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Case Studies in Composite Bridges

Exemples de réalisation de ponts mixtes

Ausführungsbeispiele für Verbundbrücken

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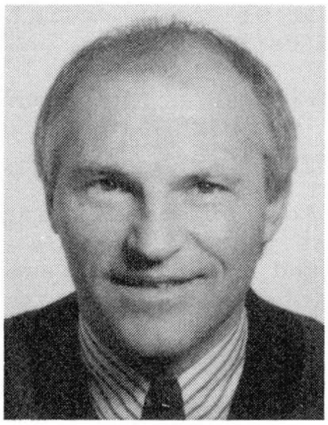

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SUMMARY

For large span bridges, the tendency, nowadays, is to use composite structures. Such structures permit taking advantage of both the lightweightness and the high strength of steel components and of the reduced cost of concrete slabs and concrete structural elements in compression. This lecture is based on the experience gained in the last twenty years by the author and his associates in connection with the design and erection of many bridges. It illustrates the wide range of use of composite structures or composite structural elements.

RÉSUMÉ

Les ponts mixtes représentent la tendance actuelle pour les ponts de grande portée. De telles structures permettent de combiner les avantages du moindre poids et de la haute résistance de l'acier avec les coûts réduits de dalles et d'éléments comprimés en béton. L'exposé reflète vingt ans d'expériences des ingénieurs responsables pour le projet et la construction de nombreux ponts. Il illustre les grandes possibilitiés d'application de la construction mixte.

ZUSAMMENFASSUNG

Für weitgespannte Brücken besteht heute die Tendenz, eine Verbundkonstruktion zu wählen. Sie vereint vorteilhaft das geringe Gewicht und die hohe Festigkeit der Stahlkomponenten mit dem günstigen Preis für Platten und Drucktragglieder aus Beton. Der Vortrag reflektiert zwanzig Jahre Erfahrung der verantwortlichen Ingenieure im Entwurf und in der Konstruktion vieler Brücken. Er beleuchtet die Breite der Anwendungsmöglichkeiten von Verbundtragwerken und -trag-elementen.

I. INTRODUCTION

In the previous lecture, Mr. LEBET presented a survey of the types of composite bridges and commented on the evolution of their design. He focused mainly on the classical types of composite bridges: the two- or multi-webs continuous girders, and stressed the fact that composite construction was also used for cable-stayed bridges and even truss bridges.

In the field of bridge construction, there is indeed a wide range for the use of composite structures or composite structural elements. I would like therefore to extend Mr. LEBET's survey on composite bridges, while restricting my talk to problems of design and erection, to which the engineers are faced in the daily practice.

This lecture is aimed at reflecting the experience got for the last twenty years by the engineers of the Design Office GREISCH at the occasion of the design and erection of many bridges.

It is obvious to me that, for large span bridges, the tendency is, nowadays, to use composite structures. Such structures allow for taking advantage of both the lightweightness and the high strength of steel components and of the reduced cost of concrete slabs and compressed concrete structural elements.

A. ARTIFICIAL COMPOSITE BRIDGES

For long, use has been made of reinforced concrete deck slabs in steel bridges. Actually these were ARTIFICIAL COMPOSITE BRIDGES; they constitute indeed self supporting steel girders on which a composite deck, made of a concrete slab and a steel grid, is laid down (fig. 1). So are :
- Most of the suspension bridges with a stiffening truss ;
- Large truss bridges ;
- Even the cable-stayed bridge built at Stromsund (Sweden, 1955),that is considered as the first modern cable-stayed bridge.

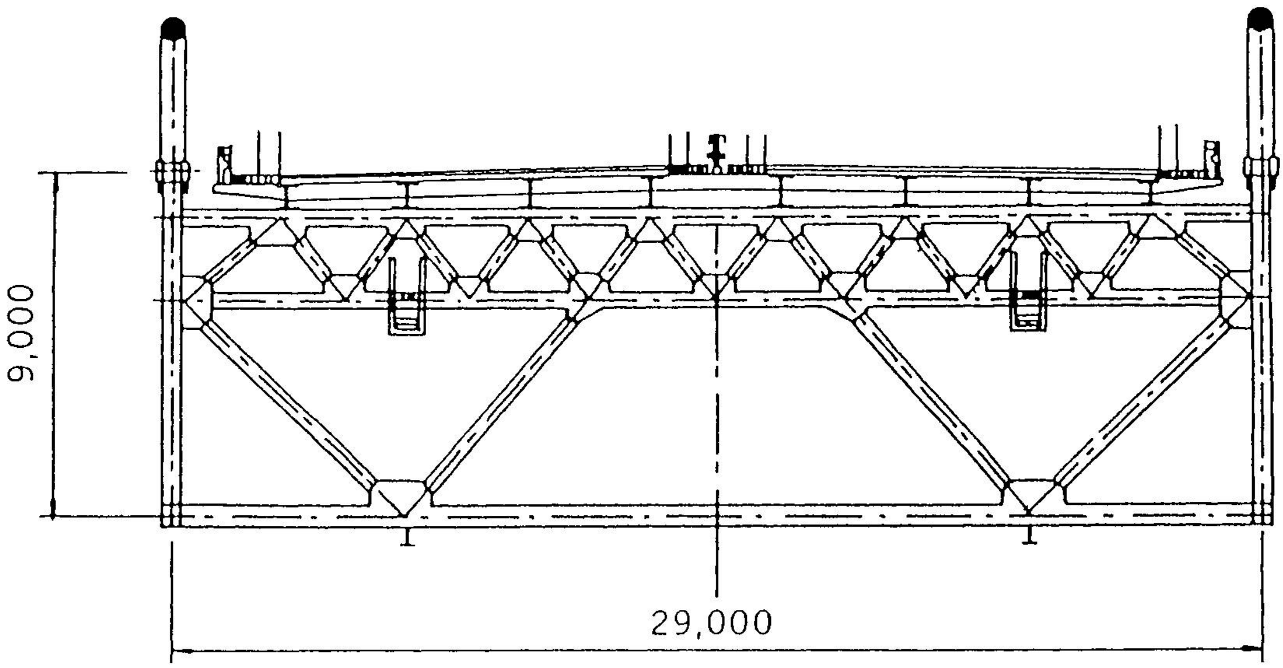


Fig.1 Typical cross section

LARGE SPAN BRIDGES where the main span is made of steel while the adjacent spans are in concrete belong to the artificial composite bridges too. In this respect, let us mention the following bridges :
- the cable-stayed bridge in Tampico (Mexico) ;
- the bridge in Cheviré (France), presently in erection, where the total span is 262 m with a steel box girder to overpass the 160 m long central span ;
- and, of course, the already famous cable-stayed Normandy bridge, which is aimed at becoming a world record (fig. 2).

Also this category should include concrete structures fitted with steel ties, such as the tied-arch bridges and the cable-stayed bridges, which will be reviewed later.

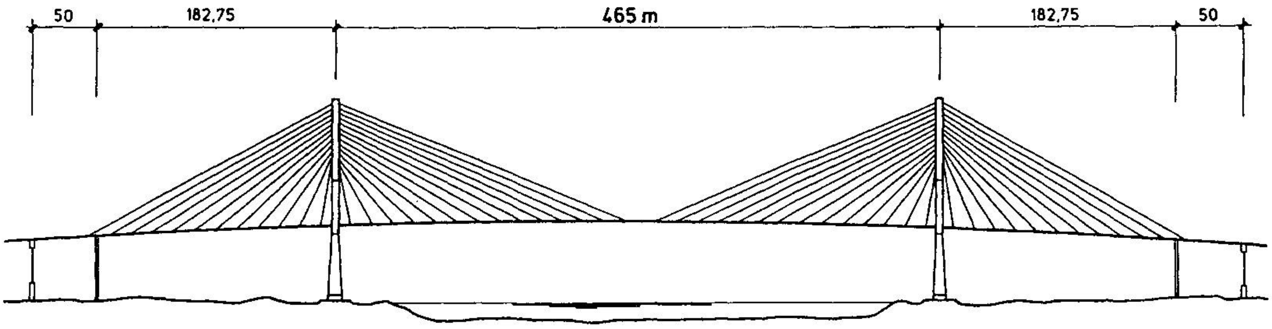


Fig.2 Normandy Bridge, France

B. ARCHES.

ARCHES are especially worthwhile being examined. The world record for arch bridges is presently the New River Bridge in the States; it is a steel truss structure with a span of 518 m. For concrete arches, the largest span is 400m at the famous Krk bridge in Yougoslavia. Two arch bridges, which are amongst the 12 largest arches in the world, are being built :

a) The bridge over the Rance river in France (fig. 3), with a span of 261 m. It is a concrete arch with a composite deck; this choice for the deck structural system has been governed by the sake for a rather light weight, required as a result of the shallow shape of the arch.

b) The "Viaduc de l'Eau Rouge" in Belgium has a span of 270 m (fig.4). It is composed of a steel arch and a composite deck, thus providing appreciable savings in weight and reduced support reactions on the foundation ground, which has not an especially good bearing capacity (fig. 5).

For other types of bridges, especially for cable-stayed bridges, clear tendancies can be observed regarding the choice of materials.
In contrast, for arch bridges, I am of the opinion that both materials - steel and concrete - and almost composite construction can be equally successful.
- The use of a concrete arch is nearly obvious at the structural point of view, because of its large compressive resistance when self-supporting. Such an arch is however very heavy and the erection procedure is therefore necessarily costly.
- A steel arch needs less powerful erection facilities; there is a tendency to build box shaped arches and to use unstiffened or lightly stiffened thick plates. Such a structural solution provides savings in manpower and cost.

My feeling is that large span composite arch bridges should develop in a near future. A similar attempt has already been made in Japan; the central portion of the arch is a steel truss, which is embedded in concrete for the adjacent portions (fig. 6).

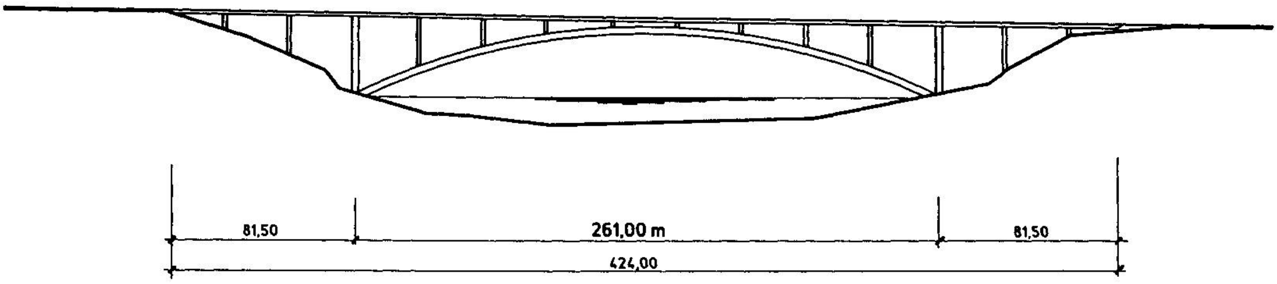


Fig.3 Rance Bridge, France

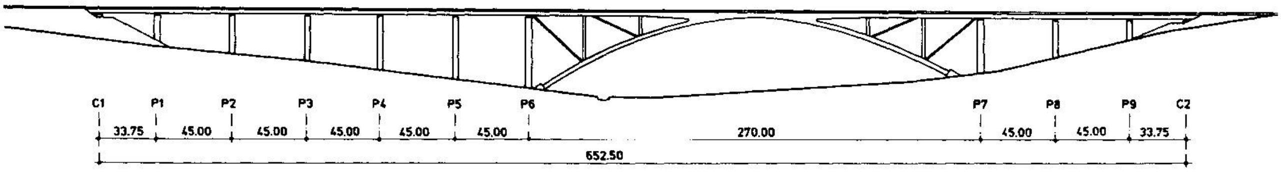


Fig.4 Eau Rouge Viaduct, view

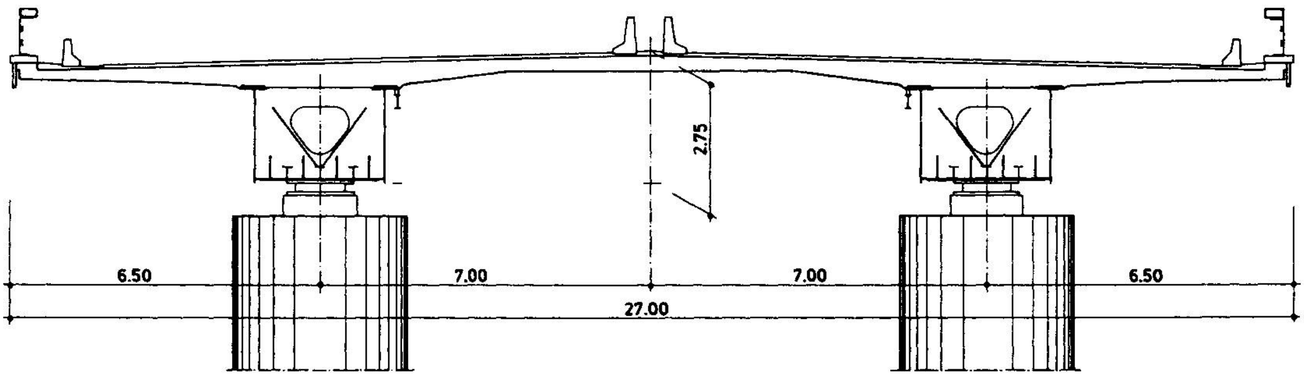


Fig.5 Eau Rouge Viaduct, cross section

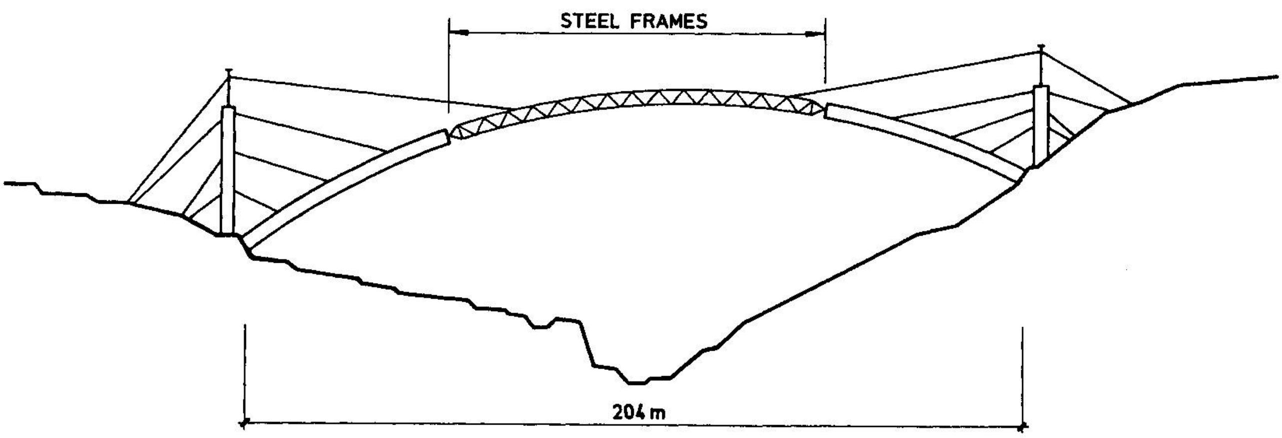


Fig.6 Bridge in Japan

C. DEFINITION.

Faced to all these types of bridges, the question may arise: when can a bridge be termed as composite - i.e. steel + concrete - bridge. In this respect, I believe that following criteria have to be fulfilled, at least for classical types of bridges :

- The cross-section of the bridge involves both materials ; steel and concrete. Such a criterion leads to exclude the Normandy Bridge from the structures under review.
- Each of the two materials contributes significantly the carrying capacity of the structure. That leads to exclude the large suspension bridges having a composite deck.
- The steel part of the structure is either fabricated by welding or bolted. Therefore cable-stayed bridges or tied-arch bridges with only the stays or suspenders in steel are also excluded.
- Each of the two materials contribute the total cost in similar proportions; that is in fact a result of above criteria.

D. EVOLVING.

Another question that may arise is : how do the bridges evolve towards composite structural construction ?
Many steel bridges have been built using plate or box steel girders and an orthotropic steel deck plate. Because such a deck requires very much manpower and because the cost of manpower is still increasing, such a type of deck is especially expensive. Under the pressure of competing civil engineering companies, a concrete slab has been progressively substituted for the orthotropic steel deck plate, while connecting this slab to the steel girders in order to get a composite action in bending.
Builders of concrete bridges also evolve towards composite bridges, especially when the available depth, as the result of the required clearance or traffic opening, is too small for concrete girders.

Sometimes pecularities of the erection site requires that the structure to be built has a limited weight, wherefrom the procedure consisting in using light steel girders on which a concrete slab is casted in situ and connected to the girders by means of shear connectors.

It also happens that the composite structure is simply the cheapest as it has resulted especially in France all along the last years when building classical bridges of medium span.

The sake of a decrease in the dead weight of concrete bridges has led to the use of composite construction. The webs of prestressed concrete bridges have been replaced by steel webs. Professor de MIRANDA built such kinds of bridges in Italy more than 20 years ago. In Belgium, the bridge in ADEGEM with a main span of 135 m is an example of this design concept. Also French research carried out for the last 10 years demonstrated how much appropriate are solutions where steel webs are either stiffened of unstiffened plates, steel trusses or corrugated steel sheets.

The bridge in MAUPRE for instance combines corrugated steel webs with a filled concrete circular tube as lower flange.

II. CLASSICAL COMPOSITE BRIDGES.

Now I should like to present you somewhat more in details the composite bridges which have been designed by our design office and for which we have also to care for the erection procedure .
I 'l try to stress all the problems which arose and which were likely to guide us in the choice of the definitive structural solution. This choice was influenced by design rules in forces, of course, but also by considerations linked to fabrication and erection processes.

For sake of objectivity, I 'l also stress the regrets we still have; indeed these bridges were not actually perfect !

These bridges may be classified as follows :
a) classical continuous girders ;
b) tied-arch bridges ;
c) cable-stayed bridges ;
d) last, structures which are not easy to classify in one of above categories.

Let us first examine the continuous girders. I fully agree with Mr. LEBET for what regards the evolution of composite bridges built in Switzerland. A similar evolution has been observed in Belgium, though some large span bridges diverge somewhat from above presented principles.

A. CONTINUOUS GIRDERS.

a. Viaduct of Secheval (fig. 7).

The total length is 300 m with imposed equal spans of 72 m; twin-deck of 18,6 m width each.
Order received from a steel workshop.
At that time - i.e. in 1975 - very few composite continuous girders do exist worldwide, except in Switzerland, that appears thus as a precursor country.

The question of tensile stresses in the concrete slab on the internal supports was a subject of controversy. Some codes and standards specified strictly the allowable tensile stresses in the concrete. In Belgium, more especially, the allowable tensile stress was specified as 25 kg/cm^2 (250 N/cm^2) in service conditions. The most economical structural system was, to our opinion, a system with two steel girders and cross-beams every 3.6 m (fig. 8); the concrete slab was connected to girders and cross-beams by means of shear connectors. An important descend of the supports - more than 3 m at the intermediate supports - was used in order to limit the longitudinal tensile stresses; this procedure has been rather costly. The steel structure was erected using the launching procedure (fig. 9); sliding bearings were located beneath the web transverse stiffeners because the resistance to patch loading of slender webs was still assessed according to methods presenting large scatters.
The concrete slab was casted in situ first in the zones of positive bending moments and completed by concreting afterwards the areas above the internal supports. This concreting sequence was aimed at reducing the amplitude of tensile stresses in the slab.
Use was made of porecast floor slabs for the side cantilevers and of a formwork shifted by means of a movable transverse gantry under the cross-beams (fig. 10).

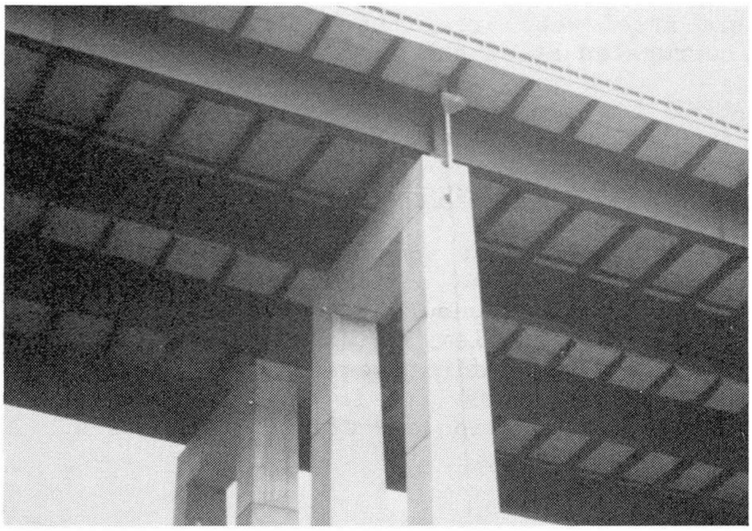


Fig.7

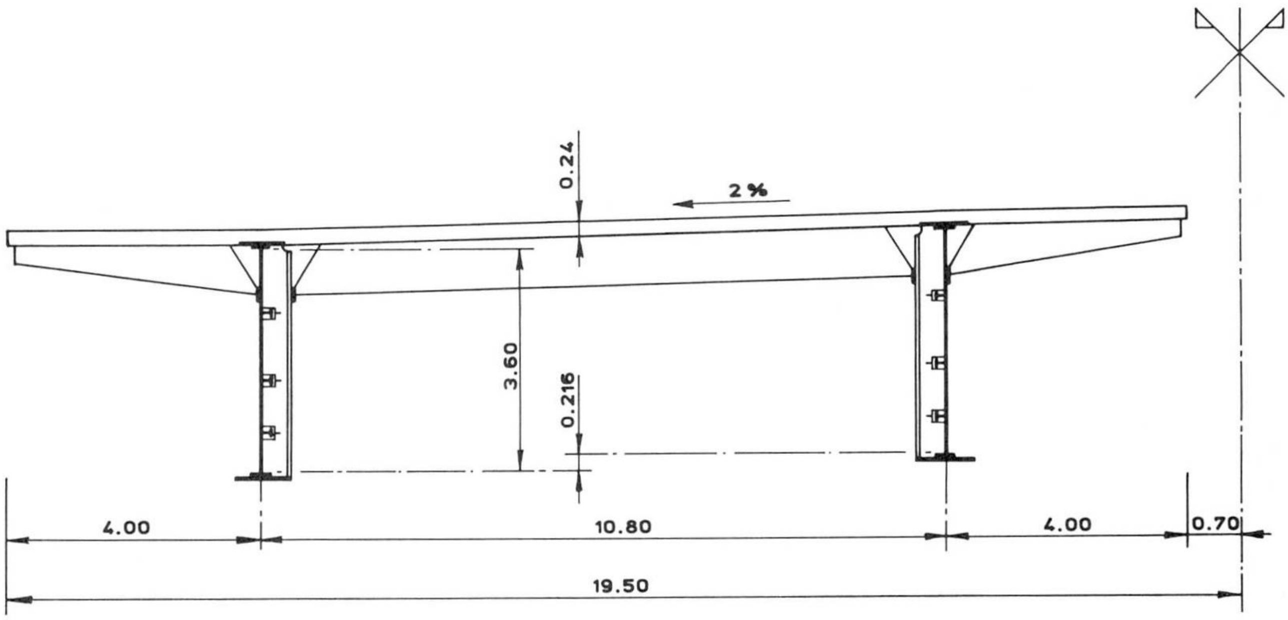


Fig.8 Secheval Viaduct

Fig.9

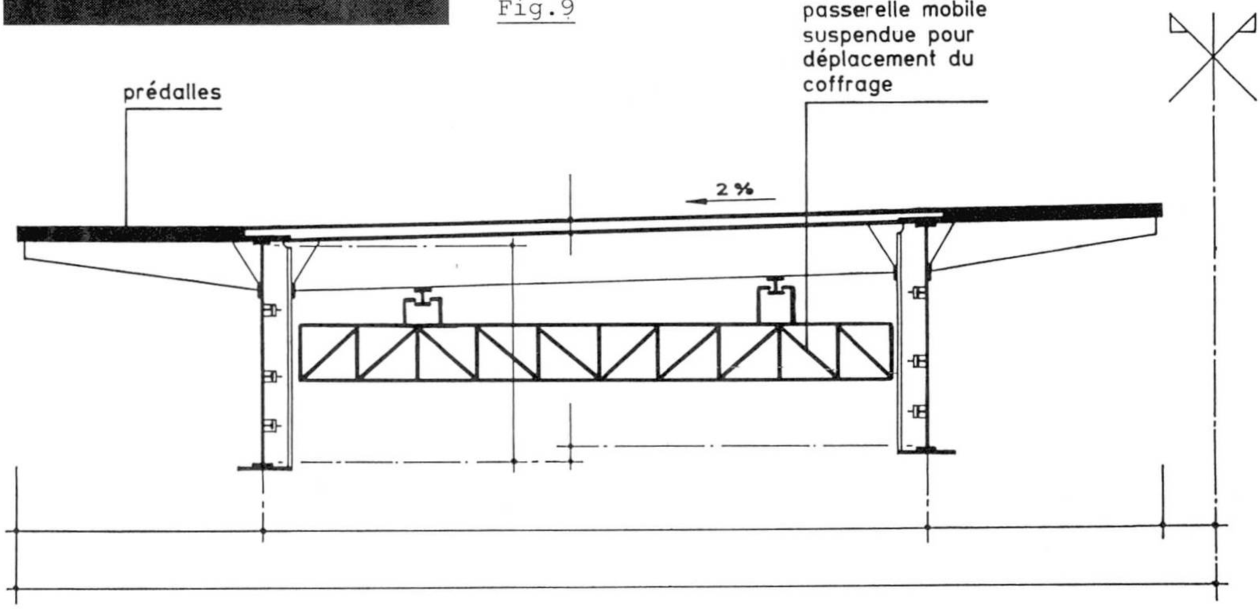


Fig.10 Secheval Viaduct

b. **Viaduct of Remouchamps** (fig. 11).

This viaduct is about 1 km long with a radius of in-plane curvature amounting 1 km. The largest spans are 117 m long; the width of the deck is 27 m and the use of a single deck was required by the owner. The design was ordered by a steel workshop, which wanted to avoid box girder sections. One of the main problems has been the torsion of the structure in service conditions and during the erection stages; torsion resulted from the large width of the deck, the in-plane curvature and the behaviour of the deck plate, the lifting of the girder portions and the concreting sequence. A conclusion drawn from the Secheval viaduct was that cross-beams were not useful at all; indeed, using cross-beams leads, in the regions close to intermediate supports, to biaxial tensile stress state, that is very determimental for the integrity of concrete material. An advice requested from DUBAS, professor at ETH Zürich, helped us in the critical analysis of the structural system and led us to agree with the design concepts used in Switzerland in this respect. In the Remouchamps Viaduct, the concrete slab has a variable thickness and is longitudinally supported on the main girders and on the secondary girders (fig. 12); it bents transversely when subject to superimposed point loads or concentrated loads. The slab is still tensiled in the longitudinal direction in the region of intermediate supports; a large amount of rebars were introduced with a view to limit the crack opening. For sake of limiting the tensile stresses in the transverse direction, the side longitudinal secondary beams are supported on inclined struts by means of neoprene bearing devices. The behaviour at the manner of a box shaped section was rendered possible because continuous horizontal bracings were located in the planes of the upper and lower flanges respectively (fig. 13).
The cantilevering erection method was used with a crane located at the end of the cantilever to lift up the girder sections.
The concrete slab was casted in situ, first in the main span using special movable formworks, which were operated from the top of the slab; then the cantilevers were casted using a classical formwork device (fig. 14).

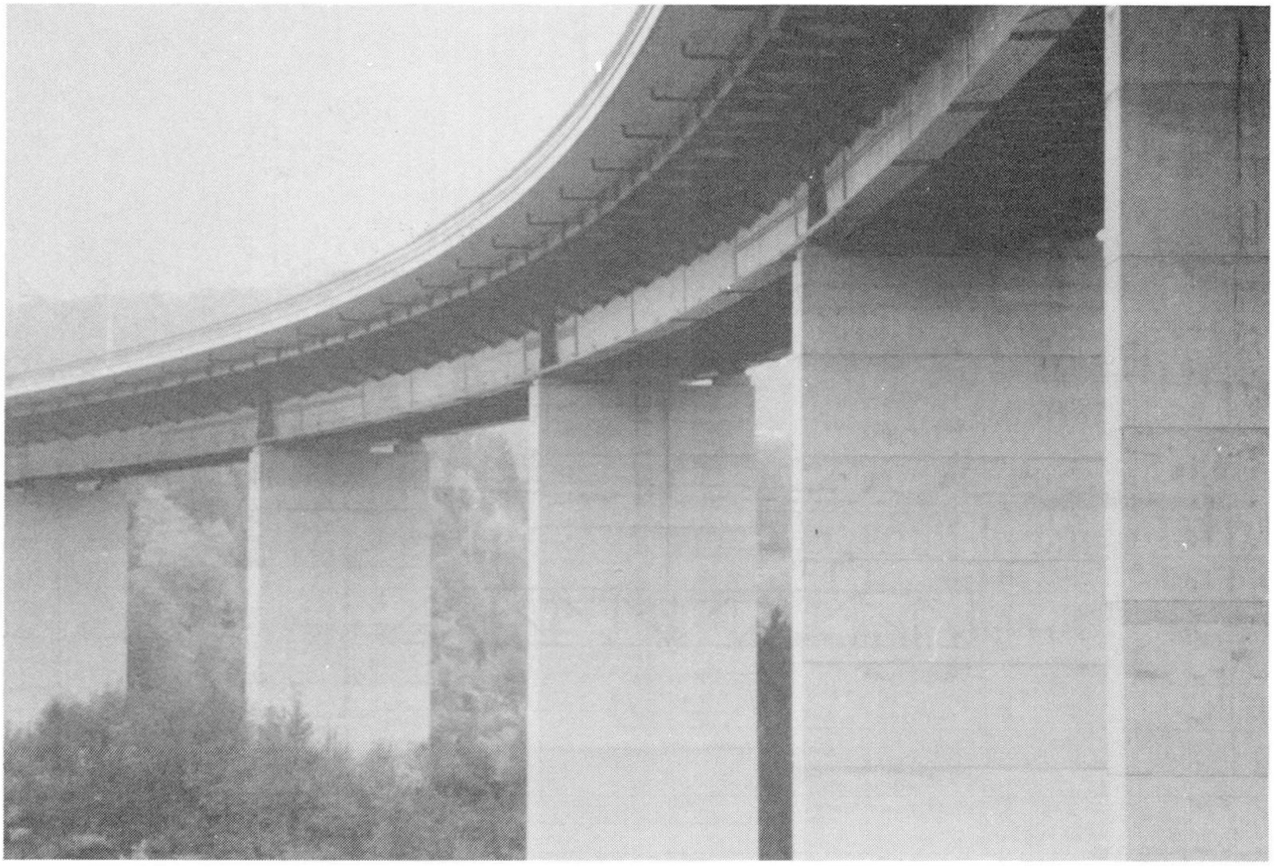


Fig.11

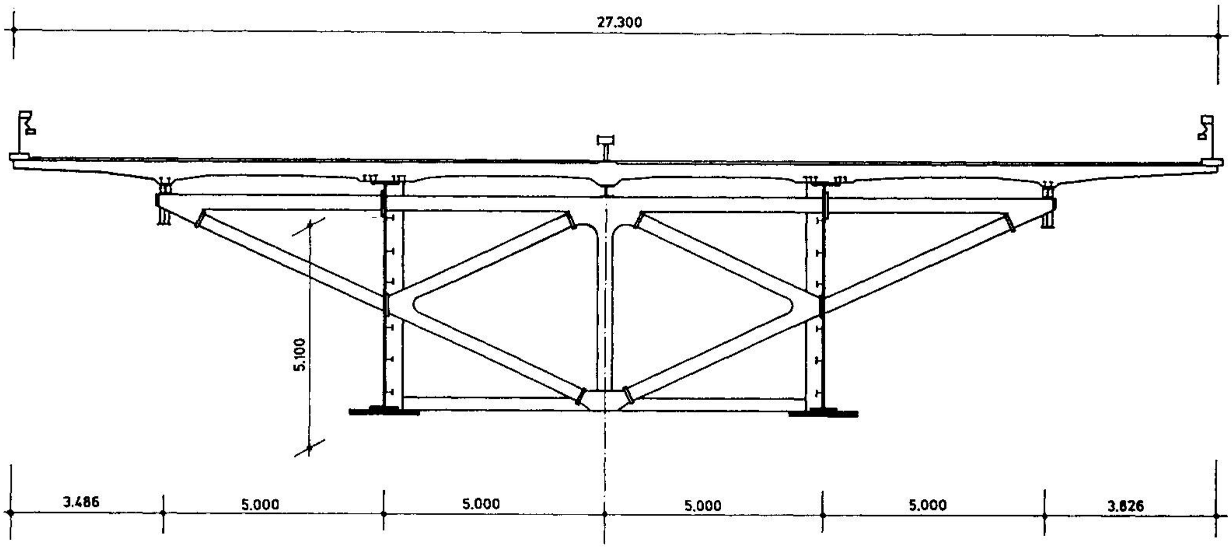


Fig.12 Remouchamps Viaduct

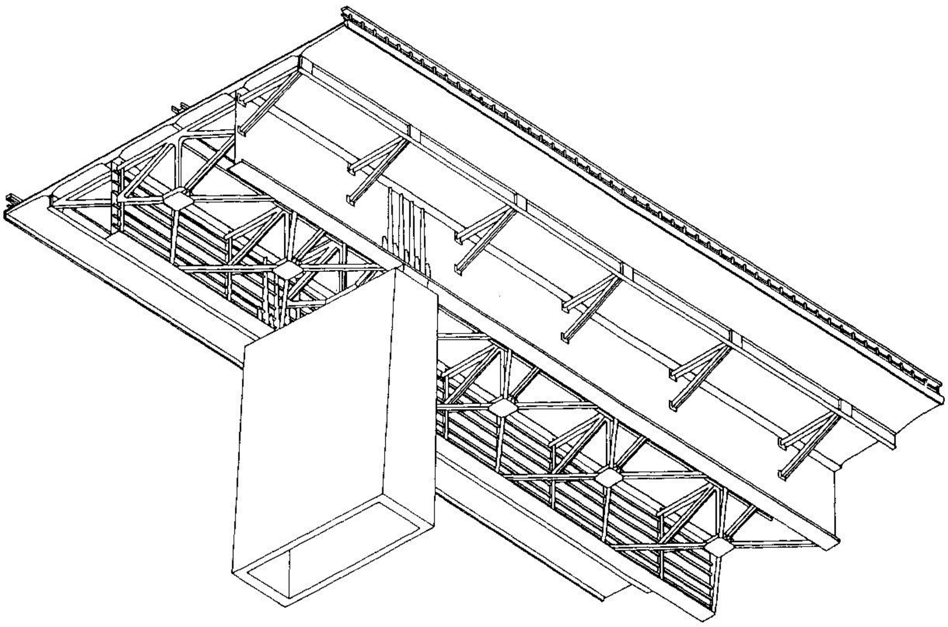


Fig.13 Remouchamps Viaduct

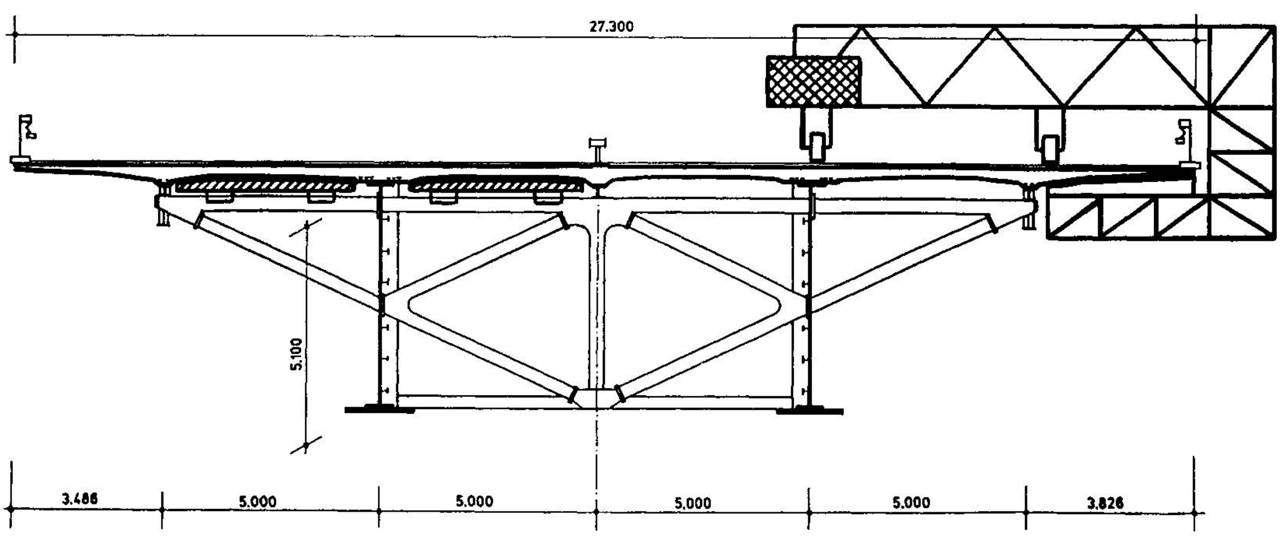


Fig.14 Remouchamps Viaduct

c. **Viaduct of Polleur.**

The largest span is about 120 m long ; the width is 32 m. It is a straight bridge in plane (fig. 15).
The design was again ordered by the steel workshop and conducted simultaneously with the design of the Remouchamps Viaduct.
Therefore considerations regarding the behaviour of the slab are similar.
The owner - the Ministery of Public Works - did not allow a bridge with two main girders and a single deck was imposed in addition. Because of the straightness and the large width, a single box girder was designed despite the bottom flange required an important stiffening.
The cantilevering erection procedure was used with a crane to lift the box portions located at the end of the cantilever.
The concrete slab was casted as for the Remouchamps Viaduct. Here, however a larger thickness was required because of the length of the side cantilevers; in order to reduce the bending moments, the slab was made of reinforced lightweight concrete. Transverse prestressing should probably have been more appropriate but this proposal was rejected by the owner.

The two last large span bridges do not belong to the category, the evolution of which was reviewed by Mr. LEBET.

When bridges of medium span are examined in the same respect, it can be concluded that the design concepts have changed in Belgium and in France, in the same way as they did in Switzerland.

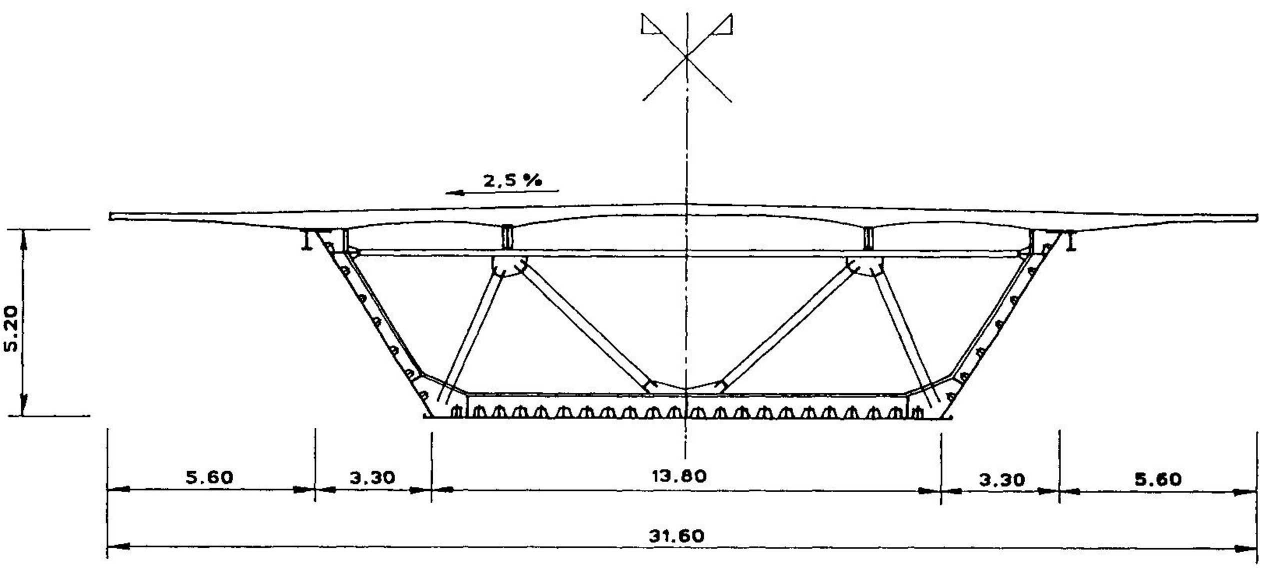


Fig.15 Polleur Viaduct

d. **Layrac bridge** (fig. 16).

The bridge in Layrac (France) is à classical continuous composite structure with two main girders; the width is 9 m and the largest span is 69 m. The steel webs are not longitudinally stiffened; the spacing of the cross-beams is 6 to 7 m. That is the most suitable example of composite bridges, which are very economical and can be fabricated as series in French workshops. This bridge was launched with afterwards bearing drops of 1 m in order to minimize the steel quantities. The concrete slab was casted in situ using a classical movable formwork. The magnitude of the bearing drop - i.e. about 1 m - requires only a simple and cheap appearance. In addition, this procedure is prone to reduce appreciably the magnitude of the tensile stresses in the concrete slab.

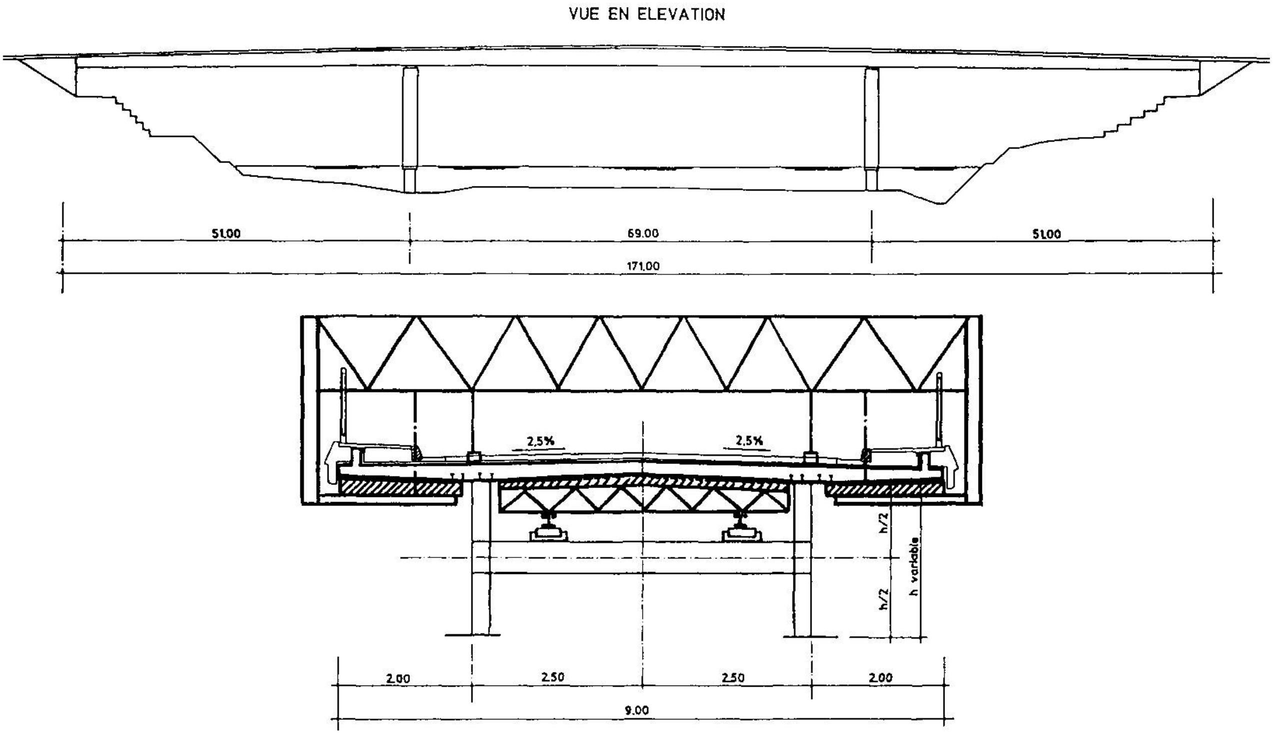


Fig.16 Layrac Bridge over the Tarn River, France

e. Grand Duchy of Luxemburg bridges.

Three bridges built recently in the Grand Duchy of Luxembourg - Syre, Itzig, Drosbach - illustrate the last step in the evolution towards a great simplicity of composite bridges. The designs of all these bridges have been ordered to our design office by steel workshops. Here are the main data of these bridges.

a) Syre bridge : spans of 36 m; width of the reinforced concrete slab : 20,5 m; erection by lifting using a crane (fig. 17).

b) Itzig and Drosbach bridges ; spans of 42 and 48 m, width of the concrete slab : 13,5 m; erection by launching.

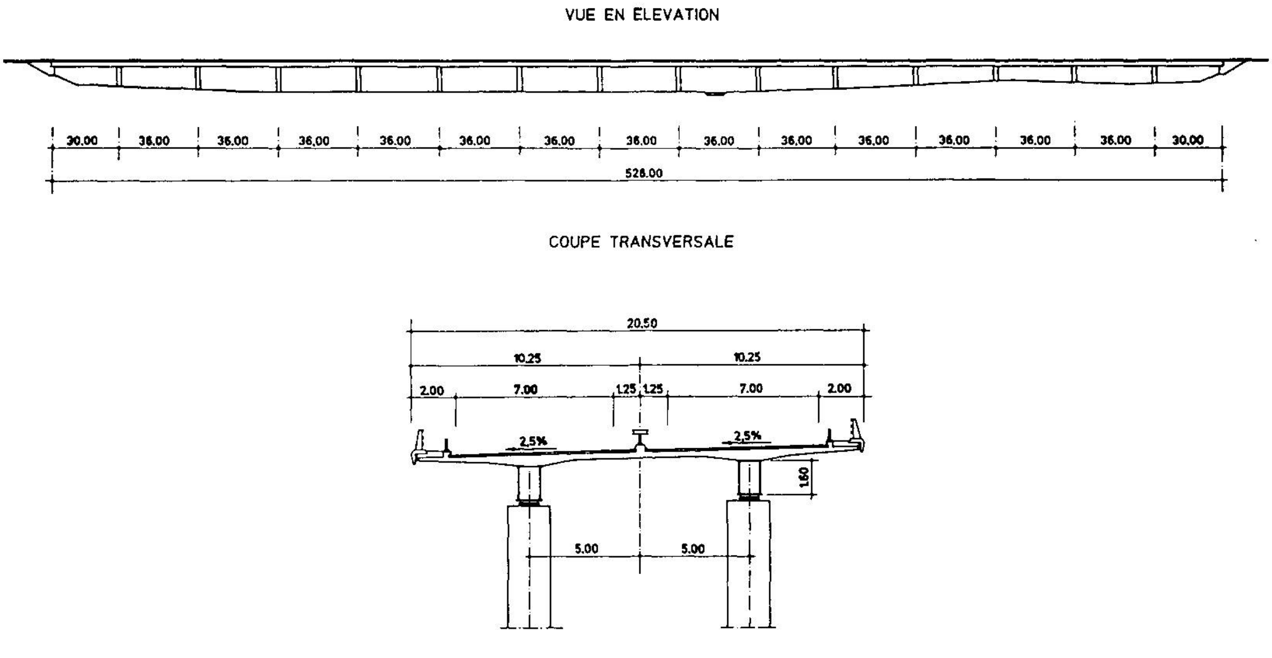


Fig.17 Syre Viaduct, Luxembourg

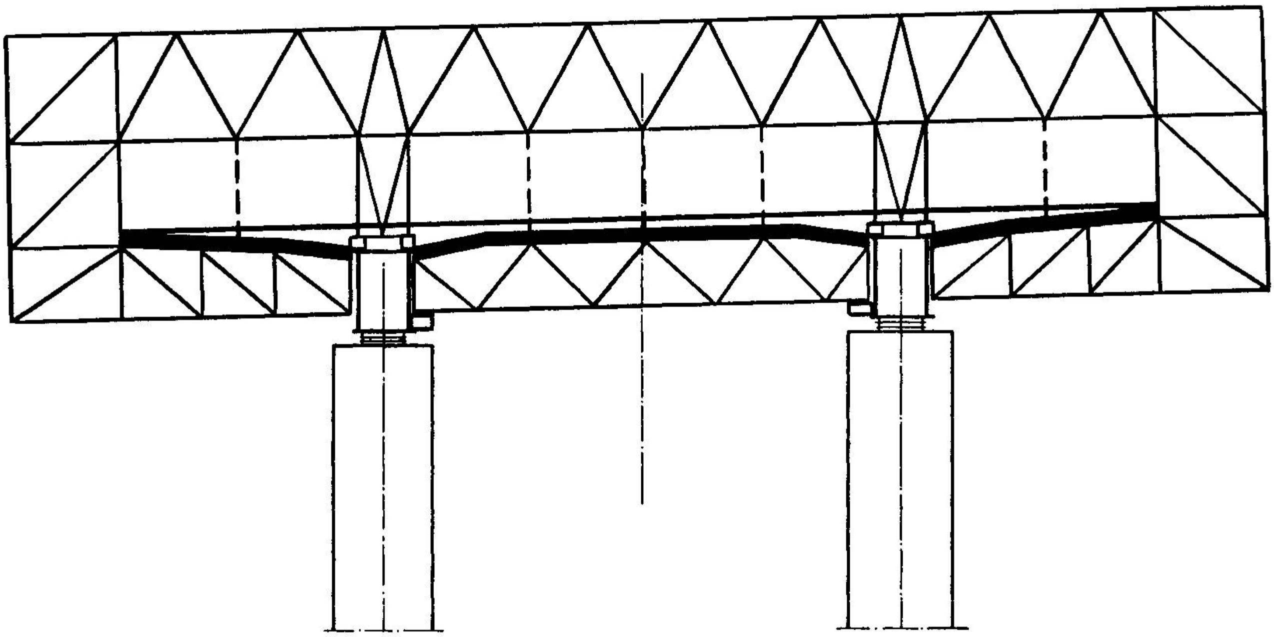


Fig.18 Syre Viaduct, Luxembourg

The main girders are two small size box girders, the component plates of which have neither transverse, nor longitudinal stiffeners. Diaphragms are located at the ends and on the intermediate supports only. In addition, there are no bracing at all connecting the main girders. Casting the concrete slab has been very easy using classical movable formworks which are supported by the steel box girders (fig. 18).

f. Railway bridges.

Till now I illustrated my comments by refering to road bridges. Composite construction is nevertheless quite appropriate and suitable for RAILWAY BRIDGES too ; nevertheless, the design criteria for railway bridges are somewhat different :

- the loads - ballast and railway traffic - are appreciably larger ;
- the allowable deflections in service conditions are much more severe ;
- fatigue strength must be analysed and investigated with a peculiar care ;
- dynamic behaviour is of paramount importance when these bridges are planned for very large speed vehicles (300 to 350 Km/h.)

Our design office is just completing the design of a bridge to be built by the French National Railways Company. This structure is more than 1,8 Km long and will be erected in the north of France (HAUTE COLME) (fig. 19). The cross-section is composed of two main plate girders and cross-beams equally spaced by 6,67 m; the spans vary from 25 to 65 m. An horizontal bracing located at the level of the lower flanges is aimed at reducing the distorsion due to torque. Such railway bridges are designed based mainly on deflection rquirements rather than on strength requirements; this fact is worth while being stressed. This bridge is now being fabricated; it will be erected by lifting using regular cranes. Casting the concrete slab in situ will be rather difficult; indeed the cross-beams, on the one hand, and above mentioned lower bracing, on the other hand, constitute as many obstacles for the move of the formworks between the main girders.

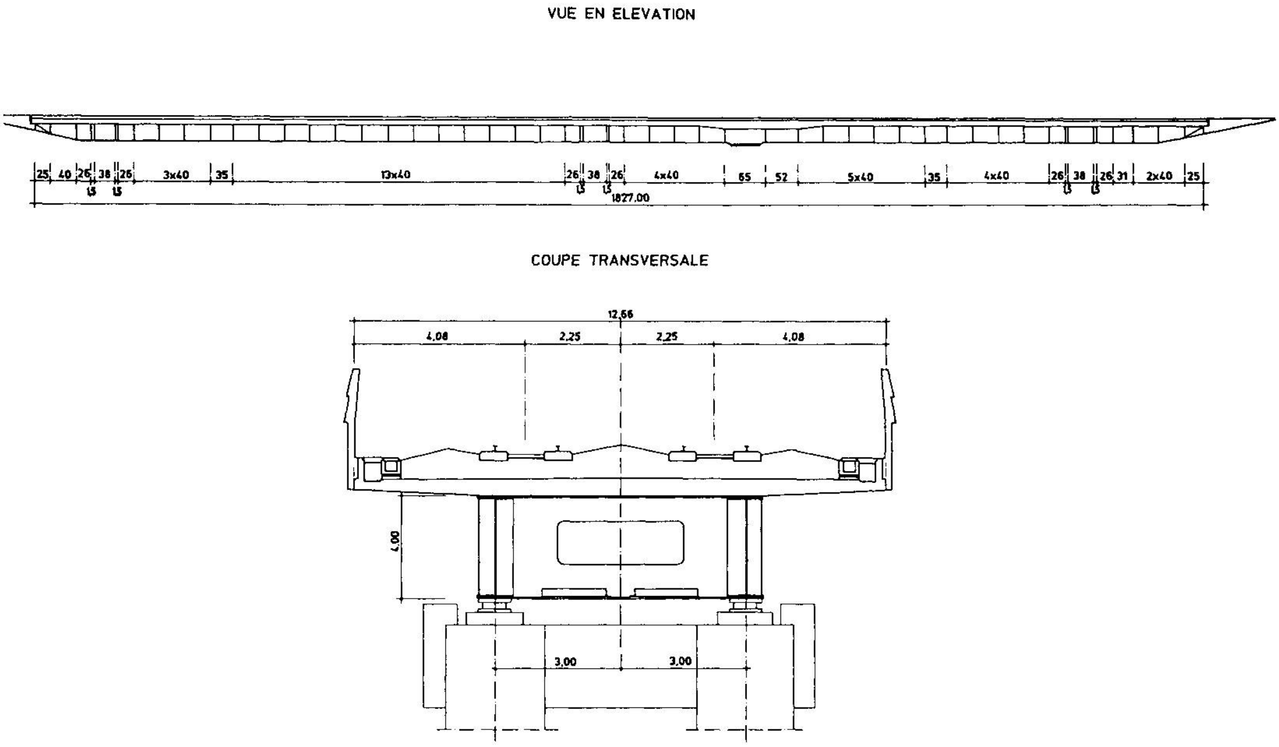


Fig.19 Haute-Colme Viaduct, TGV / high-speed train system, France

B. TIED-ARCH BRIDGES.

First, based on a peculiar case, I should like to show you how combining appropriately steel and concrete can solve many problems.
The bridge in POMMEROEUL is a concrete tied-arch bridge (fig. 20): the arch is made of reinforced concrete while prestressed concrete is used for the tie deck. This bridge, which was built 15 years ago, needs important repairs as a result of a poor quality of the concrete in the arches, a too weak prestressing of the tie and undersized bearing devices. It has been planned to demolish the arches and rebuild new concrete ones, bring an additional longitudinal prestressing to the deck and remove the bearing devices to replace them by appropriately designed ones. Our proposal has been to replace the concrete arch by a steel arch with the consequence that either additional prestressing and replacement of the bearing devices were required.

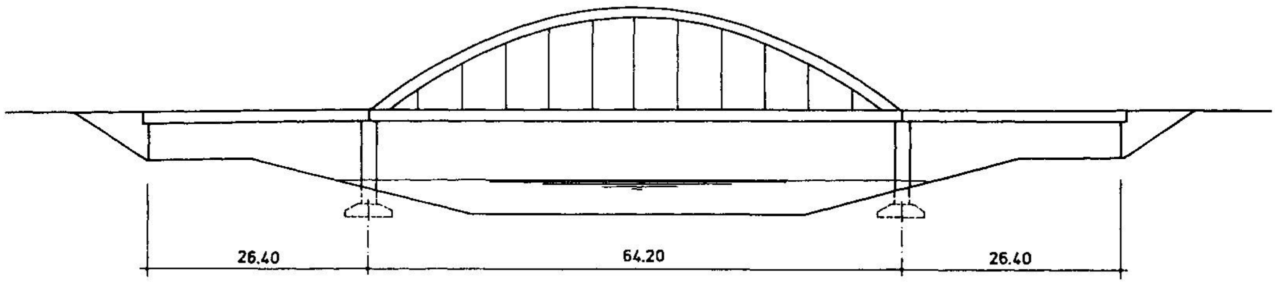


Fig.20 Pommeroeul Bridge

Let us now examine the case of tied-arch bridges WITH STEEL ARCHES, A COMPOSITE DECK AND INCLINED CROSSED SUSPENDERS. The deck is suspended to the arches and plays the role of a tie for these arches. It is thus tensiled. Therefore one can imagine to use a steel orthotropic deck plate, as we did for a first bridge, in Haccourt, over the Albert Canal. This structural system is not only expensive but also very light, what is presently a disadvantage. Indeed the suspenders are then prone to loose their tensile force for some locations of the traffic loads; that is especially not wishable at all when the suspenders are cables which have no resistance in compression.
A composite deck with a concrete slab prevents usually from this misfunction; it is anyway of paramount importance that this slab behaves correctly. One could imagine to connect the slab with the cross-beams and not at all with the main girders with a view to prevent from appreciable tensile stresses in the slab. Such a solution is not at all recommendable because of the unavoidable not compatible displacements between the two structural components of the deck. We are of the opinion that a concrete slab that is appropriately connected with the main girders by means of a lot of shear connectors and plays the role of a tie, shall exhibit a more satisfactory behaviour if the concrete slab is fitted with a high proportion of steel reinforcements is better. These have of course to fulfill all the criteria of resistance and serviceability for the different combinations of actions and comply with the appropriate limitations on the crack opening. It is then not surprising at all that the proportion of steel reinforcements may reach 300 kg/m^3 and more in the slab.

The bridge built in HERMALLE (fig. 21) across the Albert Canal has a span of about 140 m; the thickness of the slab is 25 cm. There are three longitudinal main girders. This bridge was built on the bank at about 1 km far from the site where it had to be erected. The structure composed of the steel arches, the steel grid of the deck, the precast floor slabs and the reinforcements, was transported on boats as a whole and laid down on the definitive bearing supports. Casting the concrete slab in situ has been especially convenient and easy.

The MAREXHE bridge has a span, of 100 m, a deck with 2 main girders, cross-beams equally spaced by 3,40 m and a 20 cm thick concrete slab. Again the slab was casted in situ on precast floor slabs. Tensile stresses in the slab result from shrinkage and from combined effects of dead loads and traffic loads. In service conditions, tensile stresses are limited to 40 kg/cm^2.

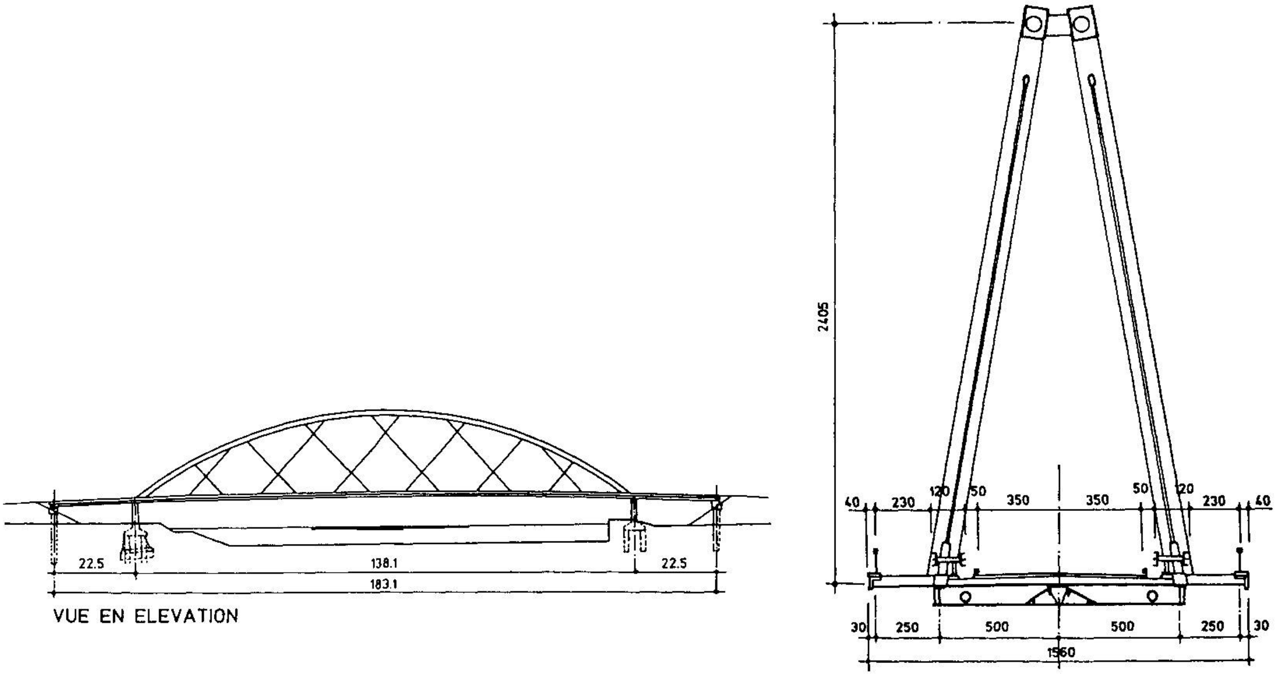


Fig.21 Hermalle Bridge, view and cross section

COUPE TRANSVERSALE

C. VARIOUS STRUCTURES.

Before considering cable-stayed bridges, I would like to examine composite structures which cannot be easily classified. They have the merit to show clearly the large variety of structural solutions which are possible by combining appropriately both steel and concrete materials. Amongst these structures, one first finds all the EMBEDDED STEEL SECTIONS, whatever they are either initially bent or prestressed or initially bent and prestressed, and whatever they are prepared on site or in workshop. They have a fundamental advantage; they allow a small depth-to-span ratio of the main girders. There is a wide range of applications where embedded sections are especially worthwhile being considered.

In Huy, on the river Meuse, a reinforced concrete bridge had to be built with a variable depth but the navigation opening to be kept did not allow locating formwork supports under the bridge. Therefore a steel truss has been built which supported precast floor slabs and has to be embedded afterwards. The steps of concrete casting were especially analized with a view to strengthen the steel skeleton at the same time the loads would increase. This steel skeleton played the role of reinforcement for the concrete and was accounted for when computing the ultimate strength of the sections.

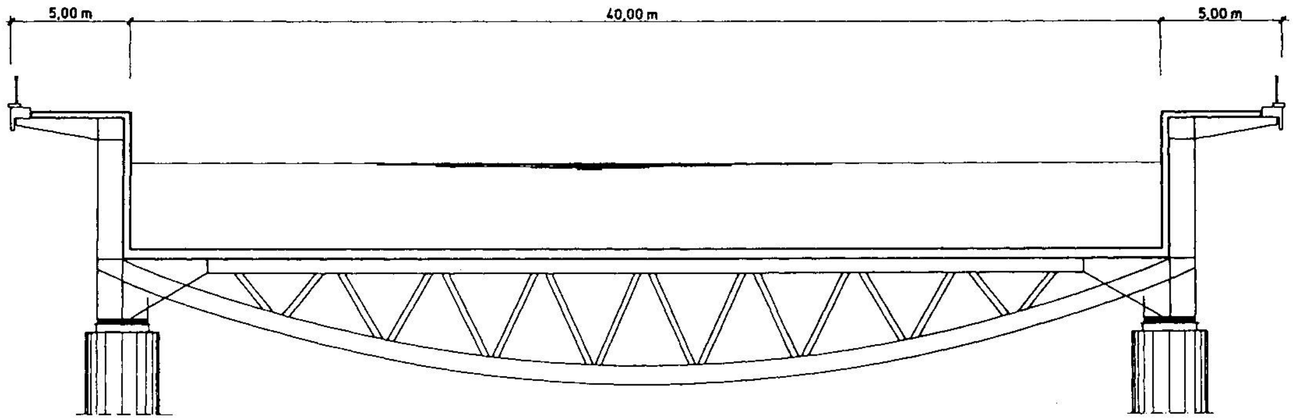


Fig.22 Channel bridge at Houdeng-Aimeries

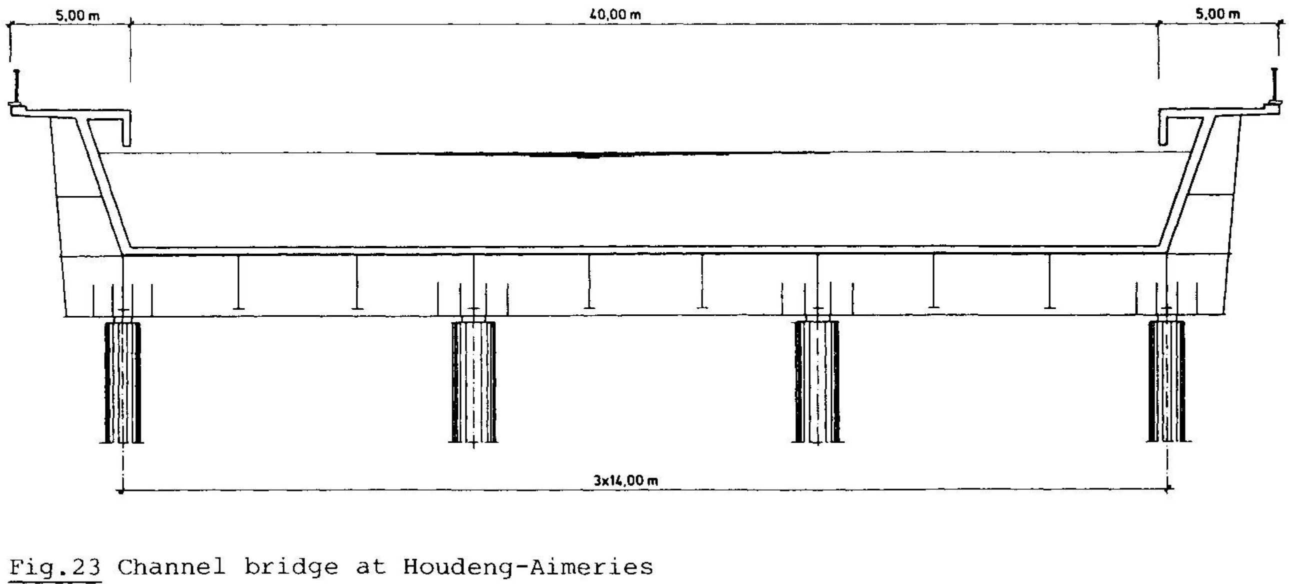


Fig.23 Channel bridge at Houdeng-Aimeries

When the prestressed concrete bridge was built by the launching erection procedure in Steinebrucke, at the German boarder, three TEMPORARY STEEL LACED PIERS were necessary. They had to be used twice; indeed the bridge was composed of two not connected parallel girders. The deepest pier was more than 80 m high and had to sustain an axial load of about 2500 tons. These temporary supports were composed of four steel circular hollow sections composing a square in plane, filled with concrete, connected by web members and diagonal in the four vertical outer faces and braced horizontally at different cross-sections over the depth. These piers had to be displaced transversely by about 15 m to enable the erection of the second half bridge. This structural system was chosen for sake of efficiency and economy.

Belgium has a network of waterways which is of large importance for the political economy of the country. This network is being modernized; therefore canals are widened and the number of sluices is reduced with a view to delete obstacles to the navigation. A CANAL-BRIDGE of 360 m long and 40 m wide is to built in Strepy, close to the worldwide known boat lift. The loads acting on this structure are of course especially large, that means 5 tons/m^2, i.e. 6 to 7 times more than a road bridge or 1.5 times more than a railway bridge.

Amongst the different projects submitted for consideration, there were several structural solutions using composite construction. Of course, with such heavy loads, the global economy of the structure requires rather small spans (Fig. 22 and 23).

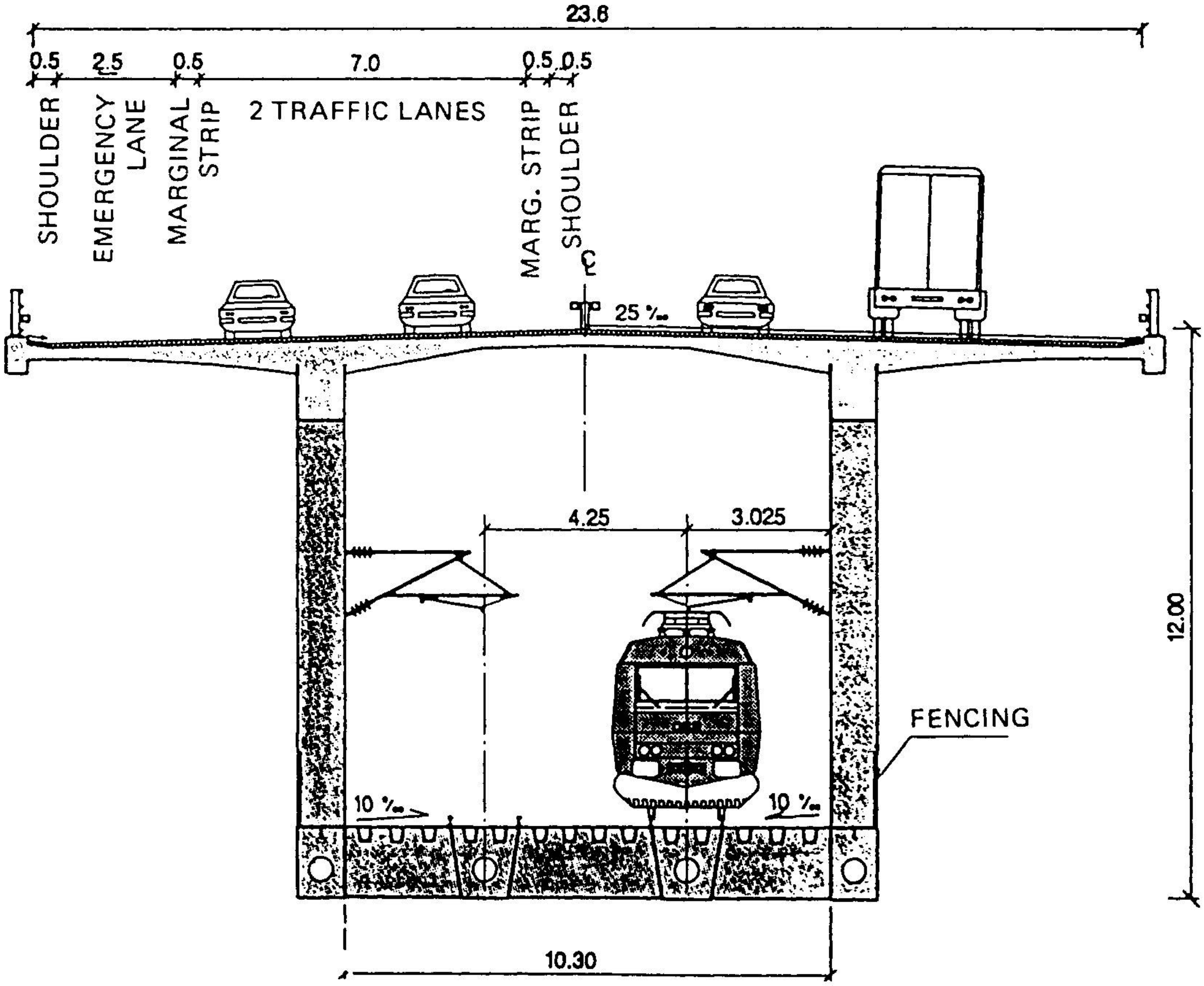


Fig.24 Cross section

A nice example of composite bridge is the project designed by LEONHARDT for the viaduct of more than 6 Km long, aimed at crossing over the GREAT BELT in DENMARK (fig. 24). The deck of this bridge has six road traffic lanes and two railway tracks.
The total length is composed of 42 equal spans of 144 m long, using composite isostatic trusses with an upper deck made of a transversely prestressed concrete slab. The depth of the truss is 12 m. This project has unfortunately not been successful.

D. CABLE-STAYED BRIDGES.

Nearly all the cable-stayed bridges built before 1970 have steel decks. They were especially costly but their design was still possible without sophisticated computer programmes.
The development of computing means has given rise to new concepts and to design of concrete or composite cable-stayed bridges. This evolution was such that no cable - stayed bridge built nowadays has a steel deck.

As for regular types of bridges, the prohibitive cost of orthotropic steel deck plates has led the steel fabricators to use concrete slabs associated to steel girders and cross-beams. Of course, the peculiarities of composite construction have oriented the decisions of the design engineers. It results from a critical review of the cable-stayed bridges erected during the last years, that (fig. 25):
a) most of the bridges with composite decks have two planes of stays ;
b) the cross-section is composed of two main girders only ;
c) the anchorage of the stays on the deck is made either by anchors located in the main girders or by anchoring onto special cross-beams.

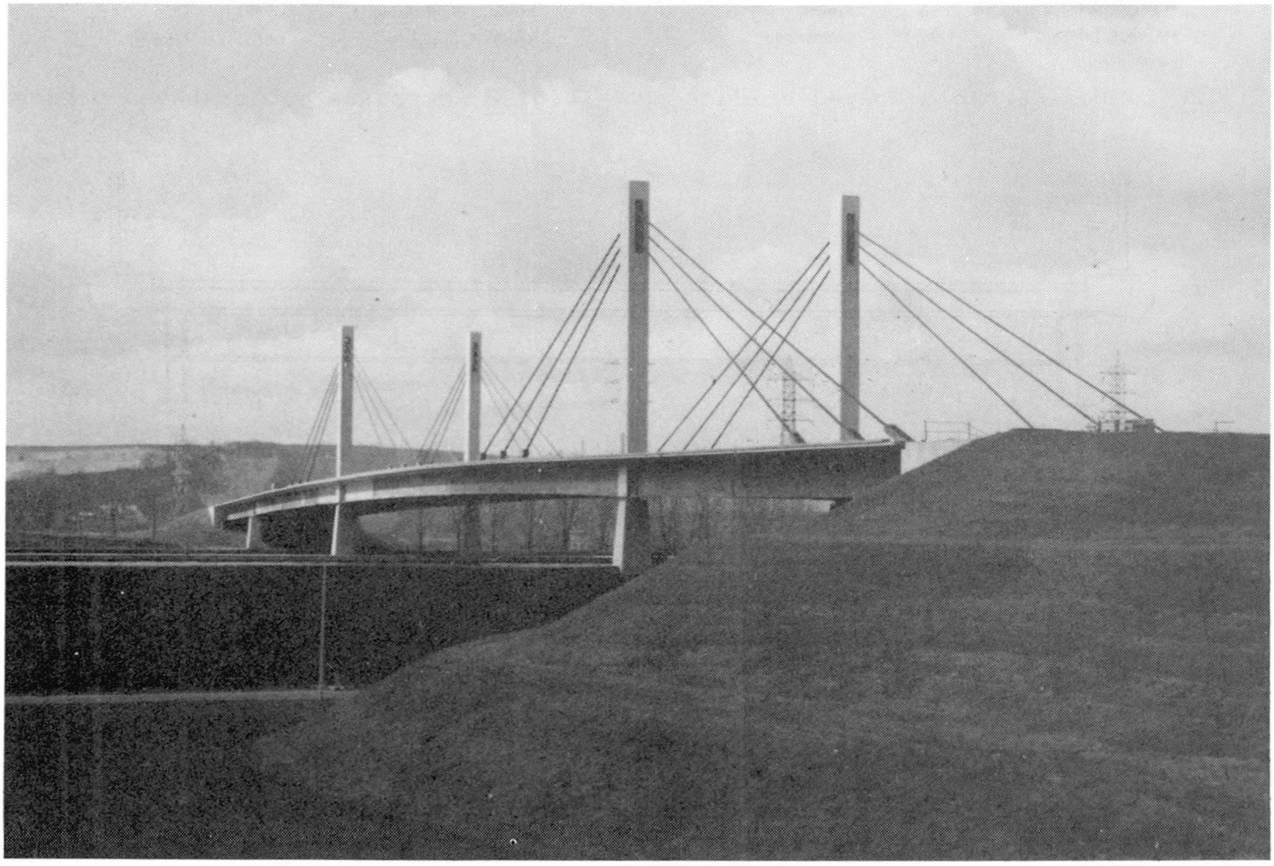


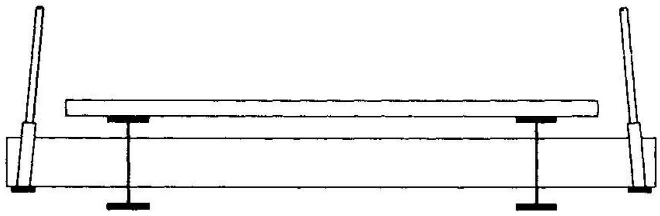
Fig.25

Why such a lack of diversity is the consequence of the following considerations.

Generally cable-stayed bridges are built by incremental cantilevering and the stays support the cantilever girders. Casting of the concrete slab is delayed compared to the erection of the steel skeleton. As a result, the horizontal component of the force in the stay must temporarily be sustained by the steel girder, as concrete slab is still lacking. The stays must be directly connected to the steel girders, what implicates two planes of stays.

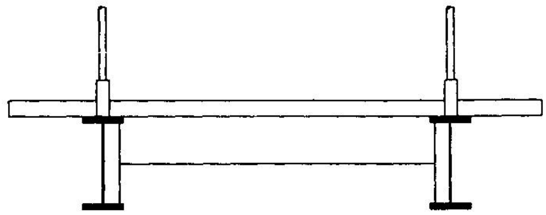
You can see here a series of composite cable-stayed bridges with two planes of stays, where the stays are anchored at the ends of appropriate strenghtened cross-beams which oversteps the width of the deck. (Seyselles - St. Maurice) (fig. 26) (fig. 27).

Here are the bridges where the stays are connected directly onto the main girders (Heer-Agimont, Charleroi, Lixhe) (fig. 28).



ISLES Bridge	(1967)	Canada
S^T FLORENT-VIEIL Bridge	(1969)	France
HOFEN Bridge	(1972)	USA
LINZ DONAU Bridge	(1979)	Austria
SEYSELLES Bridge	(1987)	France
S^T MAURICE Bridge	(1987)	Switzerland

Fig.26 Composite cable-stayed bridges



STRÖMSUND Bridge	(1955)	Sweden
BÜCHENAUER Bridge	(1956)	RFA
HEER-AGIMONT Bridge	(1974)	Belgium
LIXHE Bridge	(1980)	Belgium
HOOGLY RIVER Bridge	(1987)	India
ANNACIS Bridge	(1988)	Canada

Fig.28 Composite cable-stayed bridges

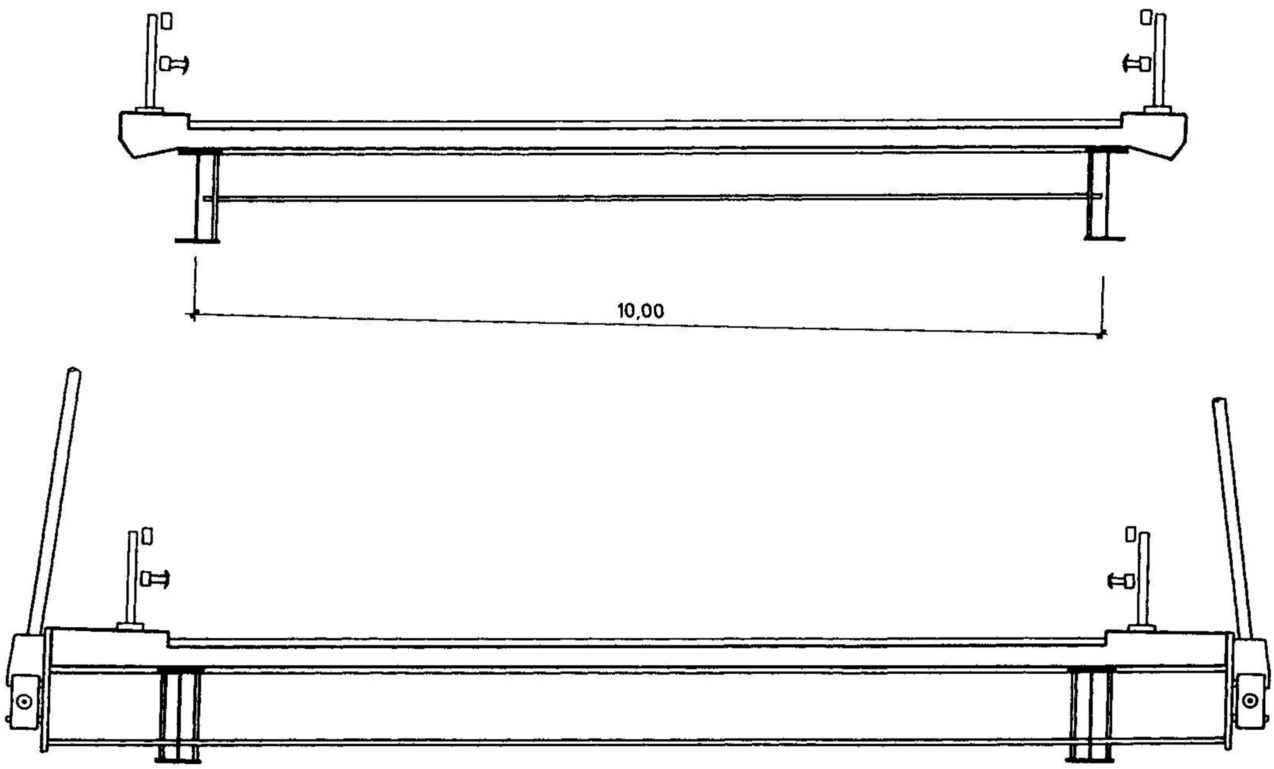


Fig.27 Saint-Maurice Bridge, Switzerland

The cable-stayed bridge in LIXHE has a central span of 126 m. The depth of the composite girders is governed by the adjacent spans that are not stayed. There are tow planes of stays. The forces in the stays are adjusted and the sequence for concrete casting are determined with a view to minimize the tensile stresses in the reinforced concrete slab. This slab is supported by two main girders and three secondary girders parallel to the main girders (fig. 29).

For the cable-stayed bridges of MEDIUM SPAN, the erection methods have evolved. The incremental cantilevering method appears as expensive, especially for girders to be erected at a small height above the foundations. Erection using lifting with cranes, launching on temporary supports, or, why not, rotation are considered nowadays more appropriate in such circumstances. These erection procedures can favour composite cable-stayed bridges with a single plane of stays only.

The bridge in LANAYE (fig. 30) made use of a special technique, based on a temporary steel grid, which is later embedded in concrete. The main span is 177 m long and the width is 13,5 m (fig. 31); there is a single tower with two inclined planes of stays. Once the concrete tower was completed, steel cantilever beams were built and supported by stays. Because of the very light weight of the suspended structure, the sag of the stays was especially large. The lower concrete flange was casted on a fixed formwork located on one of the Canal banks and then pulled towards the other bank, while being suspended onto the steel girders by means of rollers. Once the lower flange was in its definitive position, the concrete webs and upper flange were casted according to specified steps starting from the tower; the steel girders were progressively embedded in concrete so that the structure was progressively strengthened while being subject to increasing loads. The design has been especially complex because it had to account for all the steps of casting, for the history of the loading and for the wide changes in the values of the apparent modulus of elasticity of the stays.

For cable-stayed bridges of LARGE SPANS, new tendencies can be observed. For main spans larger than 400 or 500 m, concrete girders are not at all economical. Indeed the cost of the stays increases with the square of the span, the weight of the deck being assumed constant. The increase in cost becomes so important that very fast it exceeds the economy achieved by using concrete. One has then to reduce the weight of the girders by using composite girders. The HOOGLY RIVER BRIDGE in Calcutta (span of 457 m) (fig. 32) and almost the ANNACYS BRIDGE in Canada (world record with a span of 465 m) (fig. 33) are good examples where composite girders were successfully used (fig. 34). The Annacys bridge has two main girders with cross-beams and a slab made of prefabricated elements (fig. 35).

OTHER COMPOSITE STRUCTURAL SOLUTIONS have also appeared. They are still using two planes of stays, have main girders and slab made with concrete while the cross-beams are in steel.

The EAST HUNTINGTON (fig. 36) bridge in the States, with a single tower and a span of 274 m, makes use of this structural solution. It does not constitute a very appropriate example of application because the width remains rather small.
This cross-sectional view is a prospective solution, which will probably be used in a near future (fig. 37).

For VERY LARGE SPANS, the most economical solution is probably to use a main span in steel to save weight and reduce the cost of the relevant stays. The Normandy bridge is the most known example in this respect. Some other bridges of comparable spans are in project, especially in Japan. I am personnally curious to hear more about the technical data of these very long span bridges, and to see how they will influence the evolution and the design of large span composite bridges.

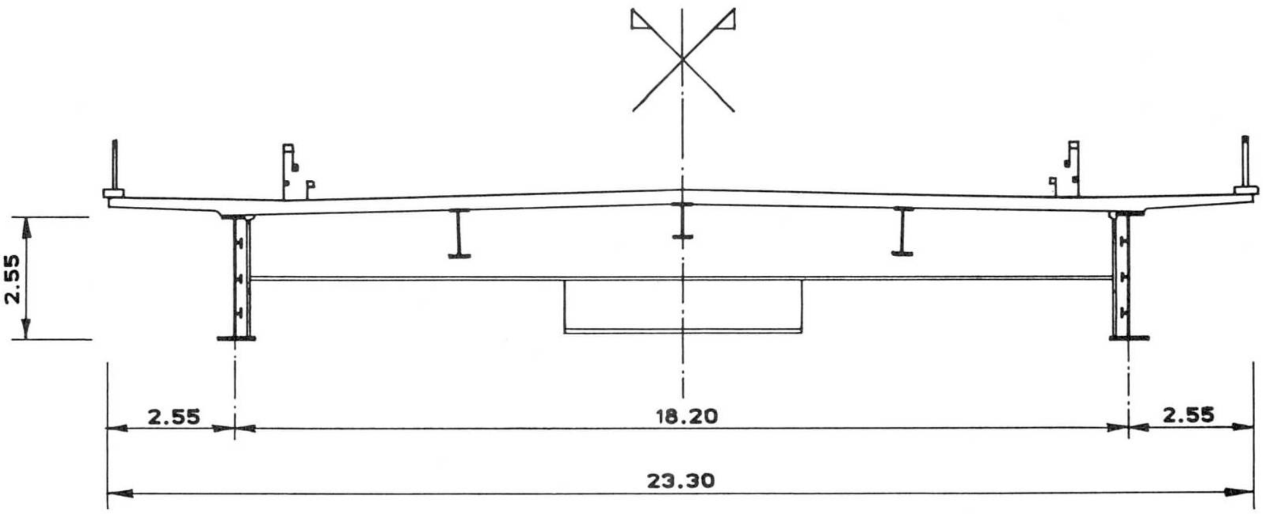


Fig.29 Lixhe Bridge

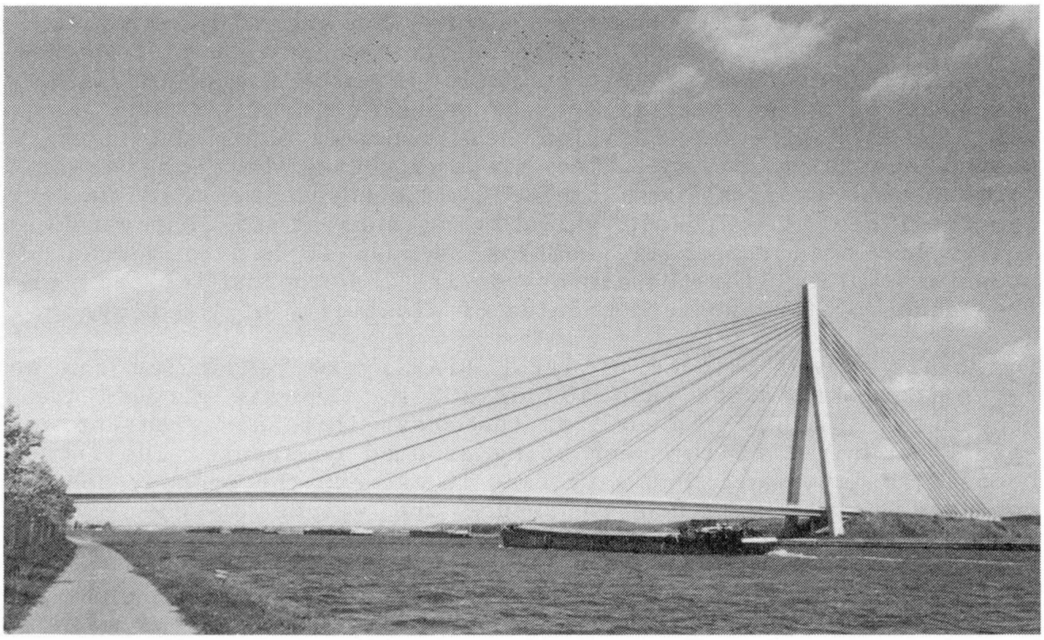


Fig.30

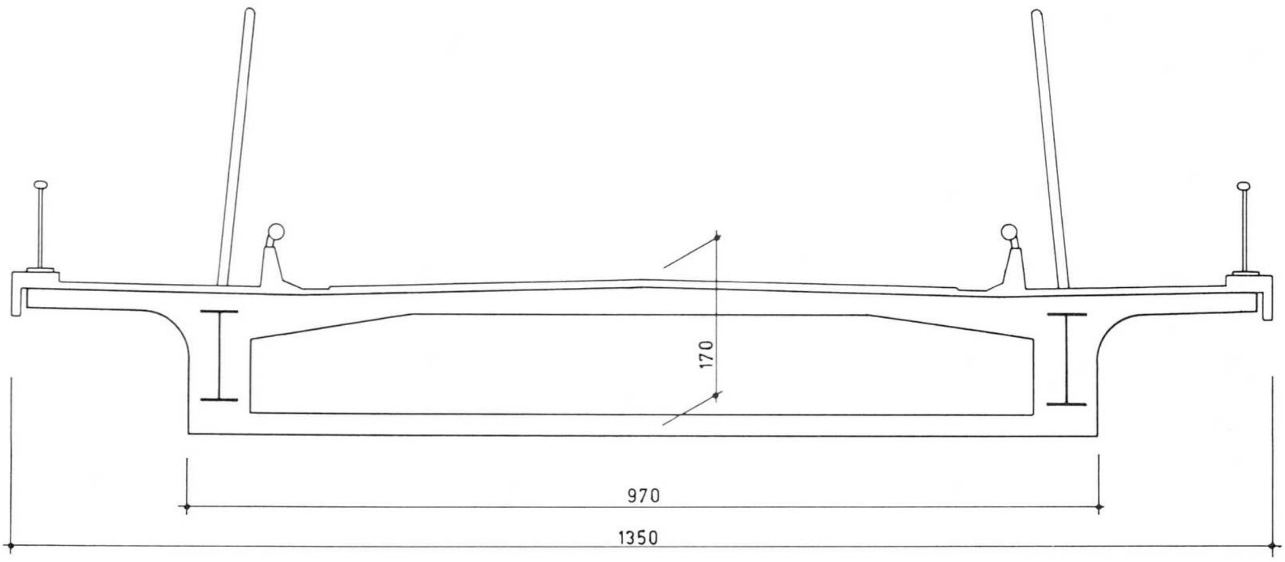


Fig.31 Lanaye Bridge

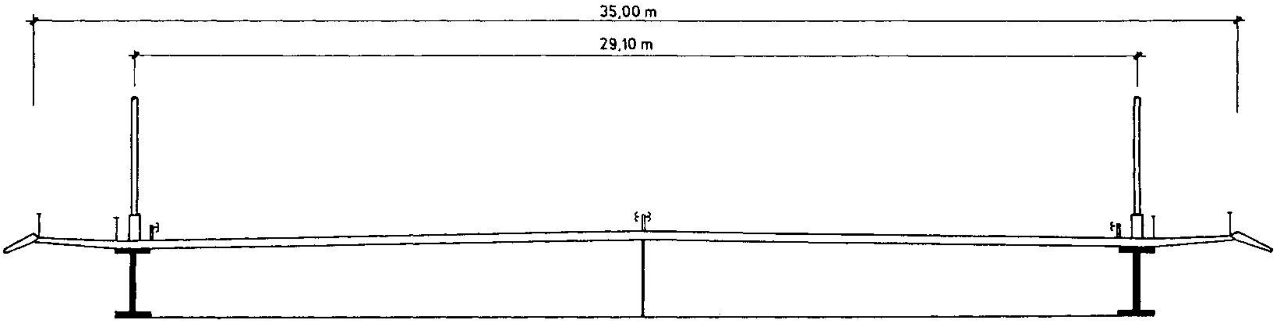


Fig.32 Hoogly River Bridge, Calcutta, India

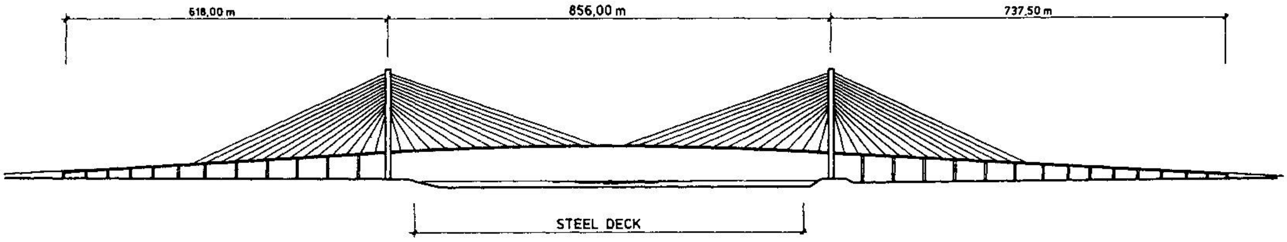


Fig.33 Annacis Cable-stayed Bridge, Canada

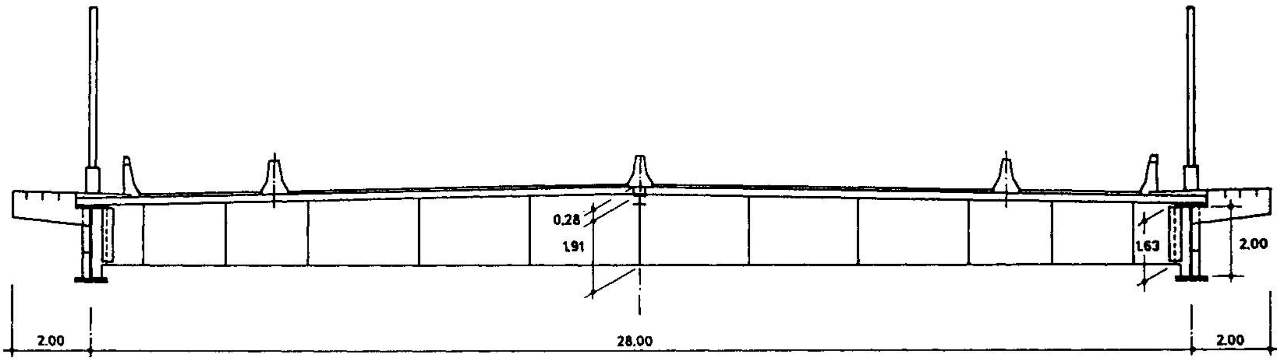


Fig.34 Annacis Cable-stayed Bridge, Canada

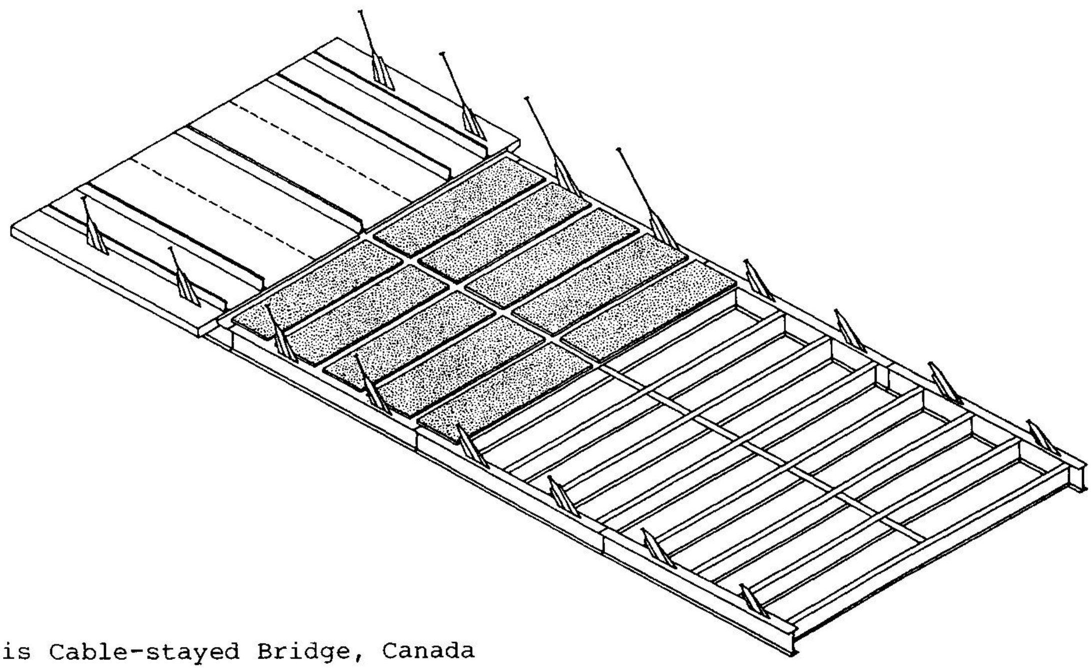


Fig.35 Annacis Cable-stayed Bridge, Canada

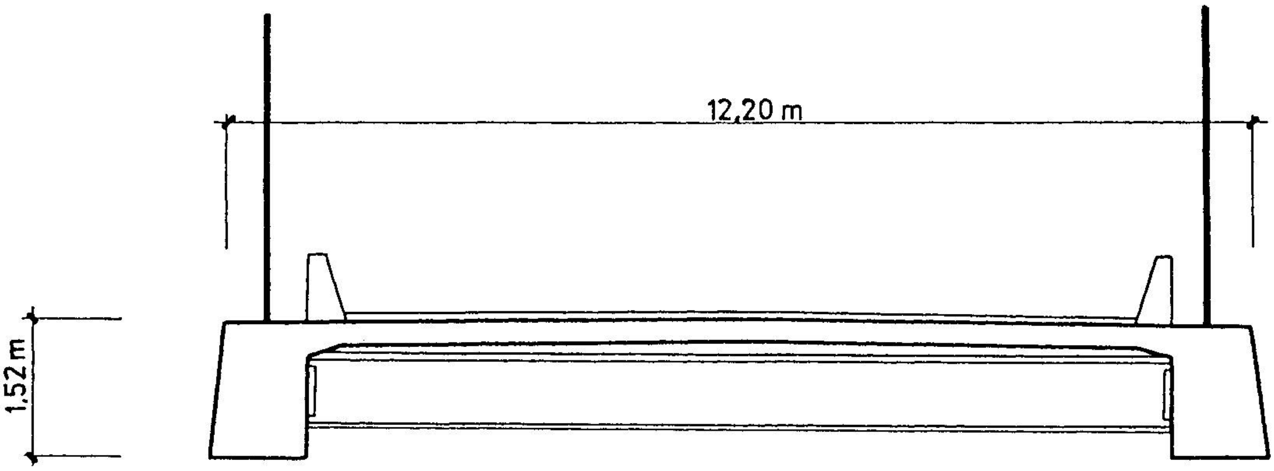


Fig.36 East Huntington Bridge, USA

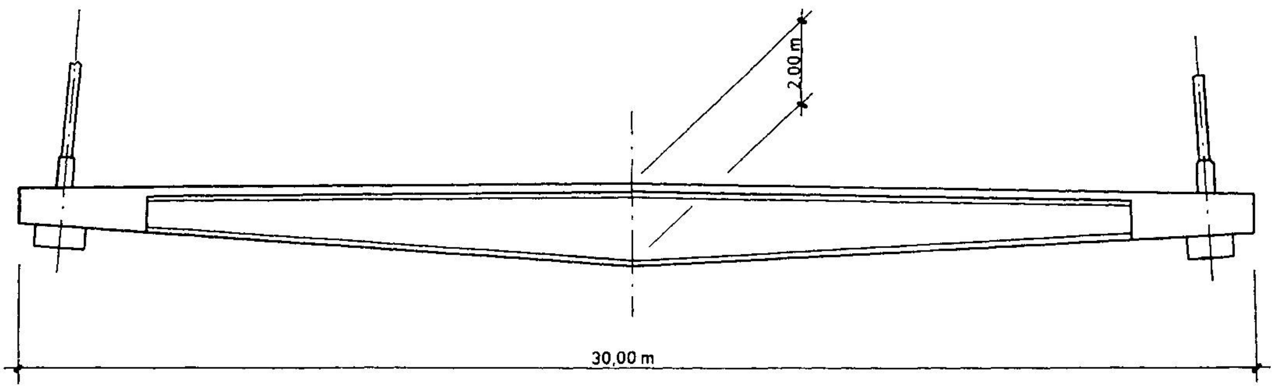


Fig.37

III. GENERAL COMMENT.

I close here my survey of composite bridges. Before examining how some detailings dealing with composite construction have been designed in our design office, I would like to add one GENERAL COMMENT.

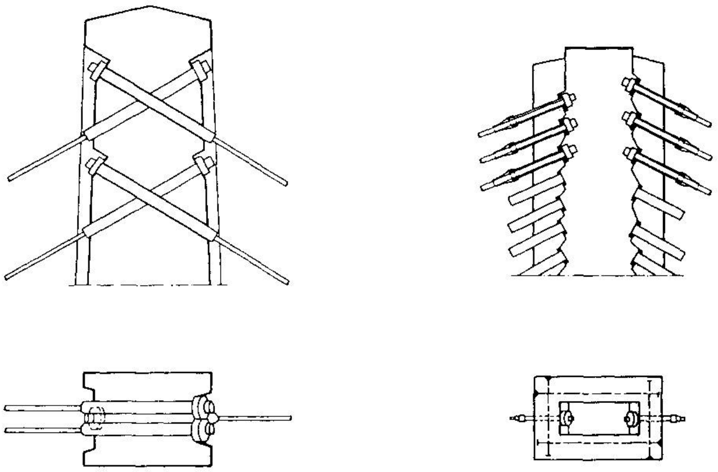
In the sixties and even the seventies, the opponents to the use of steel tried to promote concrete bridges, where, only the reinforcements were made with steel. They stressed the difficulties and the cost of MAINTENANCE AND REPAIR of steel bridges. Who would still dare argue similarly today, while concrete bridges exhibit such an unexpected and extended range of dommages in many countries?

Nowadays, both materials are used with a larger OBJECTIVITY regarding their properties and their imperfections. It is now widely acknowledged that both material require specific cares during design and fabrication and need appropriate maintenance during the whole life of the structure. More especially for what regards decks, a peculiar attention must be paid to the means that are likely to warrant waterproofing.

IV. SPECIAL COMPOSITE ELEMENTS.

For composite structures, it is of paramount importance to have a deep knowledge not only of the behaviour of each of the materials but also of the actual behaviour of the CONNECTION between both materials. The composite action is highly dependent on this connection indeed; much research work contributed a better knowledge of the behaviour and the design of several types of shear connectors. Information is still lacking regarding the fatigue strength of such connectors. Tests recently carried out at the University of Liège on embedded sections with or without connectors, subject to static and cyclic loading, led to following conclusions:

- Tests have confirmed that the ultimate bond stress is close to 15 Kg/cm^2, - what was rather well-known - but depends appreciably on the conditions for casting concrete. Casting beneath a steel flange is likely to reduce bond down to 10 Kg/cm^2 and even less.
- Embedded sections where concrete is casted in successive steps with a resulting increase in the loading of the composite section has ultimate strength and behaviour similar to those of the same composite section with concrete casted in a single step. In addition no loss of bond is observed where bond forces have to develop.
- No loss of bond due to fatigue occurs before fatigue strength of connecting means be reached.
- Ultimate strength governed by fatigue does not occur as a result of a sudden fracture but well of a progressive slip between steel plate components and concrete.



Crossing of stay cables — with prestressed bars

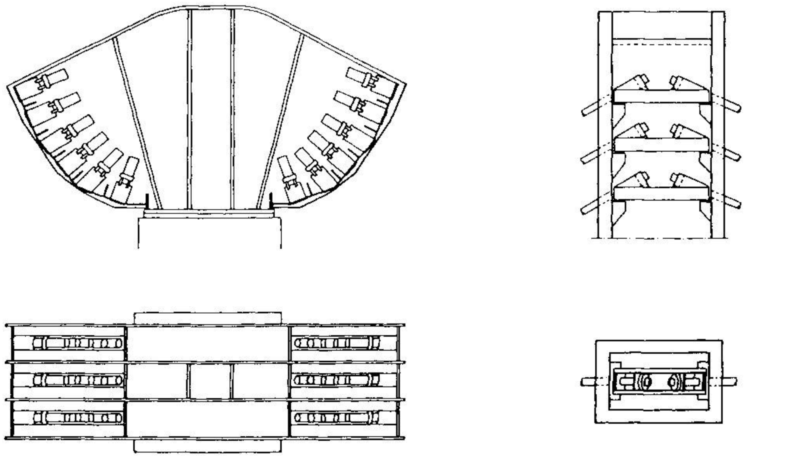


Fig.38 — Steel (Pasco - Kennewick) — Annacis

In concrete structures, one of the major problems to which the design engineer is faced the introduction of CONCENTRATED FORCES. Let me tell you somewhat more about some of such problems, that we solved by taking benefit of the composite action.

For this purpose, I have to refer to some structural elements of the bridges built in Wandre; this prestressed concrete bridge was erected by the incremental launching method, using a tempory steel nose. I shall more especially examine how tensile forces in the stays are anchored and diffuse in the slab and in the head of the tower.

It is now unanimously agreed by the design engineers that stays which are not continuous over the tower is most often the best solution. Then each stay must be anchored IN THE HEAD OF THE TOWER. There are several possibilities to anchor the stays in the tower, that is generally a concrete tower (fig. 38).

a) The stays are anchored on the outer faces of the tower. That implicates that the stays of both planes must cross each other. This solution is not satifactory because of the parasitic forces which result from and because of the lack of aesthetics and the danger of corrosion.
b) The stays are anchored on the inner faces of the flanges of a box section, the webs of which are prestressed by prestressing bars. This solution is not recommended because of the short length that is prestressed and the difficulty to protect the anchor heads.
c) The stays are anchored on a head made with steel only, as at the Pasco-Kennewick bridge.
d) The stays are anchored on a composite head; that is, to my opinion, the most satisfactory solution. I would like to comment somewhat more about that.

In the ANNACYS bridge, the pair of corresponding stays in adjacent spans are anchored on a steel beam, which allows the equilibrium of the horizontal components of the relevant forces while the vertical components are supported by concrete short cantilevers. A similar structural solution was used at the bridge in DUSSELDORF-FLEHE (fig. 39); there, however, several stays are equilibrated.

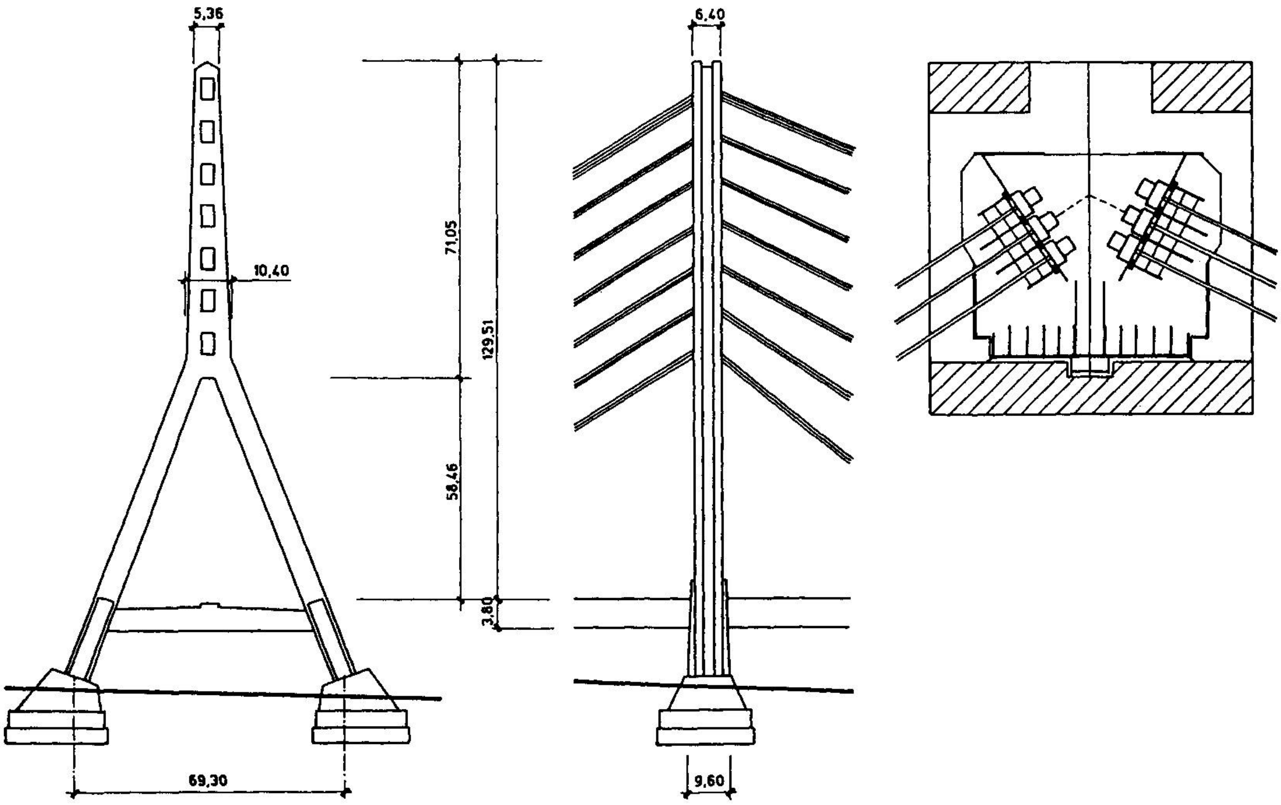


Fig.39 Düsseldorf-Flehe Bridge, Germany

Our design office has designed four CABLE-STAYED BRIDGES IN BELGIUM where the anchor uses a composite system. A steel case composed of two vertical plates fitted with anchor points for the stays is embedded in the head of the concrete tower (fig. 40). The horizontal components of the forces in the stays are directly equilibrated through the steel plates while the vertical components are transmitted to concrete by means of shear connectors. The stays are anchored on the concrete deck in appropriate embossments. The shaft of each stay bears on a thick steel plate, that distributes the load and contributes in reducing the local compressive stresses in the surrounding concrete. By welding this plate onto a steel hollow section that is embedded, the bearing plate is less stressed and can therefore be thinner; that needs an efficient bond between concrete and the hollow section (fig. 41).

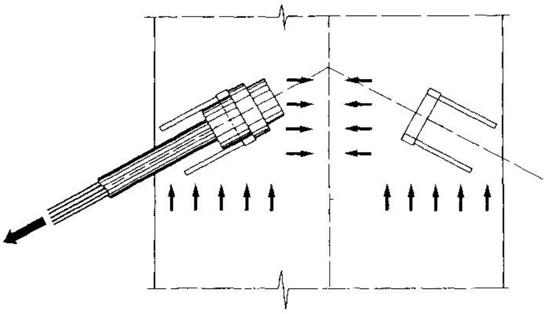


Fig.40 Anchor points at head of tower

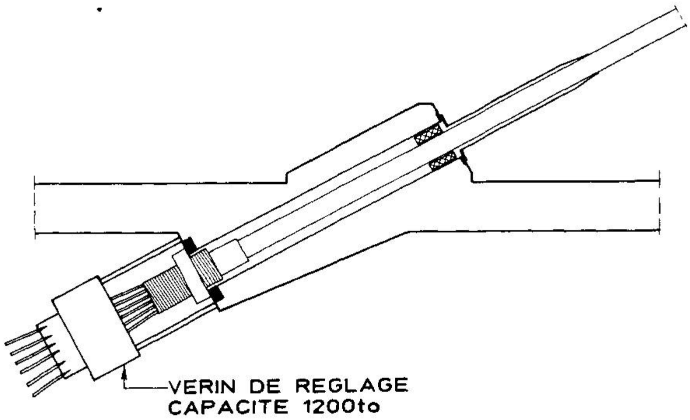


Fig.41 Tensioning jack

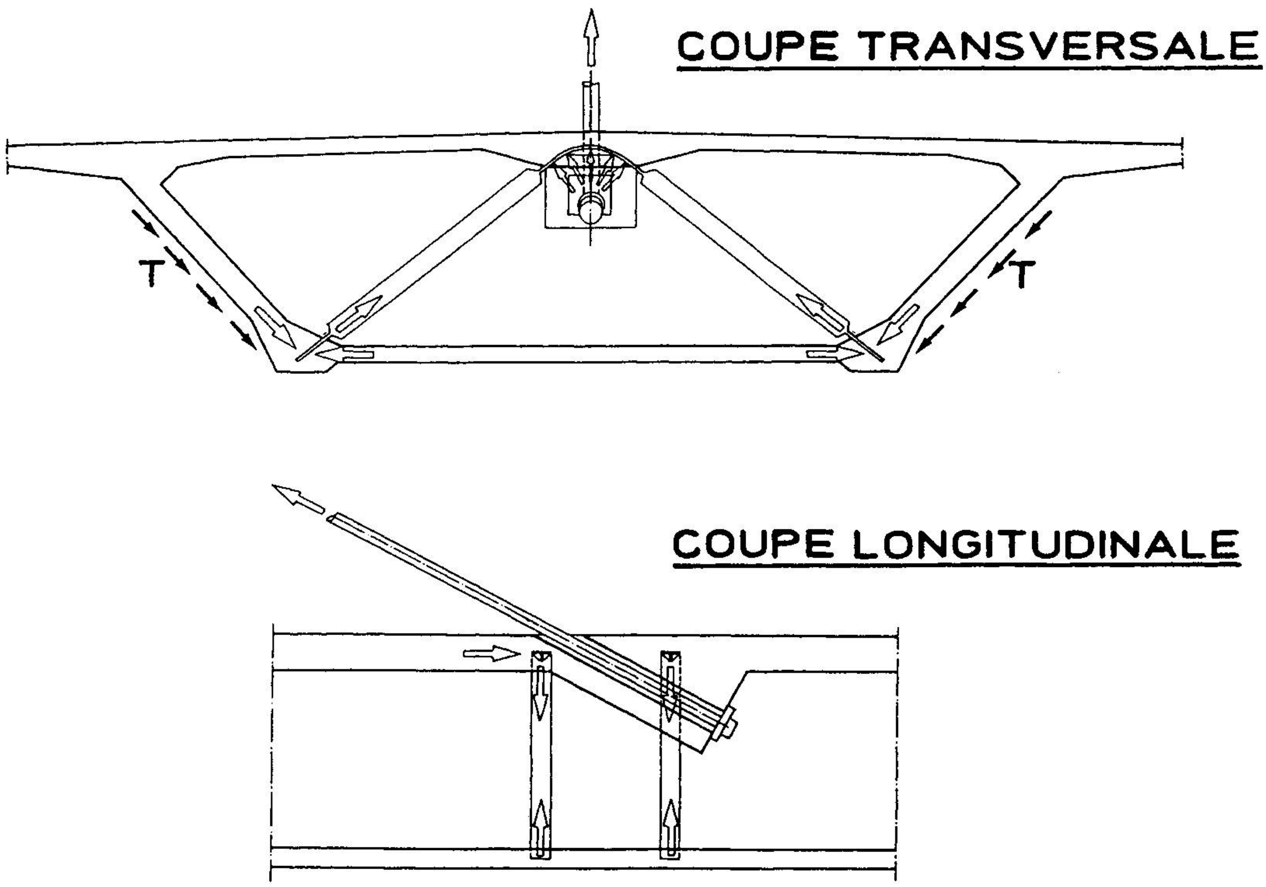


Fig.42 Transmission of forces in the stays

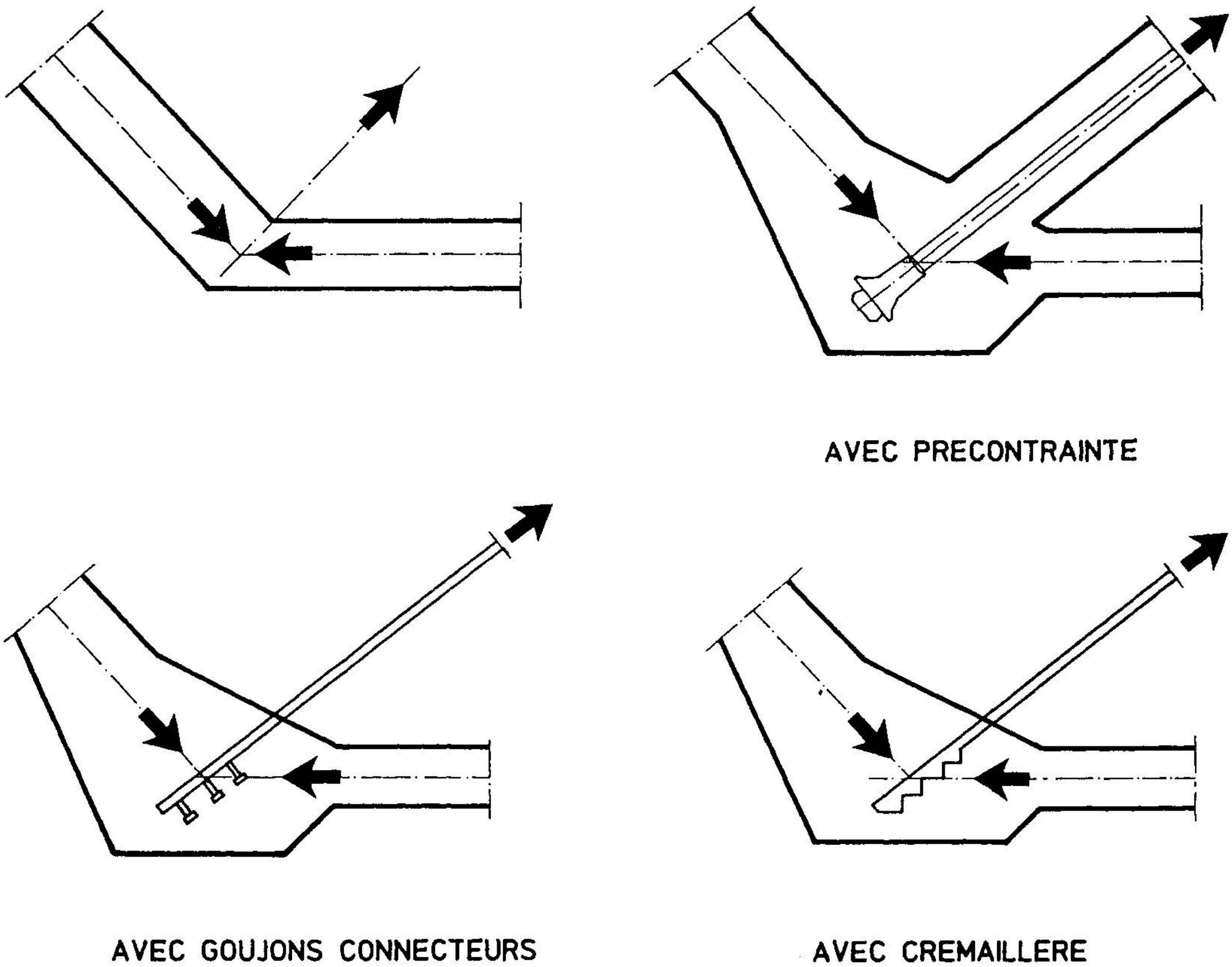


Fig.43

In box girder bridges with a single plane of stays, the vertical components of the forces in the stays must be shed down to the bottom of the webs by appropriate ties. The classical solution was to use prestressed concrete ties; it was however not easy because of prestressing losses in rather short structural elements and because of the limited space available for the anchors of the prestressing steels. In two bridges (BEN-AHIN AND WANDRE), we planned STEEL TIES instead of concrete ones; that looks more logical at a structural viewpoint (fig. 42). Each of these ties is twinned to allow an easy arrangement for the shaft of the stays. Equilibrium of horizontal components is automatically fulfilled by the continuity of the ties; continuity is got by connecting both ties by means of a curved steel plate embedded in the deck. The slight out-of-equilibrium that is due to change in torque is supported by the longitudinal bar connector inside the curvature. Anchor the ties at the bottom of the webs uses one of the follwing arrangements (fig. 43):

- either by means of shear connectors, as in the bridge at Ben-Ahin.
- either by means of an embedded serrated plate, the toothing being such that concrete is compressed only and not sheared. With this arrangement which ensures the self-equilibrium, concrete is subject to pure compression and even exhibits smaller deformations than by using shear connectors. Tests made at the University of Liège demonstrate that collapse of this anchor arrangement occurs by excessive compressive stresses in concrete; therefore the reliability can be assessed realistically (fig. 44).

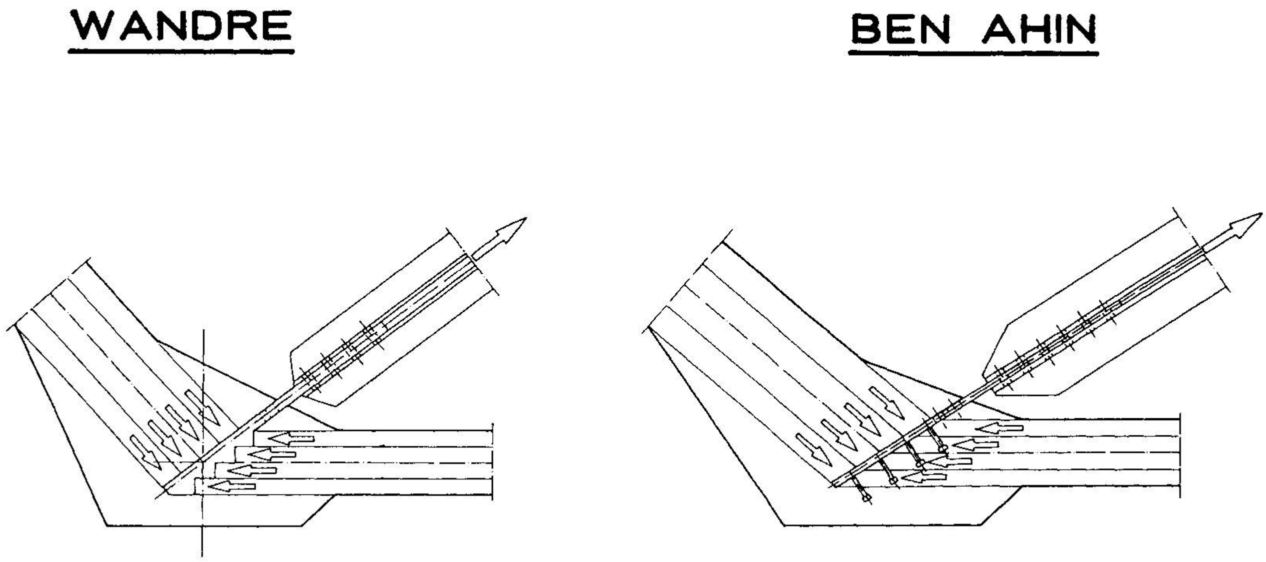


Fig.44 Anchor of the ties at the bottom of the webs

My task was not easy. I tried in a rather short time to draw your attention on some topics, that illustrate the large diversity of the problems to which the design engineer is faced. I hope I have been successful in demonstrating that both materials - concrete and steel - can be used in conjunction for a better quality and reliability of structures, provided that account be taken of their respective properties and of their structural behaviour.

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