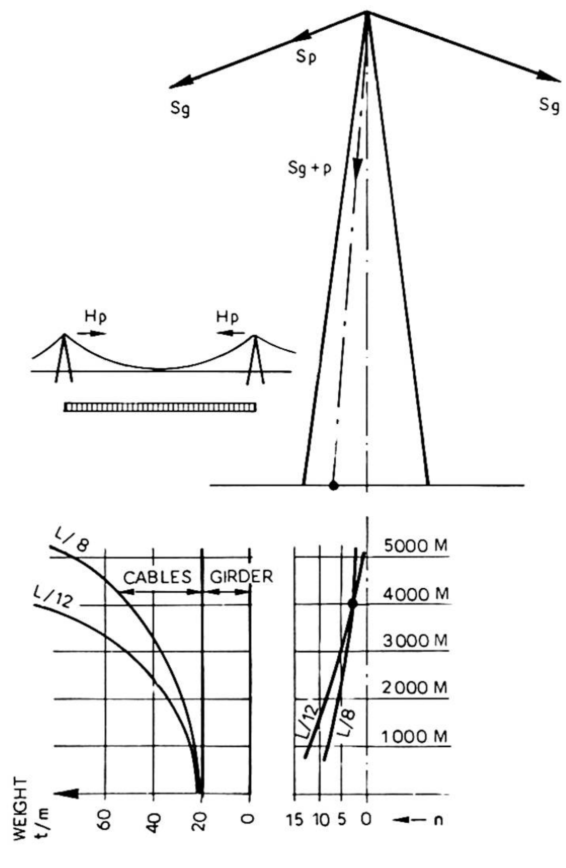


Fig. 2: Resultant forces in pylons for suspension system C and road traffic for cable sag L/8 and L/12.

3. CABLE STABILIZATION

A considerable reduction of the system deformations can be achieved by a fixation of the cables and the girder for relative longitudinal movements at midspan. The fixation can be established by a clamp locking the cable and the girder centrally, whereby the girder transfers the necessary longitudinal forces for the stabilization to the anchorages or to the rigid pylons as shown in fig. 3 where the force paths are shown for both a three span and a single span suspension system.

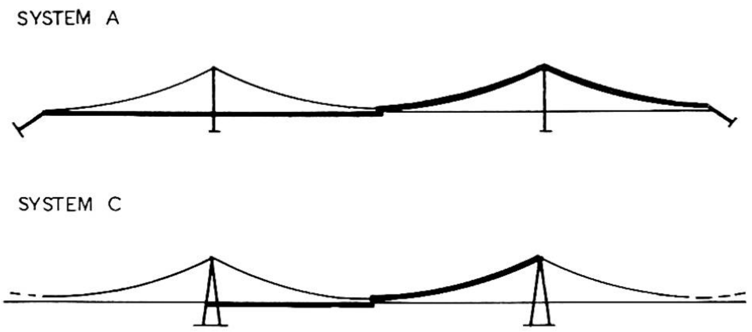


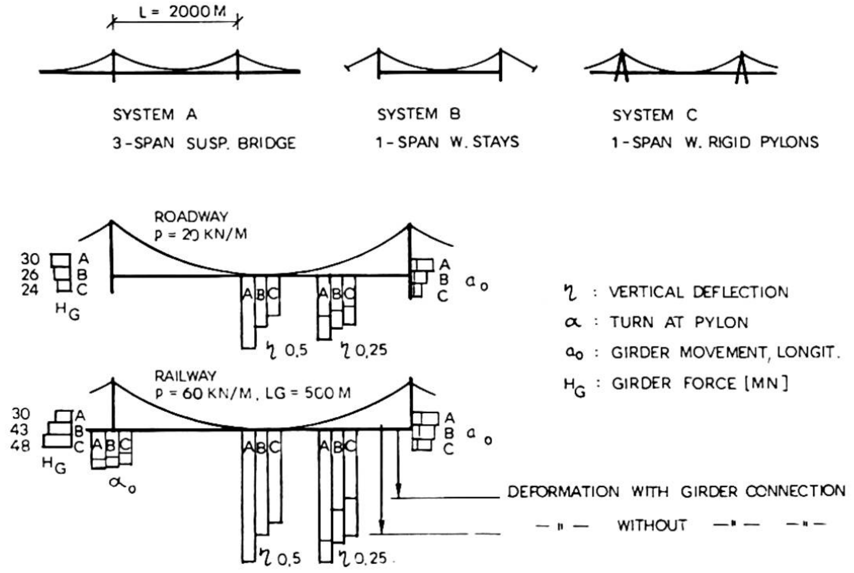
Fig. 3: Stabilization of the cables at midspan by longitudinal fixation. The force path is shown by a solid line.

The most adequate solution is to utilize only the tensile capacity of the girder, partly because it is larger than the critical compressive load and partly because the tension will tend to have a stabilizing effect on the girder for lateral deflections. The fixation of the girder at the pylons can be made with passive hydraulic cylinders, as assumed above, only capable of transmitting tensile forces. The hydraulic systems allows slow temperature induced movements of the girder while fast movements from traffic and wind are hindered. This alternative statical system arranged to carry traffic loads has no effect for symmetrical loads whereas it is very effective for asymmetric loads, where the effective span width is reduced giving a large reduction of the vertical deflections of the girder near the quarterpoints and close to the pylons and of course also the longitudinal girder movement.

In fig. 4 the effect of the fixation is illustrated for three suspension systems with a free span of 2000 m for roadway and heavy railway traffic. The deformations without and with the girder fixation at the pylons are given. The asymmetric vertical deformations are reduced 20 - 40% and the longitudinal movements are reduced to one quarter of the free longitudinal movements. This reduction is of great importance for the design of the complicated railway expansion joints for large span lengths.

The magnitude of the fixation forces are naturally depending on the intensity of the traffic loads, but will usually correspond reasonably with the tensile capacity of the girder, which is normally available at no cost. The girder forces are reduced by the following:

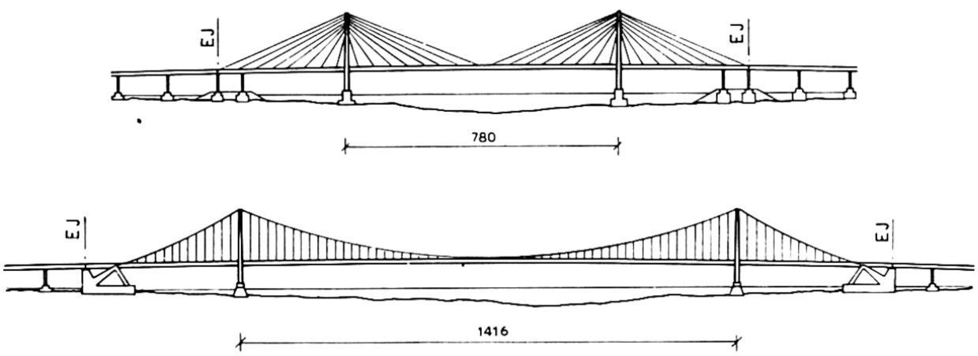
- the cable fixation is elastic, corresponding to the tensile deformations of the girder and the cable
- the cable stabilization by tensile forces implies that the tensioned part of the girder is in principle free of (or less exposed to) direct traffic loads
- larger traffic loads due to a wider girder etc. are normally balanced by a larger cross sectional area of the girder and consequently a larger tensile capacity
- a central cable fixation allows a larger cable sag and correspondingly the tensile forces in the girder from traffic loads will be reduced.



<u>Fig. 4</u>: Effect of cable fixation at midspan by use of the bridge girder.

4. GIRDER CONFIGURATION

The bridge girder itself can also reduce the deformations, although for slender girders the effect is local. This can be achieved either by an active stabilization described in section 5 or by an appropriate girder configuration at the ends of the suspended spans. In figure 5 is shown the transition between the main spans and the approach spans for the Store Bælt project proposals for combined roadway and railway bridges for a suspension and a cable stayed bridge respectively (2). By the extension of the girder beyond the suspended span the requirements of maximum angular discontinuities in the rails have been fulfilled in both the vertical and horizontal direction. Consequently a simplification of the otherwise complicated expansion joints was possible.



<u>Fig. 5</u>: Girder arrangement and expansion joint position (EJ) for suspension and cable-stayed project proposals for Store Bælt for combined road and railway traffic.

5. GIRDER STABILIZATION

A problematic item for suspension bridges is the structural design of the girder crossing at the pylons: The elastic suspension of the girder in the adjoining spans are terminated by rigid supports at the pylons, which amplifies the angular discontinuity and in addition to girder movements, large vertical and horizontal forces are transferred to the pylons, due to traffic and wind loads.

Some medium suspension bridges are made with continuous girders through three spans, without expansion joints between the anchorages. The continuous girder at the pylons reduces the deformations close to the pylons considerably and thus increases the traffic comfort due to the elimination of the angular discontinuities at expansion joints.

Structural systems with very long spans requires expansion joints at the pylons to accomodate the temperature deformations and in multi span systems e.g. as shown in system C in figure 1, this is the only place to arrange expansion joints. However, by use of hydraulic systems it is possible to arrange support and fixation systems for the bridge girder, which within wide limits can be arranged to fulfil the requirements to continuity and expansion capability. In figure 6 is shown an arrangement for a three span suspension bridge with the following features:

- Expansion joint movements in longitudinal direction without constraints for slow temperature induced movements and fixation for faster movements from traffic loads. Further a damping effect.
- Torsional fixation of the bridge girder, by a hydraulic device, that allows free vertical movements (3). The girder is elastically suspended in hangers made with a suitable low modulus of elasticity.
- The transfer of bending moments is assured by use of pairs of hydraulic cylinders crosswise connected corresponding to the arrangement for the fixation for torsional movements.
- In horizontal direction the girder may be simply supported or as shown partially fixed at the pylon. The transfer of bending moments can alternatively be arranged in the same manner as for the vertical bending moments.

The arrangement can of course be made simpler - according to the needs - by elimination of components and a change of the corresponding functions. The hydraulic systems are all made with passive hydraulics i.e. the forces will only occur as a resistance to movements of the bridge girder. Further some of the hydraulic systems may work actively in connection with special operational situations or generally when the monitoring system has registered exceedance of allowable movements. Finally the hydraulic systems will contribute, actively or passively, to the damping of girder oscillations.

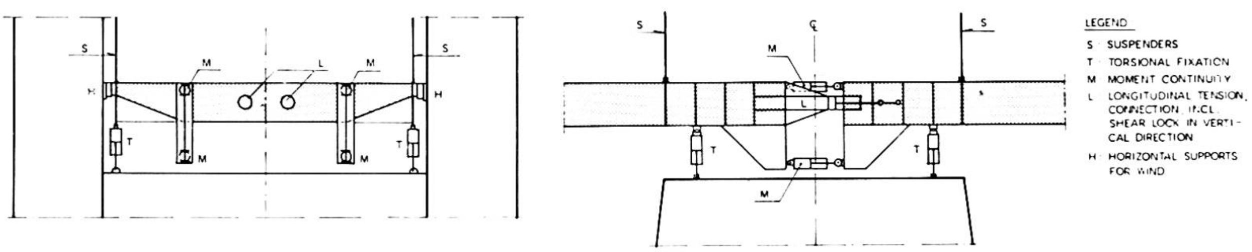


Fig. 6: Hydraulic systems for movement control.

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