The bi-stayed bridge

Autor(en): **Muller, Jean / Lockwood, James**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **64 (1991)**

PDF erstellt am: **30.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-49350

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

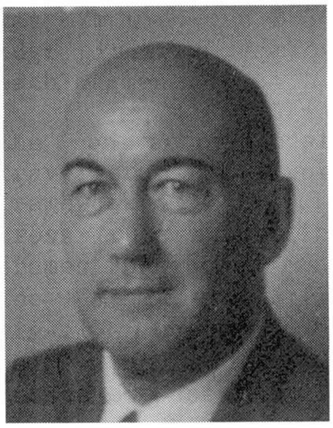
The Bi-Stayed Bridge

Le pont bi-haubané

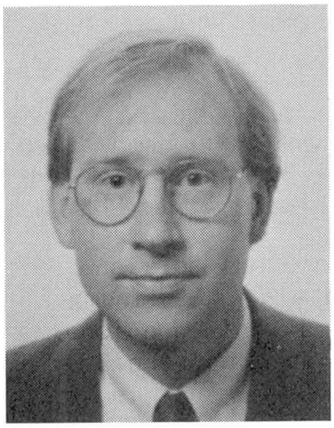
Die Bi-Schrägkabelbrücken

Jean MULLER
Director
SCETAUROUTE
St Quentin/Yvelines, France

James LOCKWOOD
Senior Project Eng.
Jean Muller International
St Quentin/Yvelines, France



Born 1925, Engineer ECP, Doctor Honoris Causa of Lausanne University, Director of the Bridge Engineering Dep. of SCETAUROUTE and Technical Director of Jean Muller International.



Born 1960, MSCE degree from Univ. of Washington, Seattle, WA. Currently working with Jean Muller on special projects including composite and cable-supported bridges.

SUMMARY

A new bridge concept using both self-anchored and earth-anchored stays is developed through its construction methods. It is shown in the text that with the available materials and the usual proportion between dead and live loads, it is possible to extend the limit of the maximum clear span of a stay supported deck to 2500 to 3000 m. The advantages of deck rigidity under traffic load and low construction costs inherent to the bi-stayed bridge can therefore be applied to spans only previously heretofore reserved for suspension bridges.

RESUME

Un nouveau concept pour un pont haubané utilisant à la fois des haubans traditionnels et des haubans ancrés dans le sol est exposé au travers de la méthode de construction. Il est montré qu'avec les matériaux disponibles, et pour les rapports usuels entre les charges permanentes et les surcharges, il ets possible d'étendre la valeur de la portée libre maximale d'un pont haubané à 2500 ou 3000 m. Les avantages du tablier rigide vis-à-vis des charges de circulation et des faibles coûts de construction inhérents au pont haubané peuvent en conséquence être valables pour des travées jusqu'à ce jour reservées au ponts suspendus.

ZUSAMMENFASSUNG

Ein neues Brückenkonzept, das sowohl selbstverankerte wie auch erdverankerte Schrägkabel benutzt, wird mit Hilfe eines Bauverfahrens entwickelt. Es wird im Text gezeigt, dass mit dem vorhandenen Material und dem üblichen Verhältnis zwischen ständiger Last und Verkehrslast die maximale Spannweite eines seilverspannten Balkens auf 2500 bis 3000 m gesteigert werden kann. Die Vorteile der hohen Balkensteifigkeit unter Verkehrslast und der niedrigen Baukosten solcher Bi-Schrägkabelbrücken können deshalb auch Spannweiten ermöglichen, die bisher den Hängebrücken vorbehalten waren.

1. INTRODUCTION

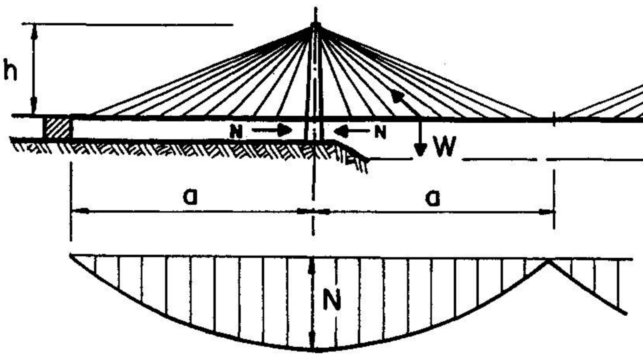
Very long span bridges of over 1000m have been built, to date, with suspended decks. The two most common types of these structures are the suspension bridge and the cable-stayed bridge. Using the materials available, the maximum clear span of the suspension bridge is over 3000m. As the clear span increases, however, the cost of the main suspension cables and anchorage blocks rises very rapidly. In addition, the vertical deformations and longitudinal slope variations of the deck under imposed loads quickly become critical. The ratio of the clear span to the tower height must be limited to 9 or 10 to control these deformations while the more economical ratio to limit the cost of the cables and anchorage blocks is approximately 6. To overcome this disadvantage, engineers have been working for over 30 years on cable-stayed bridges. In this system, the height of the pylon can be up to double that of the suspension bridge, such that the cost of suspension (staying) is reduced while increasing the structure's rigidity. The maximum clear span of a cable-stayed bridge is between 1000 and 1500m using existing available materials. This span is determined by the deck's resistance to compression and not from critical deformations under imposed loads.

The bi-stayed bridge was developed to overcome the problems described above. This new concept shows that with conventional materials and a specific sequence of construction methods, it is possible to attain span ranges comparable to a suspension bridge with a structure having the inherent long span qualities of a cable-stayed bridge.

2. PRINCIPLES OF THE BI-STAYED BRIDGE

In developing the principles of the bi-stayed system, the load-carrying characteristics of the cable-stayed bridge are reviewed (Fig. 1). In this case, the deck is suspended from multiple stays spread uniformly along its length more or less symmetrically on either side of the pylon. For a deck supporting a total load w per unit of length, and assuming that all stays are anchored at the top of the tower, the axial load in the deck varies parabolically from zero (at midspan and extremity of lateral span) to a maximum value N around the pylon equal to wa2/2h. To simplify, the weight of the stays is not included. The span range of the cable-stayed bridge is therefore determined by the capacity of the deck to resist this axial compressive force.

In its simplest form, the bi-stayed bridge (Fig. 2) is an extension of the cable-stayed bridge in that the entire mainspan is supported by stays. The cable-stays consist of both self-anchored and earth-anchored cables. The self-anchored stays (h1) are located in the sidespans of the bridge and are distributed over a nearly equal length (a1) away from the pylons in the mainspan. The earth-anchored stays (h2) are of greater length and anchor into the deck over the remainder of the mainspan (a2) at equal distances away from the centre keystone. The earth-anchored stays bend over the pylon tops and anchor into a separate anchor block located immediately beyond the extremity of the structure. These stays therefore cause no further compression in the bridge deck near the pylons. However, the balance of axial loads between the stays and the deck in the central part of the bridge (Fig. 3) creates a series of tensile forces such as T2 which accumulate to cause a total axial force of N2 (Fig. 4) starting at the keystone in the central span. The total axial force N in the deck of the mainspan created by the horizontal components of the earth-anchored stay forces consists of a compressive force N1 at the pylon and the tensile force N2 at the midspan. Assuming that the vertical loads are constant along the deck and neglecting any influence of the non-uniform weight of the stays, it can easily be found that if a1 = 0.7a so that a2 = 0.3a, the result is N1 = N2 = N/2. It is therefore possible, with the same material characteristics, to increase the length of the mainspan in a ratio of 1/0.7 or 1.4.



$$N = \frac{W a^2}{2 h}$$

Fig. 1 Generalized cable-stayed bridge schematic

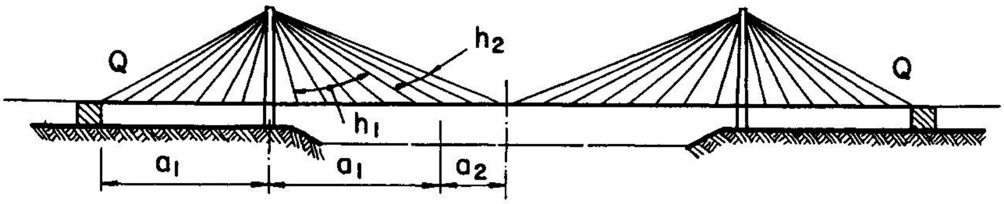


Fig. 2 Generalized bi-stayed bridge schematic

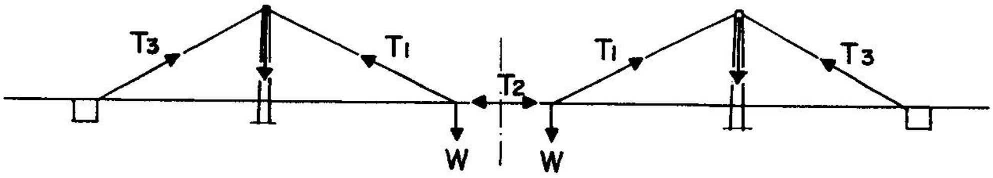


Fig. 3 Force distribution placing tension at midspan

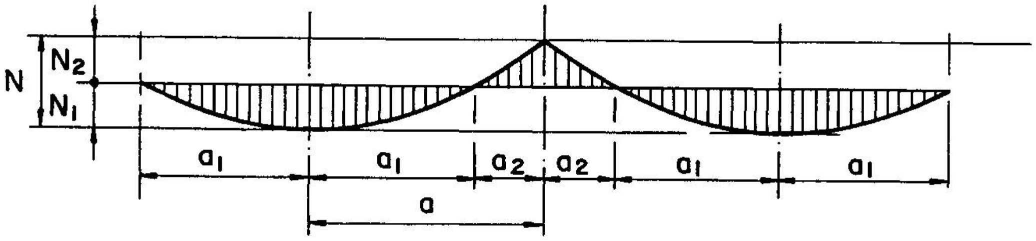
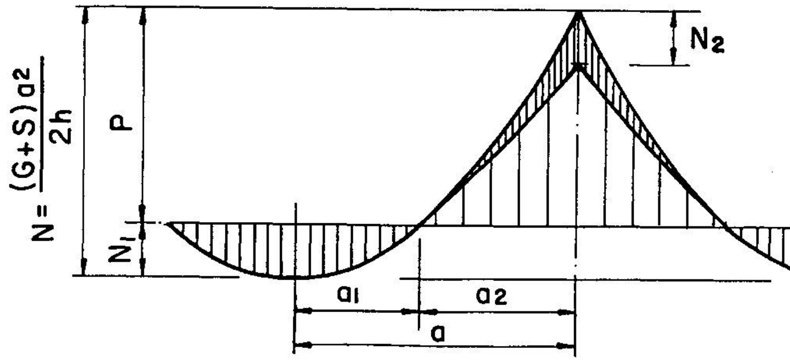


Fig. 4 Axial forces in deck without prestress



$$N_2 = P \frac{G}{G+S}$$

Fig. 5 Axial forces in deck with prestress

The mainspan length may be increased further using a second innovative device. In the bridge deck, the tensile force T2 can be compensated by an internal deck prestress so that when the deck bears all its loads (live loads included), the axial force at the keystone of the central span is zero. The maximum force at the keystone will therefore occur when the deck only bears its permanent loads and is compressive. In other words (Fig. 5), the resulting compressive force N2 under stay forces and internal prestress is only produced under permanent loads while the force N1 in the deck at the pylon is produced under all loads, including live load. In a long span bridge (over 1000m) the permanent loads G are 3 times greater than the live loads S, so that G = 3S or G + S = 4S.

From the diagram in Fig. 5, it is shown that the total reference force N now consists of N = N1+P, P being the prestress force calculated to balance the total load G+S = 4S. Therefore, the remaining force at the keystone in the mainspan is only N2 = P/4. The optimum equilibrium will be obtained when N1 = N2 = P/4 so that N = N1 + P = 5P/4 and N1=N/5. Theoretically, the maximum span of the bi-stayed bridge is $\sqrt{5}$ or 2.2 times that of a conventional cable-stayed bridge, thereby making it possible to attain span ranges comparable to those of suspension bridges.

3. STRUCTURAL BEHAVIOUR

The deformational behaviour of the bi-stayed bridge with a 1200-m mainspan is compared to that of a suspension bridge in Fig. 6. The design loads (rail and traffic) were placed in the most unfavorable locations for maximum displacement at midspan. In the suspension bridge, the midspan deflections were 10.6m and 6.1m for deck inertias of 10.0m4 and 20.0m4 respectively. For the bi-stayed bridge, the maximum displacement is only 2.1m with a deck inertia of 15.0m4 in the composite steel central region and 22.0m4 elsewhere. From these values and the deflected shapes shown in the figure, the rigidity of the bi-stayed bridge and its ability to transfer the loads efficiently to the stiffer backspan is evident.

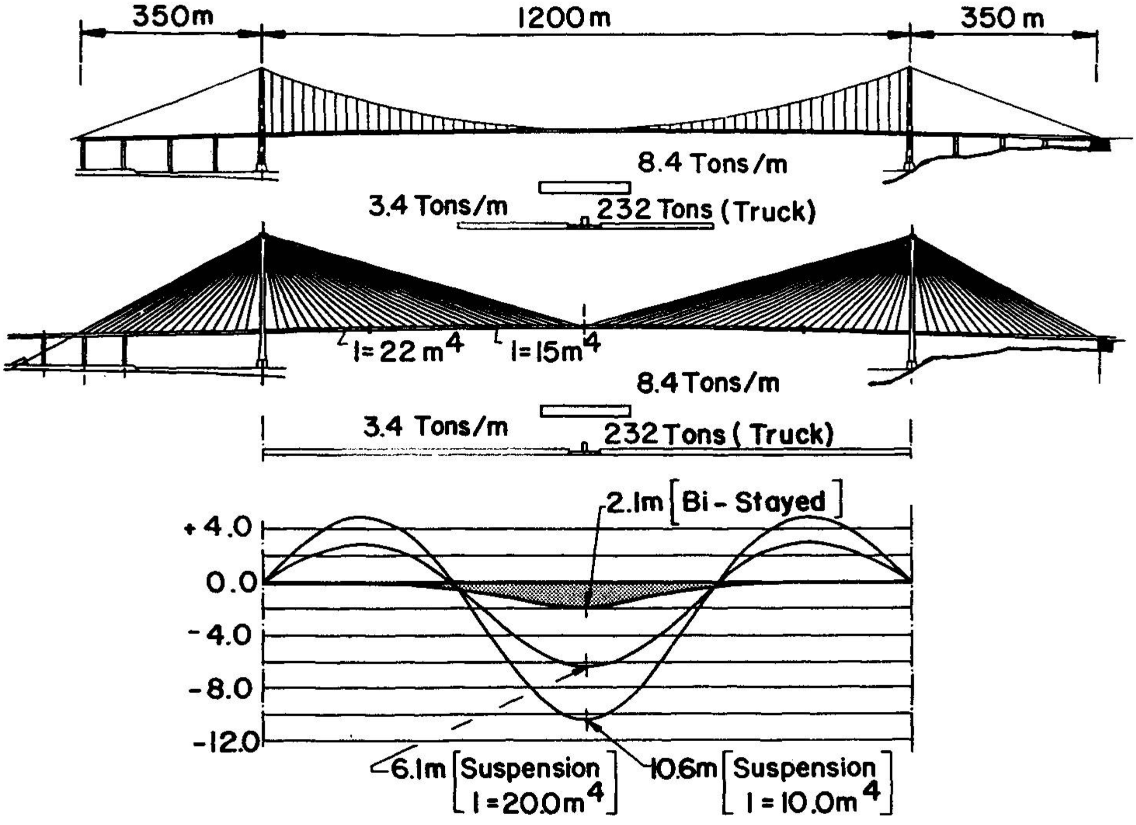


Fig. 6 Comparison of deformational characteristics

4. CONSTRUCTION

The construction methods required to build the bi-stayed bridge are conventional and use the same technology as that found to construct a cable-stayed bridge. These procedures are described with reference to Fig. 7. This schematic is that used to build the 1200-m bi-stayed bridge of Fig. 6. The foundations, pylons and anchor blocks are assumed to have been previously constructed. In this structure, the central 800m of bridge deck is steel composite and the remainder constructed of concrete. To minimise weight and therefore axial forces in the deck during construction, the top slab is placed on the composite section at the end of construction.

4.1. Self-Anchored Stays and Jack Installation

The bridge deck is built in balanced cantilever to a distance of 400m in the mainspan and 350m in the sidespan (Fig. 7.a). The number of self anchored stays on each side of the pylon are equal with an increase in stay spacing in the lighter composite section. The moments in the pylons remain balanced.

4.2. Earth-Anchored Stays

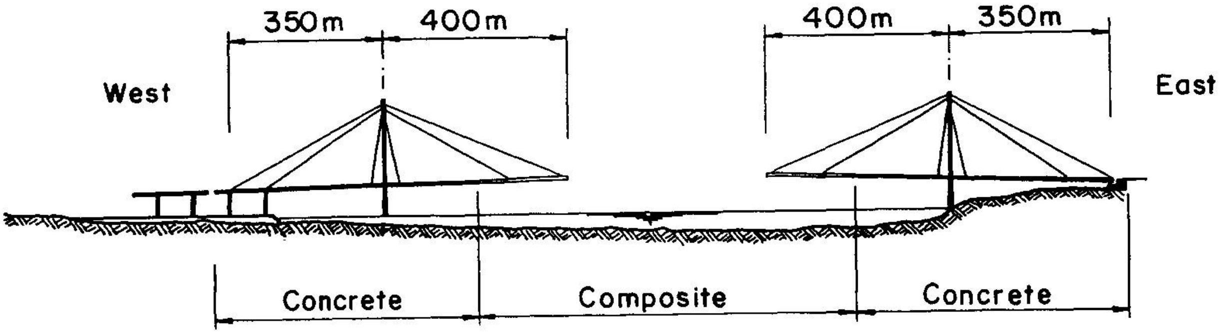
The concrete sidespan is now complete and the jacks are placed in the expansion joint between the anchor block and the superstructure (Fig. 7.b). On the west side, the force developed in the jacks is to be transferred to the foundation through the approach structure. The earth-anchored deck is built in cantilever away from the pylon in the mainspan until reaching the keystone at the centre. The stays supporting the deck are continuous over the saddle and anchored off the bridge into the earth anchorages. The horizontal axial forces induced on the deck are therefore resisted at the anchor block through the jacks by the equal and opposite horizontal force existing here from the same stays. The equilibrium of the system is always maintained as the reaction R is developed. It is shown in Fig. 8 for the bridge during construction that the maximum reaction on the jacks at this phase is 5920 tons and the maximum axial force in the deck at the pylon is 22270 tons.

4.3 Prestress and Finishing Works

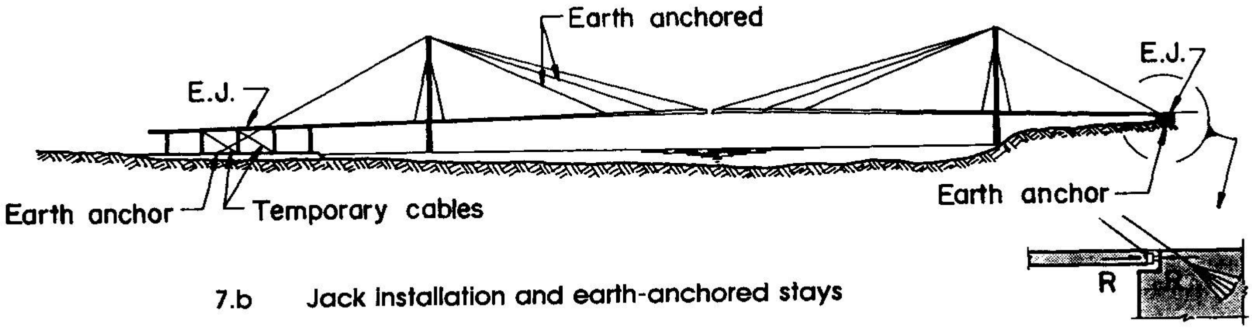
The post-tensioning is now stressed in the mainspan (Fig. 7.c) on the composite section. The jacks on either side are released simultaneously with the prestressing operation to control stresses. Because the compression is now greatly reduced in the deck at the pylon, the concrete top slab is cast onto the composite section. Finally, the jacks are removed from the expansion joints. The post-tensioning arrangement used results in the axial forces shown in Fig. 8 for the bridge in operation after all finishing works are complete. It is important to note that the deck compression of 19270 tons at the pylon is only 13 percent less than the maximum value during construction. At midspan, the tensile force of 26830 tons is that required by the post-tensioning to limit the axial stresses at midspan to zero under both dead and live loads. A precompression of 5570 tons therefore exists on the section here under dead loads only.

5. CONCLUSION

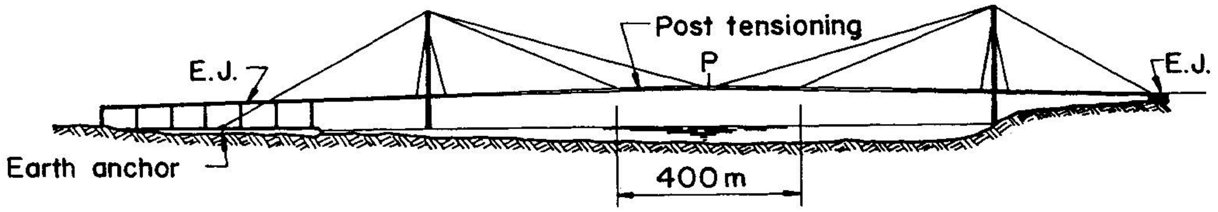
The bi-stayed bridge offers the engineer the span range of the suspension bridge with the long-span qualities of the cable-stayed bridge. Because both the construction methods and materials used are conventional, this new system will offer economic advantages as well.



7.a Self-anchored stays

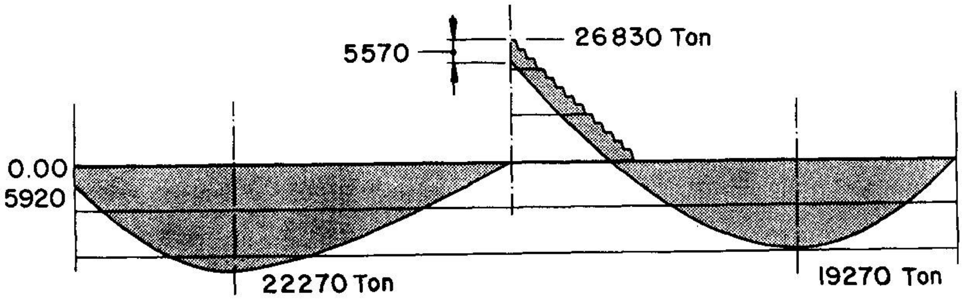


7.b Jack installation and earth-anchored stays



7.c Prestress and finishing works

Fig. 7 Construction schematic of bi-stayed bridge



BRIDGE DURING CONSTRUCTION
Deck axial load at closure

BRIDGE IN OPERATION
Deck axial load under dead load and post tensioning

Fig. 8 Axial forces in deck during construction