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Bridges with Multiple Cable-Stayed Spans

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Michel Virlogeux, born 1946, worked as civil servant in Tunisia (1970-1974) and then in France at the SETRA. Head of the large bridge division (1980-1994), he designed many bridges among which the Normandie Bridge and the Ré Island Bridge. Now Consulting engineer, he worked as consultant for the Portuguese Administration for the Vasco de Gama bridge.

Abstract

This paper is devoted to a very important development of cable-stayed bridges, bridges with multiple cable-stayed spans. Beginning with historical reference to pioneer bridges by Ricardo Morandi, it evokes the very few bridges built with several cable-stayed spans. It ends with the presentation of recent and important projects which evidence the possibilities of this new concept.

1. Historical background. The specific problem of multiple cable-stayed spans.

The first bridge with multiple cable-stayed spans is the Maracaibo Bridge, designed by Ricardo Morandi and completed in 1962, with six pylons and five main cable-stayed spans 235 metres long ; the pylons are extremely rigid, with an inverted V shape longitudinally and with an additional V to support the deck ; they are rigidly connected to a deck section cantilevering on both sides ; the bridge is completed with simply supported spans to close the bays between the different cantilevers tied to their pylons.

This concept is perfectly adapted to the specific problems of bridges with multiple cable-stayed spans : the pylons are extremely rigid and can directly balance the effects of live loads on either sides ; and with the drop-in spans between the cantilevers supported by the pylons, length variations produced by temperature variations and by concrete creep and shrinkage can freely develop. The single drawback of this solution is its high cost and weight.

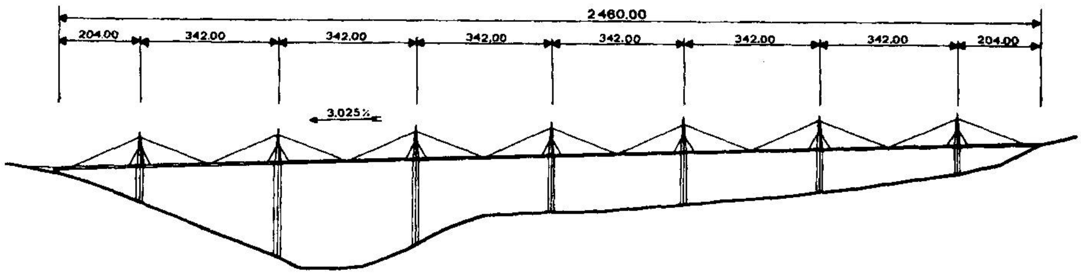
Several solutions others than Morandi's design could be developed, such as the use of head cables or of special cable-stays designed to fix (or tending to fix) the pylons. But, the best solution is the research of an adapted distribution of rigidities between deck , piers and pylons to resist bending forces and limit deflections. Length variations can develop freely if sliding bearings are installed on most of supports ; one line of bearings is enough if the deck is very rigid, but two lines are needed to take advantage of the rigidity of piers. In both cases, the excentricity of the reactions on the piers produced by the deck movements must be considered in the analyses. Another solution consists in designing piers made of two parallel flexible shafts which provide the desired bending rigidity, but which do not strongly oppose to longitudinal movements. A last solution consists in introducing an expansion joint in some spans, with a continuity beam to transfer bending forces through the joint.

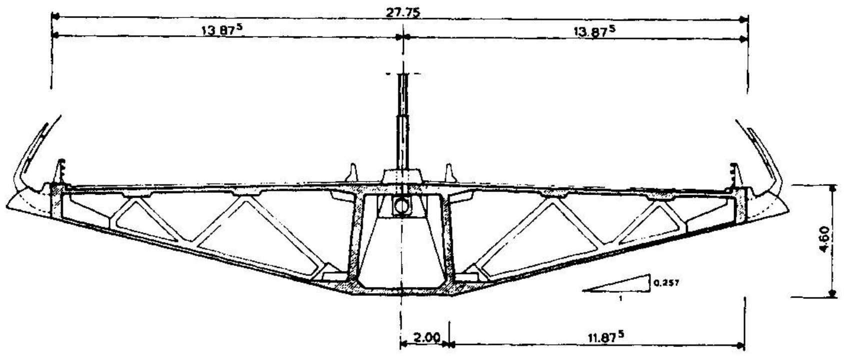
Though some bridges have been built with more than one central cable-stayed span - such as the Kwang-Fu Bridge in Taiwan, the Colindres Bridge and the Arena Viaduct in Spain and the Mezcala Bridge in Mexico - none really used these concepts, because most of them were limited to two central cable-stayed spans, with only one pylon without backstays.

2. New projects

The Pont de la Rade in Geneva, designed by Jean François Klein and Pierre Moia in 1993 - 1994, has four pylons and three central spans 350 metres long. It has a slightly curved alignment for the bridge elegance. The deck is extremely wide, 33.46 metres. Its design is specially elegant, balancing rigidity between a relatively slender deck (an elegant streamlined box-girder, 3.50 metres deep), and rather rigid piers and pylons. Length variations are permitted by the relatively limited distance between the central point and the extreme pylons, but also by soil conditions. Unfortunately the Geneva population voted against the project for financial reasons.

The Millau viaduct is even more ambitious ; almost 2.5 kilometres long, it comprises seven pylons and six central spans 342 metres long with two piers about 240 metres tall. The development of the project has been extremely complex, with an initial design by the SETRA between 1990 and 1993 and with two design competitions. The cable-stayed solution with multiple spans, developed from our conceptual design by SOGELERG - Europe Etudes Gecti - SERF and the British architect Sir Norman Foster, was selected in July, 1996, and the project has been completed in September, 1998.Two alternatives are proposed, the deck being either in prestressed concrete or in steel, with almost the same design adapted to the specific conditions





of multiple cable-stayed spans and to the extreme wind forces due to the high position of the bridge in the valley. The rigidity is distributed between the deck, piers and pylons. The deck is a trapezoidal box-girder, with a rather narrow bottom flange. The pylons, 90 metres tall, have the shape of inverted V for a very high rigidity. The design of piers is more complex, since the taller ones have to resist important forces due wind and second-order effects ; and the extreme ones - about 90 metres high - must adapt to very important length variations due to the bridge size ; this led to the final design of solid piers which divide into twin flexible shafts in the upper part, 90 metres high.

A last idea must be evoked to complete this overview : the total suspension concept. It adapts very well to multiple cable-stayed spans since it allows for free length variations without any interference with the rigidity of piers and pylons.

The conceptual design of the Rion-Antirion Bridge was developed by the Grands Travaux de Marseille following the Morandi's concept with drop-in spans between cantilevers. We suggested to have a continuous deck, totally suspended from the four pylons. The concept has been immedialely adopted with many advantages as compared to the initial design : continuity, a regular distribution of cable-stays in the spans to perfectly balance loads... Rigidity this time comes from the pylons, made of four legs with an inverted V-shape in both directions. The final project, now being detailed by GTM and Ingerop, has a continuous deck with five spans, 286 - 3 x 560 and 286 metres long ; and pylons are rigidly connected to the piers, a much more comfortable situation than installing a cantilever on sliding bearings and dampers to reduce seismic forces.