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Variety of Composite Bridge Construction

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Summary

The construction of composite bridges is rising and numerous publications give an outline of the success met by this type of bridge. Everywhere in the world but with developments differing according to the countries, innovations and improvements come up. Girder and truss bridges, arch and bowstring bridges and, of course, cable-stayed bridges, all types of bridges allow to benefit from the steel concrete composite technique to design high quality bridges, so much in terms of economy as of aesthetics and durability.

1. Introduction

For the last few years, the construction of composite bridges has known a growing success worldwide, with developments of course differing according to the countries.

This wide success can be explained by the improvements and innovations that occurred these last two decades in many industrialized countries.

Most often, they can be :
- either a progress in the use of materials, which characteristics have been improved (high resistance weldable steel, plates with variable thickness),
- either more daring designs, permitted by a better knowledge of structural mechanics (unstiffened webs),
- or improvements of techniques and construction methods, facilitated by the development of handling means and by the industrialization of the tools in the workshops.

The innovations are also due to the abilities of the composite structures to solve, with elegance, lightness and economy, problems that seemed unadapted to full concrete bridges or too expensive for steel bridges with an orthotropic slab.

Less spectacular innovations, although their importance will appear as the years go by, are related to the improvement of the execution, to the care in the design of the details, to the quality of the materials and, most of all, to the aesthetical quality of the bridges.

Presently, there is no doubt left that the innovations have first to be searched to increase the overall quality of the bridges : technical quality and durability, but also aesthetical quality and care of the environmental integration.

The future of the composite bridges is full of promises; beyond its numerous qualities (lightness, fast and secure realization, weak sensitivity to differential settlements), they have a henceforth major advantage, they are durable. The promises are even greater if the effort is made to design them in accordance with their specificity and not as bad copies of steel or concrete bridges.

The evolution of the calculation methods on a theoretic level (progress in the stability, torsion and fatigue domains) and the computer means allows to simplify the structure. The number of stabilizing elements, such as the stiffeners, cross beams and wind-bracings, decreases and they are sometimes even completely suppressed.

This tendency towards a greater simplicity is even reinforced by economical requirements. Facing the increasing costs of the manpower and the rather stagnant cost of the steel, the bridge builders add even more to this simplicity to decrease the working time.

The evolution of the knowledges, the calculation means and the manpower costs cannot explain by itself the totality of this change. Twenty or twenty-five years ago, the first criterion to choose a variant for a bridge, either a composite or prestressed concrete one, was its price; other criterions, such as durability or aesthetics, were often further relegated.

This order in the appreciation criterions has led to quite a few disappointments. Some bridges, after a few years only, had to be heavily repaired. Other ones, rather inaesthetical, have been severely criticized among the population. Therefore, the hierarchy of these criterions has evolved. Presently, we think that price, durability and aesthetics have the same importance.

2. The principles

The initial justification of the composite structure is the idea to use at best the own qualities of the materials :

- the concrete, for its good compressive strength and its low cost per volume unit,
- the steel, for its high tensile strength.

The typical example is obviously the cable-stayed bridge. We all know that the pylon and the deck of modern multi-hangers bridges are mainly compressed, along with weak bending moments, as the hangers are obviously only tense.

The cross-section of this same box-girder cable-stayed bridge with a central layer of hangers, shows steel inner tense struts and a concrete compressed box-girder. These are the leading principle for the WANDRE and BEN-AHIN bridges in Belgium, for the ELORN bridge in France...

The second justification, that explains the quality of the composite beam, comes from an economical analysis of the various constituents of the resistant structure of a bridge deck. The price of a full metallic bridge is burdened by the exorbitant cost of the orthotropic slab that, in spite of a very light weight, asks a very important working time.

On the other hand, in concrete bridges, the webs of the girders are usually too thick on a matter of resistance, as the minimal thickness is usually bounded to technologic requirements such as the presence of prestressing cables and the concreting operations.

The third justification is the possibility to use steel for its lightness in areas where the weight has a baleful influence and to place the concrete where the dead load of the structure, either has little influence, or is favorable to the stability. Numerous examples have been built on basis of this principle these last years, the CHEVIRE and DEL MILENARIO bridges and, of course, the most famous one, the NORMANDY cable-stayed bridge.

3. The deck slab

For more than 20 years, bridges have been built with composite girders, continuous on their bearings, where the concrete deck slab has to suffer from severe tensile stresses. The experience shows that these bridges behave very well as the tense slab is either prestressed enough or largely reinforced and, of course, as used is made of a high quality concrete.

Unfortunately, many of those continuous composite structures have insufficient reinforcement steel and know longevity problems, particularly in countries where de-icing salts are used. The problems related to the durability of the deck slab are similar to the ones of the full concrete bridges; they need a special care and a extremely compact concrete.

4. The bridges

The different kinds of bridges will reviewed about and, in each case, the large variety of solutions able to be brought by the composite construction will be pointed out.

4.1 Girder bridges

The last two decades have shown a wide simplification of the composite structures, for the full web girder and truss girder bridges.

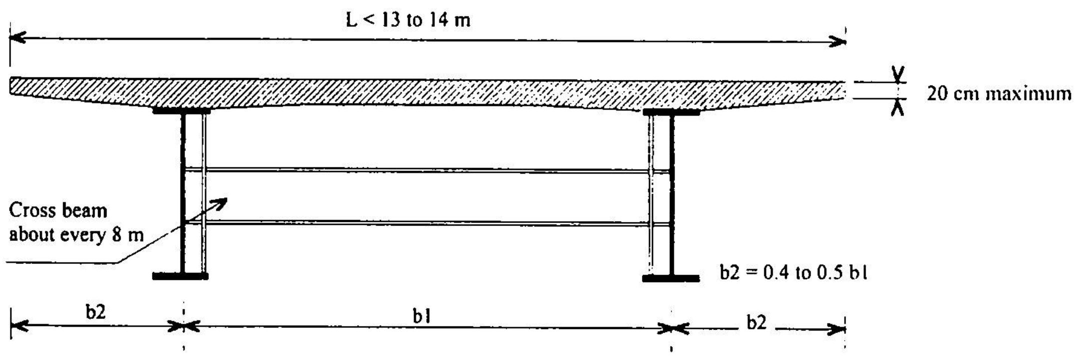

Fig. 1 Composite by-girder structure with cross beams

The traditional bridge (fig. 1) has two longitudinal girders, bounded to the concrete deck slab by shear connectors. A limited number of cross beams, welded to the vertical stiffeners, binds the main girders. This type of bridge can be used both for road and railway traffic and allows spans over 100 m.

For wide bridges, the present tendency is to keep as much as possible the by-girder system, either by transversal prestressing in the deck slab or by the use of more cross beams closer to each together and a cantilever external slab.

By-girder bridges with a lower deck can also be used for both road and railway traffic as this High-Speed Rail bridge in France or this magnificent small ROMANCHE bridge due to the engineer Tonello.

For spans no longer than 60 m, a even simpler design than the by-girder system is made of two small rectangular box-girders with no stiffener, no cross beam, no transverse member, but only a diaphragm at the bearings on pile. This solution, due to its simplicity and its small surface to be painted, is very economical to built and will also have low maintenance costs.

The comparison of the lengths of the lines of welding, the transversal butt joints and the surfaces to be painted easily shows the interest of this design. It is obvious that the most recent methods to check the stability of the plates have to be used to come up to such a simplicity. Some national regulations, as the Swiss and Belgian standards, allow the evolution of the calculation methods. Other ones, more conservative, do not allow it yet. The Bridges Eurocodes are indeed still to come.

As much as possible, the box girders with stiffened bottom are avoided for they are less economical. Their high torsional rigidity is an advantage, that makes them necessary as the plane curvature is high or for long spans.

Box-girder bridges allow to cross long spans. In Spain, the nice bridge of Professor Martinez-Calcon, with a 180 m long span, has been a world record. I don't think to be mistaken as I affirm that the CANORI bridge in Venezuela, designed by the Leonard office and later presented by Mr. Saul, holds the present word record with a 213 m long main span. Both these bridges have a bottom of box-girder that is metallic in the zone with positive bending moments and metallic strengthened with concrete in the zone with negative bending moments on bearings.

For many years, researches have been undertaken, on the one hand, by the designers of metallic bridges to get their bridges more economical and, on the other hand, to the concrete supporters to lighten their structures.

Original solutions have come up :

- the CHAROLLE and DOLE bridges, with pleated webs,
- bridges with tridimensional truss as in the Boulogne area in France or in Japan, with a maximal 119 m long span,
- the LULLY bridge in Switzerland, with a triangular truss made of cylindrical tubes.

Truss beams bearing a concrete deck slab constitute an elegant alternative to the classical by-girder system. Requiring higher beams but offering good transparency, these structures ask for exactness and much sobriety in the design of the details and connections.

As examples, the small CRUCHTEN bridge, built with higher elastic limit Histar steel and the new BLOIS bridge, with a truss of variable height, for which the lightness of the structure has unfortunately to suffer from a lack of delicacy in the design of the bearings.

The most beautiful and impressive examples of composite truss bridges are railway bridges. The most famous one is the NAUTENBACH bridge in Germany, with a 208 m long span. Others examples exist too in Austria. All these bridges will be presented during this session.

Another bridge, with shorter spans but very elegant, is the ARC bridge in France, presently under construction. The great Spanish engineer Torroja has already designed quite a few of these bridges...

Another particular truss bridge is the DREIROSEN bridge in Switzerland, with two roadway levels. This idea is more and more largely used, even for very long cable-stayed bridges.

4.2 Arch bridges

A transition can be made from the truss girder bridges to the arch bridges with two examples of original bridges :

- the ANTRENAS bridge in France, half arch, half spatial tubular truss,
- another bridge in Czech Republic, with a metallic tubular arch filled with concrete.

During these last two decades, the long arch bridges have been built in concrete, which seems quite normal for an mainly compressed structure. However, a few particular bridges with interesting characteristics show the composite structure as the solution of the future.

In Italy, a small steel-concrete composite arch bridge shows how easy can be the construction of this type of structure.

On a flattened concrete arch, to limit the stresses in the concrete, a light composite deck is launched. That is the ROCHE BERNARD bridge in France.

In Spain, several metallic arch bridges with a composite deck are really beautiful. The RICOBAYO bridge has to be pointed out.

In Belgium, an arch bridge with 270 m long span (fig. 2) has a particularly small height for the arch elements (1/100 of the span); this gives a very light and transparent structure. The use of thick plates and the small cross-section of the box-girders allow to avoid stiffeners and wind-bracing and, therefore, to realize an economical bridge.

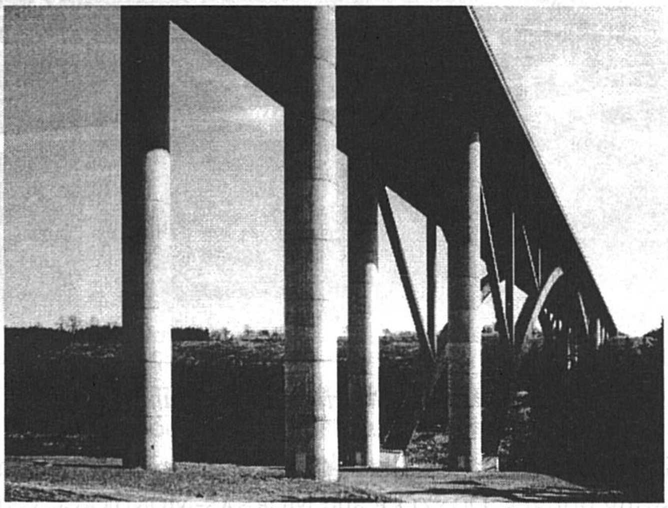

Fig. 2 EAU ROUGE viaduct in Belgium

We firmly believe that this type of arch, much lighter and less sensible to the quality of the foundation soil and to the seismic effects, has a real future towards similar concrete bridges.

The most marvelous examples come from China, which is the topic of another paper. During these last years, the Chinese engineers have built several arch bridges whose metallic tubes were filled with concrete. The longest one, word record with a 420 m long span, is the WANXIAN YANGTZE RIVER bridge, presently under construction. In this last case, the metallic tubular arched is coated with concrete.

4.3 Bowstring bridges

These bridges mainly comprise a compressed chord, the arch, and a tense chord, the deck. They allow numerous variants contravening to the base principles of the composite structures. Most often, the arch is metallic and the deck is either in concrete or steel-concrete composite.

An example of this kind of bridge with a prestressed concrete slab, the CHANXHE bridge, is under construction in Belgium. Another one is the RONQUOZ bridge in Switzerland.

A concrete arch showed unacceptable fissures, the prestressing of the tense deck was insufficient and the bearing outfits were too weak. The replacement of the concrete arch by a much lighter metallic arch was the solution to all these problems.

Bowstring bridges, with an approximately 150 m long span an a steel-concrete composite deck are very elegant solutions to cross a river or a canal, as the HERMALLE (fig. 3) and MILSAUCY bridges in Belgium.

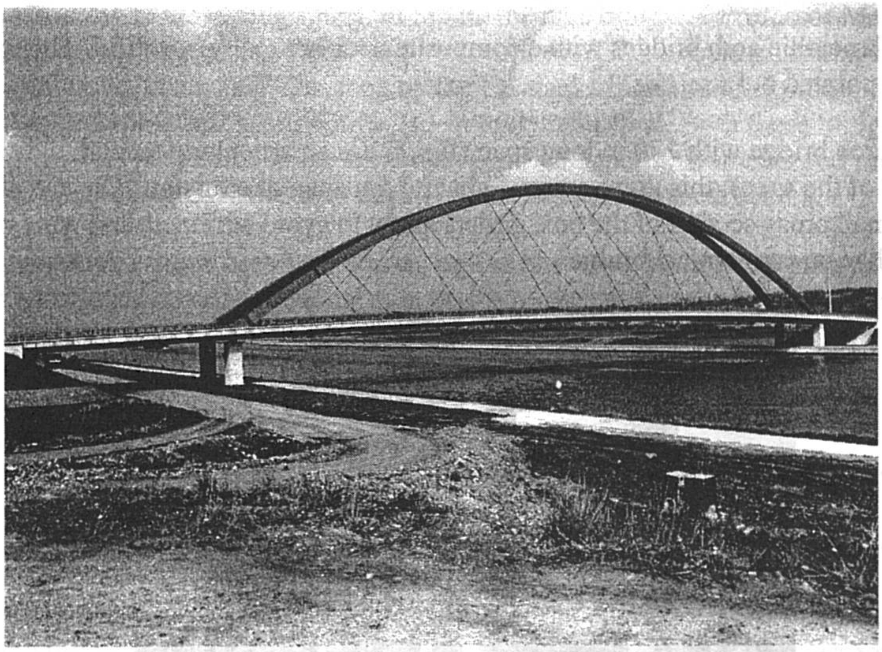

Fig. 3 HERMALLE bridge in Belgium

On the Mediterranean High Speed Rail track, the National French Railway Company is presently building composite bowstring bridges, DONZERE and MORNAS-MONDRAGON, particularly well adapted to the fatigue resistance and dynamic behavior requirements.

Once again, we have to point out the Chinese bridges with cylindrical tubular arches filled with concrete et spans up to 200 m.

4.4 Cable-stayed bridges

The cable-stayed bridges are without any doubt the most fashionable modern bridges at the present time. Here too, the composite structures are interesting, both in the overall design and to solve particular problems.

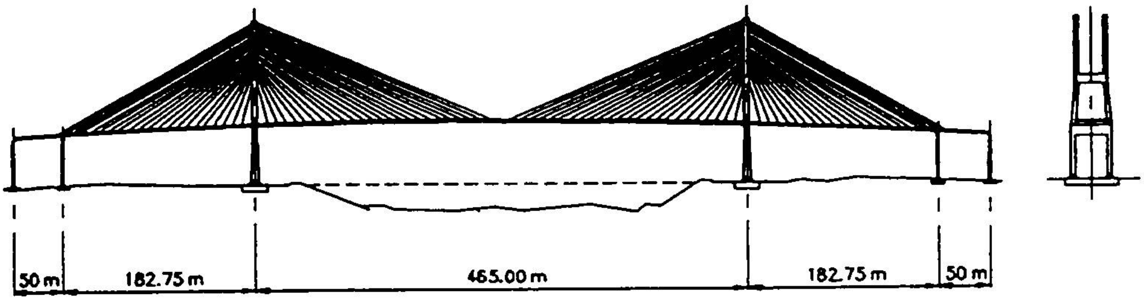

Fig.4 ANNACIS cable-stayed bridge in Canada

Perhaps is it useful to remind of the ANNACIS bridge in Canada (fig. 4), composite cable-stayed bridge with a 467 m span, absolute word record for cable-stayed bridges for many years. Presently, the YANGPU bridge in Shanghai (fig. 5) has a 603 m long span with a similar design, two longitudinal beams supported by two layers of stays et bounded together by cross beams bearing a reinforced concrete slab. The NORMANDY bridge, present world record for all categories cable-stayed bridges, is also a composite structure, as its central span is metallic and the balancing spans are made of prestressed concrete.

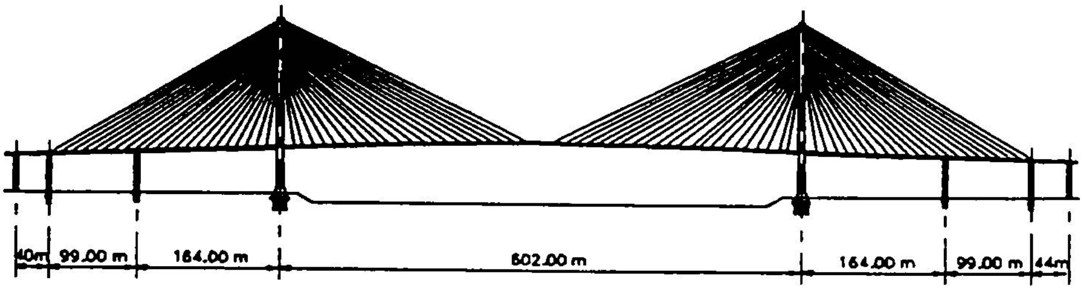

Fig.5 YANGPU cable-stayed bridge in Shangai

The metallic cable-stayed bridges, less expensive than the suspended ones, are now believed to reach 1500 m spans between pylons. The experience shows that the full metal deck with orthotropic slab is mainly dedicated to the very long spans. Up to 700 m or maybe even 800 m, the composite structures can be reasonably considered as the optimal solution.

The bridges built these last few years show the trend of those structures. The ANNACIS and SHANGAI bridges are typical examples : the classical "composite cable-stayed bridges". This denomination is usually understood as a cable-stayed structure with metallic beams and a concrete deck slab, as pointed out earlier. The objective is of course to use at best the best characteristics of each material.

The steel allow the prefabrication in workshop of small beam elements, quite light and very resistant, with precise dimensions and easy to assemble. This prefabrication occurs as the foundations and the pylons of the structure are built on site, which reduces the construction time towards other techniques.

On the other hand, those classical composite bridges rely, more the other full metal or full concrete decks, on the construction method.

Indeed, for a classical composite section, in a very simplified schema of longitudinal behavior, the shear forces and the bending moments are handled by the metallic beam and the concrete deck slab takes the big compressive forces due to the inclination of the stays. That is why the composite bridges built by the cantilever method are designed following the by-girder type with two layers of hangers.

In that case of two layers of hangers, the stays can be fixed either directly on the longitudinal beams, where the balance of the horizontal and vertical forces is realized, as for the ANNACIS and YANGPU bridges or on very rigid transversal beams that transmit the forces of the stays to the main beams, as for the new SEVERN bridge in England.

The construction of the deck on site has to be scheduled very precisely. The metallic beams are placed in balanced cantilever. For each beam element, a hanger has to be placed to bear it. The transversal elements, the cross beams, complete the metallic structure.

The construction of the deck slab, either in precast elements or concreted on site, will follow regularly the assembly of the metal and actually, as close as possible. Let us recall that the concrete slab handles the major part of the compressive forces in the deck. The slab has therefore imperiously to be efficiently connected as early as possible to the main beams, which, as said earlier, are bounded to the stays.

The most delicate things to be treated in this kind of structure are the following ones :

- the steel-concrete connection, of course,
- the anchorage of the stays and the transmission of the vertical forces to the deck slab,
- the effects of shrinkage and creep,
- the problems of wind stability of this composite deck with external girders, whose aerodynamic profile is not really good.

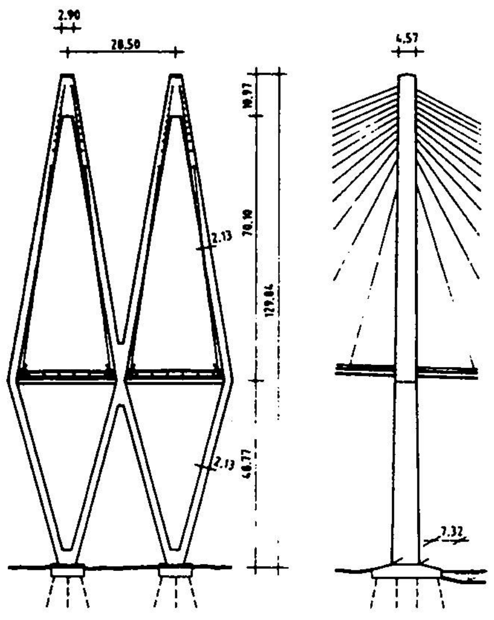

Fig.6 BAYTOWN bridge in the USA - Tower layout

The principles that I just described, the classical transversal cross-section and the construction method, have usually been used to the major existing bridges (listed below), with just a few small differences.

-	YANGPU	China	(1993)	602 m (world record)
-	XUPU	China	(1996)	590 m
-	ANNACIS	Canada	(1986)	465 m
-	HOOGHLY	India	(1993)	457 m
-	SECOND SEVERN	United Kingdom	(1996)	456 m

The BAYTOWN bridge in the United States of America (fig. 6) has the particularity to be constituted of two separate decks and two bounded pylons, which insures an obvious transversal stability.

Three bridges have to be pointed out, as they show noticeable differences towards the classical schema described earlier :

- the RAMA VIII bridge in Bangkok, with a single Y-inverted pylon, two layers of hangers and a wide composite girder-box,
- the KARNALI bridge in Nepal, with a 325 m long main span, a single pylon, two layers of hangers and a composite truss deck,
- the TING KAU bridge in Hong-Kong (fig. 7), with three pylons, two main spans, four layers of hangers, used for the suspension and for the stabilization of the central pylon.

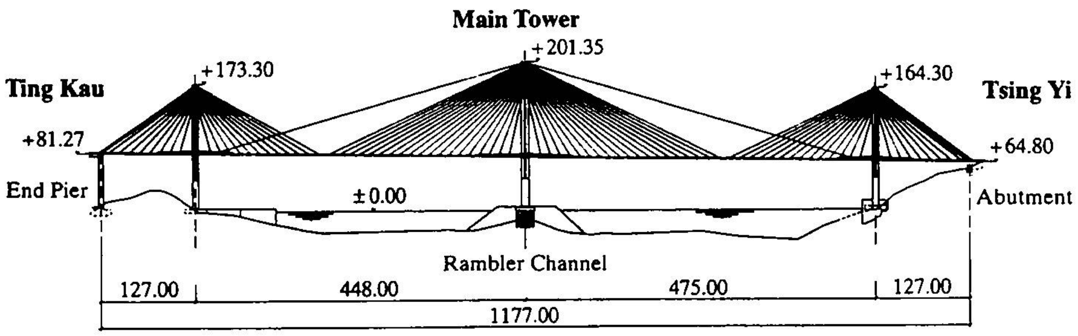

Fig. 7 TING KAU bridge in Hong Kong

The present tendency to use thinner and thinner transversal cross-sections, needing two or even four layers of hangers, comes from the following establishment : the bending solicitations in the deck are proportional to the proper rigidity of the deck if the multiple stays are regularly disposed on the length of the bridge. A direct consequence of the thinning down of the deck is obviously the decrease of the surface exposed to the wind.

However, the aerolastic stability requires a significant torsional rigidity as the span reaches 500 m, even with a double layer of hangers.

If, during these last years, a general tendency has led the designers to thin down the decks thanks to a better knowledge of their behavior, thick decks have to be designed to solve specific problems as for bridges for heavily loaded railway tracks or roadways on two levels. The thin decks are subject to deformations that are incompatible with the railway traffic requirements. That is why truss or high inertia box-girder decks are used.

That is the case for decks with two levels of traffic, as the new KAP SHUI MUN bridge in Hong Kong, the HIGASHI KOBE bridge in Japan and the new ORESUND bridge In Sweden, presently under construction.

The developments towards high performance, as well for steel as for concrete, will soon allow to build composite bridges with a main span probably over 800 m long. Anyway, it will still be necessary to adapt and to improve the aerodynamic characteristics of the decks.

Among those long bridges that impress us by their exceptional dimensions and the achievements that they required, the last ones show some originality. We believe that the composite construction offers a wide diversity of solutions, already pointed out in the last presented bridges. These are smaller bridges, not built with the cantilever method and therefore offering more liberty of design, as for example the SEYSELLE bridge in France, the SAINT-MAURICE bridge in Switzerland and several bridges in Finland.

Another bridge, soon to be built, the KORTRIJK bridge, shows that the combination of two materials can solve difficult problems with much elegance. This small bridge crossing a river in the middle of the town, needed a very thin deck for obvious reasons of navigation clearance and grade profile of the crossing road. Furthermore, for aesthetical reasons and cross-roads congestion problems, a single central layer of hangers was imperative, providing to solve the problem of the balancing stays of the pylon. This has been realized with this stand-shaped metallic pylon, restrained in the prestressed concrete deck.

The ALZETTE bridge in Luxembourg (fig. 8) is a symmetrical cable-stayed structure with a single central pylon and one layer of semi-radial hangers. An important characteristic is the horizontal curvature, rather uncommon for a cable-stayed bridge. The curvature, measured at the longitudinal axis, has a radius of 1750 m.

Fig.8 ALZETTE bridge in Luxembourg

The steel concrete composite deck is composed of two steel trapezoidal box girders with bracing frames and a reinforced concrete deck with a variable thickness. There are no longitudinal stiffener in the webs and in the bottom of the box-girder.

This composite deck, lighter than a concrete box-girder and more economical than an orthotropic slab, forced itself for the transversal solicitations on the pylon, due to the plane curvature, required a light structure.

Another very interesting curved cable-stayed bridge, the ARENA viaduct in Spain, has six pylons and seven cable-stayed spans.

Last example of a particular composite cable-stayed bridge, but it has not been realized. All the movable bridges were, up to not so long ago, metallic structures. However, some movable composite or even totally prestressed concrete bridges are built.

It is absolutely obvious that the extra-weight of a movable bridge has a direct financial impact on the mechanisms and in the electric power consumption. However, for long spans, the wind effects become preponderant in the design of the mechanisms, as well for the swing bridges as for the bascule bridges. That is why the importance of the various parameters of the economical balance of the project evolves and, more and more, the orthotropic slab will also give way to composite solutions with concrete deck slab.

Some interesting suspended bridges with a small main span have also to be pointed out. The deck, either composite or in concrete, combined to the metallic suspension cables, allows to build high quality economical bridges. Two example : the footbridge over the NECKAR river in Germany and the VRANOV LAKE bridge in Czech Republic (fig. 9).

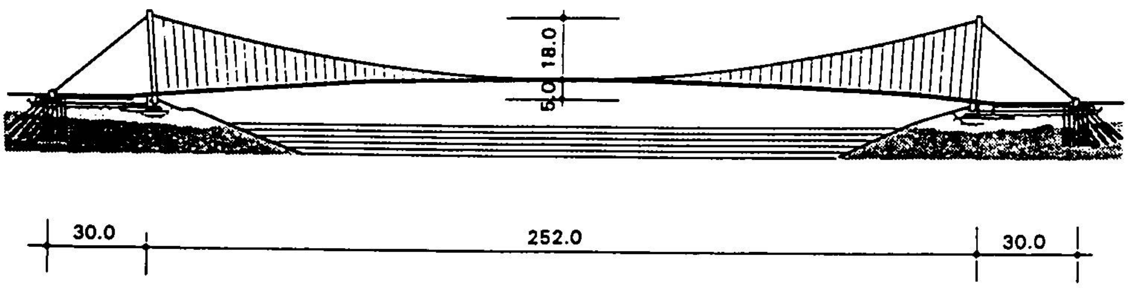

Fig.9 VRANOV LAKE bridge in Czech Republic

5. Conclusion

The impressive quantity and the variety of composite bridges having been built during the past two decades show enough how this kind of bridge has fine prospects before it.

With the increasing length of the spans, the steel continues to be the indispensable material, as the composite structures, in spite of some reticences, compete more and more the prestressed concrete bridges for medium and smaller spans.

These composite structures will be all the more competitive as the regulations will allow us to design simple structures, limiting or avoiding the expensive stiffeners.

We cannot forget that the composite construction requires from the engineer a good knowledge of both materials, without apriorism but with the constant care to question established ideas.

If, in addition, the engineer disposes of performing calculation means and if the regulations, too often retrograde, allow him to reap advantage of them, he will be able to design economical, efficient and high quality bridges.

The harmony of a composite construction is expressed at best with this footbridge in Japan, the INACHUS bridge (fig. 10).

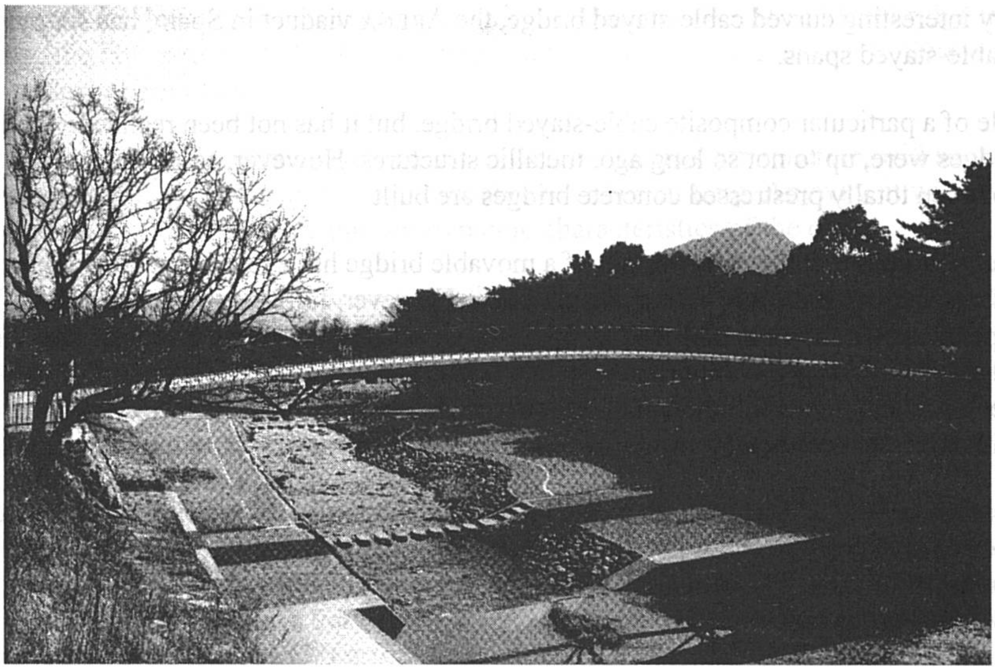

Fig.10 INACHUS footbridge in Japan

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