Long Span Structures for the Gibraltar Crossing

Structures à grandes portées pour le détroit de Gibraltar

Weitgespannte Tragwerke für die Strasse von Gibraltar

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SUMMARY
The paper summarizes the main results of an ongoing study regarding the technical feasibility of long span bridge superstructures for the Gibraltar Crossing. Different cable supported multi-span bridge systems and stiffening girder designs relevant for the crossing have been compared technically and economically. This includes evaluation of aerodynamic stability based on section model tests performed in wind tunnel.

RÉSUMÉ
L'article résume les résultats principaux de l'étude en cours relative à la faisabilité technique de superstructures de ponts de longue portée permettant la traversée du détroit de Gibraltar. Plusieurs systèmes de ponts à travées multiples suspendues et plusieurs conceptions de tablier rigide pour la traversée ont été étudiés sur le plan de l'économie et de la technique. Cette étude comprend une évaluation de la stabilité aérodynamique basée sur des essais sur modèle de section en soufflerie.

ZUSAMMENFASSUNG
Der Artikel fasst die Hauptresultate einer noch unbeendeten Studie über die technische Durchführbarkeit von Brücken grosser Spannweiten für die Strasse von Gibraltar zusammen. Verschiedene kabelgetragene Brückensysteme, alternative Formen des Versteifungsträgers sowie ihre aerodynamischen Eigenschaften an Sektionsmodellen im Windtunnel werden untersucht und getestet.

1. INTRODUCTION

The Spanish government agency SECEG, along with its Moroccan counterpart, SNED, was created in 1979 to launch studies with the purpose of establishing a fixed link between Europe and Africa across the Strait of Gibraltar. This agency has entrusted a group of engineering consultants and selected specialists lead by Carlos Fernandez Casado S.A. and Cowiconsult with a feasibility study for a long span bridge superstructure. This paper summarizes the main results of this ongoing study.

2. BRIDGE SITE AND TRAFFIC

The study comprises two options for the traffic conditions at the crossing. Either a 4 lane road bridge or a combined solution with a 4 lane road and a single track railway.

The most realistic bridge alignment is in the western part of the straits at a natural sill with maximum water depth of approx. 300 m. At this alignment the total length of the bridge will be 28 km. A shorter alternative alignment requiring a central bridge pier on a water depth of 450 m has also been considered.

Due to the very important water depths and problems regarding navigation, seismic activity and complex foundation conditions the economic optimum span length for the deep water section of the bridge is in the range of 2000-3000 m. For the shorter alternative alignment extreme spans of approx. 5000 m would be necessary.

3. STATICAL MAIN SYSTEMS

A number of statical main systems relevant for the actual span range considered have been studied and compared technically and economically (fig. 1).

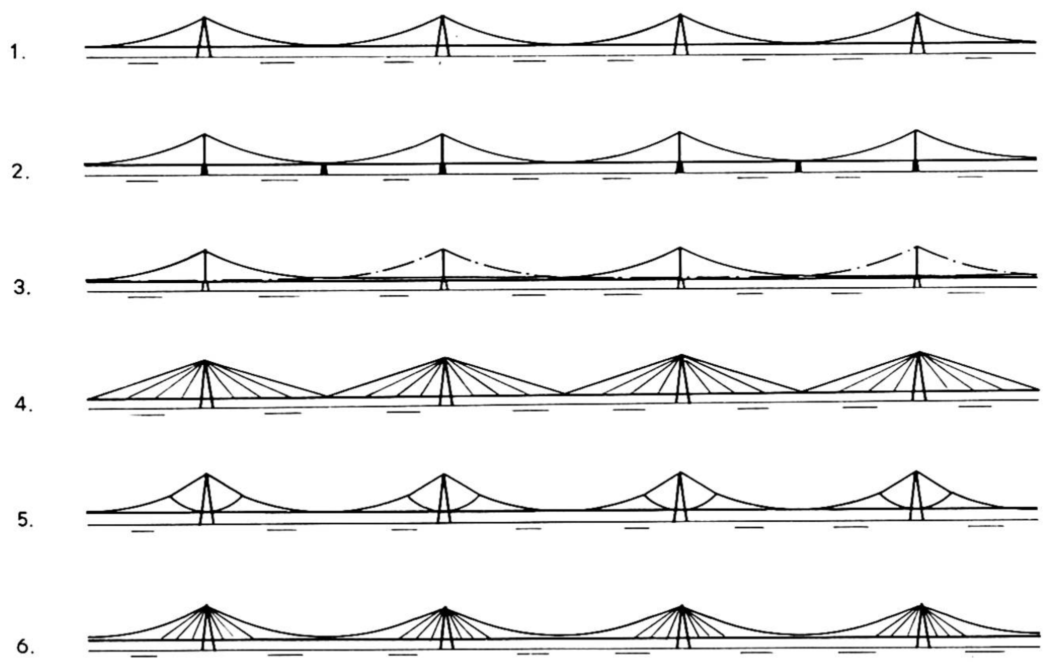

Fig. 1 Statical Main Systems

3.1 Multispan Suspension Bridge System With Rigid Pylons (system 1)

This system consists of a row of 1-span suspension bridges with expansion joints at the rigid (A shaped) pylons capable of transferring differential unbalanced cable forces with small deformations at the top of pylon. The main cables runs continuously through cable saddles on the pylon tops from anchor block to anchor block, i.e. over a distance of approx. 18 km.

3.2 3-span Suspension Bridges in Series (system 2)

This solution is composed of a number of classical suspension bridges - one main span and two symmetrical side spans - arranged in a row with common anchorage structures for neighbouring systems. The concept is known from the San Francisco Bay Bridge and latest from the Bisan Seto Bridge in Japan.

3.3 Multispan suspension Bridge System with Complementary Main Cables (system 3)

Like system no. 2 this solution is based on flexible plane frame pylons. Instead of the intermediate anchor blocks this system is stabilized by means of special double, overlapping main cables. Each cable running continuously over two spans is anchored at the pylon bases. This means that the piers shall be able to transfer unbalanced cable forces as for system no. 1, however, at the considerably lower pylon base level.

3.4 Cable stayed Bridges in Series (system 4)

This cable stayed bridge system is in principle composed as system no. 1 with expansion joints at the rigid (A-shaped) pylons, which requires that the girder acts as a tension element in the statical main system.

3.5 Multispan Suspension Bridge with Supplementary Stay Cables (system 5)

Combined system where the girder in the areas near the pylons are carried by stay cables to the extent that the girder can be utilized as a tension element without special strengthening. The remaining part of the girder is carried by the suspension bridge cables. This system acts as a variant of system 1.

3.6 Multispan Suspension Bridge System with Alternative Cable Arrangement (system 6)

By this special main cable arrangement the bridge span is divided into three load carrying sections by funicular cables. The toppoints of the funicular cables (= 'fictious saddle points') are suspended from high pylons by stay cables. The purpose by this arrangement is to achieve a stiffening of the main cable system by introducing "fixed nodes". Furthermore the length of the hangers near the pylons and thus the additional deflections of the girder due to hanger elongations are reduced.

3.7 Technical/Economical Comparison

The main conclusion of the comparison performed is that solution no. 1 and the related variant no. 5 can be considered as the most adequate. System no. 2 is approx. 10-15% more expensive as the savings for pylons and main piers cannot compensate the additional costs of the intermediate anchorages. Furthermore system no. 2 is more flexible due to the great sidespan - mainspan ratio of 0.5. This can of course be reduced such that system 1 and 2 are at the same level regarding stiffness, but in this case the differential cost will be increased. Accordingly system no. 3 will for comparable stiffness requirements be considerably more expensive than solution no. 1 among others due to the much greater amount of cable steel required. This difference is strongly increasing with the span length but already significant at 2000 m. Furthermore the erection and certain structural details for the interaction between main cables, girder and hangers are considerably more complicated and less clarified that for the two previously mentioned suspension bridge solutions. System no. 4 requires a smaller amount of cable steel that the other solutions. On the other hand a large additional amount of steel for the girder and higher pylons are necessary. Furthermore the girder cross section will be variable adapted to the variation of the great axial forces, which is a drawback for a rational industrial fabrication of girder elements and the erection procedure. System no. 6 implies a complicated joint connection at the 'fictious saddle points'. The achieved improved stiffness for this system compared to e.g. system no. 1 is evaluated not to justify the problems regarding the detailed design of the joint and the erection work as a suitable stiffening can be obtained by other means at a relatively lower cost.

4. STATICAL MAIN SYSTEM, ALTERNATIVE ALIGNMENT

For the before mentioned shorter alternative bridge alignment the topographical conditions naturally leads to a solution with two main spans of each approx. 5000 m and two side spans of each approx. 2000 m (fig. 2). Thereby the anchorages can be placed on the shores of the strait. In order to achieve a satisfactory stabilization of the system it is necessary to design the centre pylon with an A-shape while the two side pylons can be conventional plane frame structures.

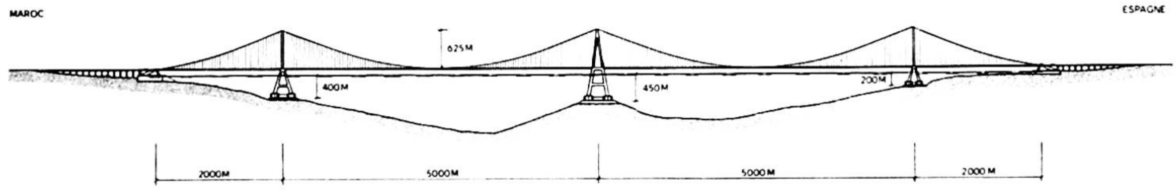

Fig. 2 Statical main system, alternative alignment

5. GIRDER DESIGNS

For bridges with very long free spans an essential aspect is to design the girder and suspension system so that sufficient safety against catastrophic oscillations due to wind induced effects is obtained. Sufficient stability can be achieved by using very heavy and stiff bridge girders, but aiming at reaching a more economical design various lighter girder designs representing different principles for obtaining aerodynamic stability have been investigated (fig. 3).

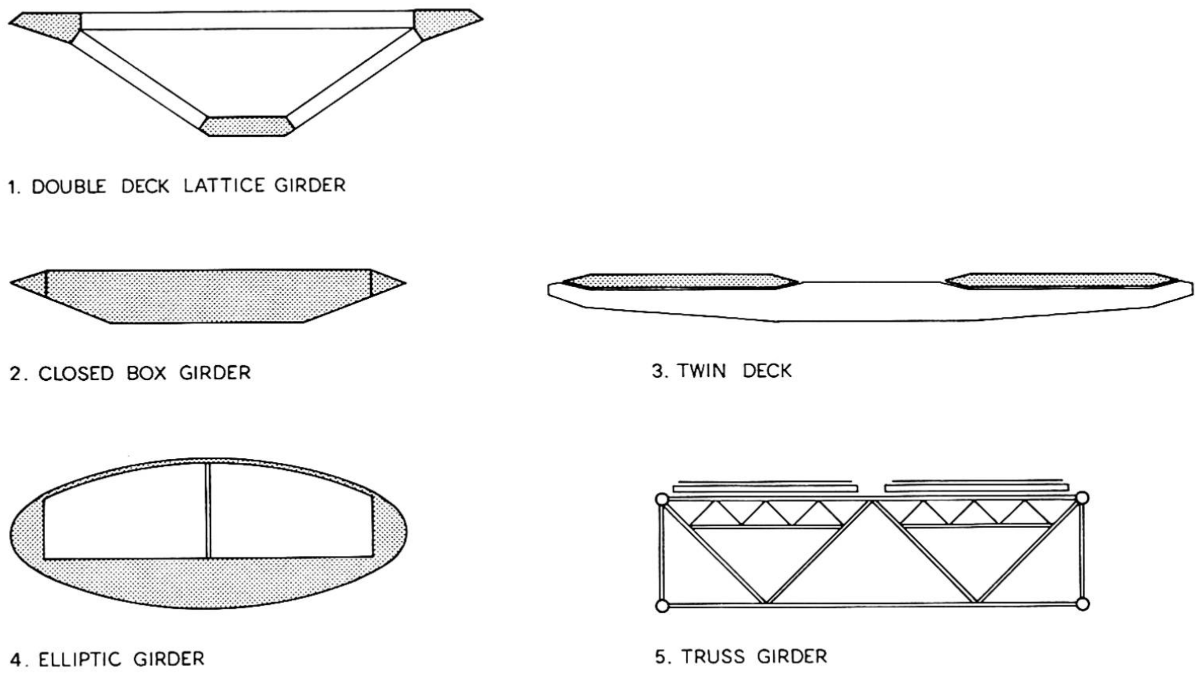

Fig. 3 Girder designs

5.1 Double Deck Lattice Girder

This is a 2-level torsional stiff lattice girder with a single track railway below and the road traffic on the upper ortotrophic deck. Furthermore a variant of this cross section with a longitudinal 2 m wide slot in the upper deck allowing the wind to pass freely through the central part of the deck surface has been considered.

5.2 Closed Box Girder

This closed aerodynamically shaped box girder type for a road bridge is well known from a number of existing great suspension bridges in Europe.

5.3 Twin Deck

The twin deck girder principle for a road bridge can, as shown on the figure, be designed with two relatively small box girders interconnected by a horizontal truss system and supported on cross beams at each hanger plane. Other variants of this solution as e.g. direct suspension of the two closed box girders in four main cables as well as alternative designs of the cross beams will be possible.

5.4 Elliptic Cross Section

The elliptic solution is a very interesting alternative among others regarding aerodynamic aspects and, furthermore, it provides a total protection of bridge traffic (an important quality for a 28 km long bridge 80 m above the sea surface).

5.5 Conventional Truss Girder

The truss girder proposed for a road bridge is mainly composed of steel tubes. Alternatively the cross section can be designed as a 2-level solution with the single track railway placed on the lower truss. The principle for this traditionally very stiff girder design is wellknown from USA and the latest great Japanese suspension bridge projects.

5.6 Aerodynamic Stability

Aerodynamic section model test in wind tunnel are planned to be made for girder types 1, 2, 4 and 5 with dynamic properties corresponding to the statical main system no. 1 (see chapter 3) and a free span of 2000 m. Tests have been performed for the double deck and the closed box girder. The main result for both cross sections is that observed critical wind speeds are lower than the required critical design wind speed. However, it has been observed as expected that a longitudinal slot in the upper deck of the double deck cross section tend to increase the critical wind speed. When the test results for the two remaining girder types are available it will be decided whether modified solutions shall be investigated experimentally. A possible improvement could be to make the cross section wider introducing a 5-6 m central longitudinal slot. The two parts of the deck must at the slot be interconnected by a stiff horizontal truss such that the torsional stiffness of the cross section is maintained. The added weight and greater width for this modification will in itself also tend to improve the stability. Another possibility to increase the critical wind speed for classical flutter will be to obtain a greater difference between the system eigenfrequencies for bending and torsion. This can in principle be achieved by an alternative design of the main cable arrangement as illustrated below (fig. 4).

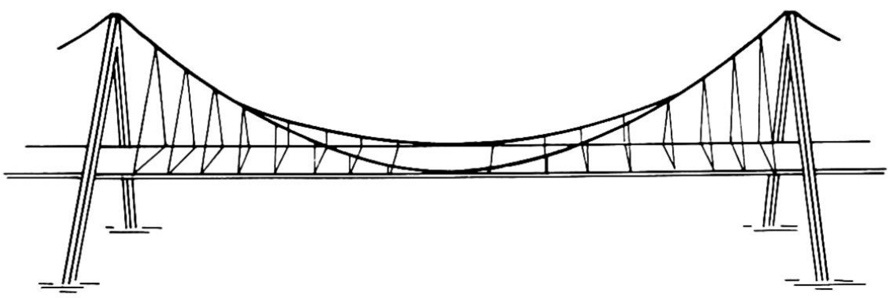

Fig. 4 Alternative main cable arrangement

6. PYLONS

For the actual span range between 2000 and 3000 m the pylons will reach a height of 300 to 400 m above sea level as a free navigation clearance of 70 m is required. Both solutions in concrete and steel have been investigated. Due to relatively great earthquake loads, concrete pylons have been considered less suited as their great weight generates large horizontal seismic forces, which among others makes the pier structures considerable more expensive. A design with big legs without cross beams built up by rings of steel tubes has been proposed for the actual project. Nevertheless other solutions are currently being proposed.

7. ERECTION OF MAIN CABLES

The erection of the main cables is an important aspect in the construction of the bridge types considered. The proposed erection principles are based on fabrication of parallel wire strands on the site at one of the anchorage structures and pulling the individual strands in one continuous operation over the entire bridge length to the opposite anchorage. Both pulling of strands and arrangement of these to form the final cable are known techniques which can be performed with suitable economy and safety. The advantages by this concept is especially that the operations with the cable material are performed close to the shore and that no unbalanced forces from cable erection are introduced on the pylons. The following erection of the stiffening girder can be performed in stages with a distribution of suspended girder elements in the invidividual spans corresponding to the capacity of the pylons to transfer unbalanced horizontal forces.