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Design and Construction of the Normandie Bridge

Etude et construction du Pont de Normandie

Entwurf und Bau der Normandie-Brücke

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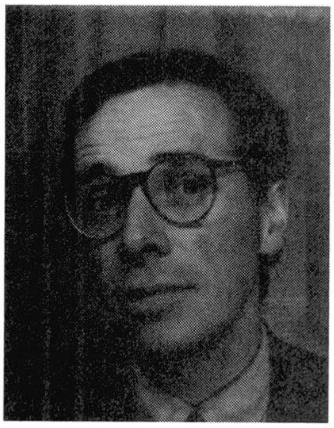

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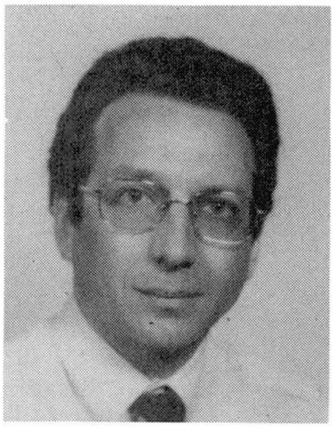

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SUMMARY

The Normandie Bridge will have one of the longest cable-stayed spans in the world, i.e. 856 metres long. This paper describes the evolution of is design, between 1987 and 1990, which is limited but reveals interesting problems and gives some possible solutions. The construction began with some preliminary works (access embankments; temporary access bridge; protection of the North pylon against ship collision). The erection of the main bridge began in September, 1990, with the construction of the piles constituting the foundations of the North pylon and of the South abutment and piers.

RESUME

Le Pont de Normandie sera l'un des plus grands ponts à haubans du monde, avec une portée centrale de 856 mètres. Le présent article décrit l'organisation des études d'exécution de cet ouvrage et évoque l'évolution de sa conception, entre 1987 et 1990. La construction du Pont de Nomandie a commencé par quelques travaux préliminaires (remblais d'accès; pont provisoire en rive droite; protection du pylône Nord contre les chocs de navires). La construction de l'ouvrage principal a commencé en septembre 1990 par le forage des pieux de fondation du pylône Nord, et des pieux de la culée et des piles en rive gauche.

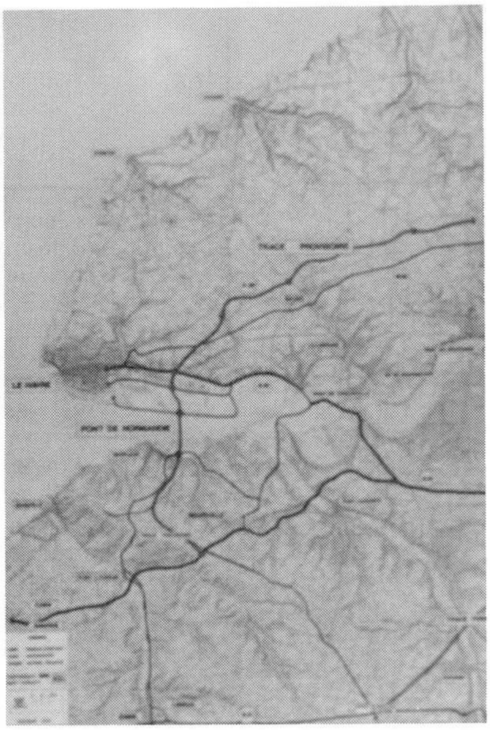
ZUSAMMENFASSUNG

Die Normandie-Brücke wird mit 856 m Mittelspannweite eine der längsten Schrägseilbrücken der Welt sein. Der Aufsatz beschreibt die Organisation der Ausführungsplanung und gibt einen Rückblick auf den Werdegang des Brückenentwurfs zwischen 1987 und 1990. Nach vorbereitenden Arbeiten (Auffahrtdämme, temporäre Zugangsbrücke, Schutz des Nordpylons gegen Schiffsanprall) begann im September 1990 der Bau der Hauptbrücke mit der Pfahlgründung des Nordpylons und des südlichen Widerlagers und der Pfeiler.

1. INTRODUCTION. THE PROJECT. THE ORGANIZATION OF THE CALL FOR BIDS

About 15 years ago, the "Chambre de Commerce et d'Industrie du Havre" has considered necessary to build a new bridge over the river Seine, at its very mouth, in front of the town of Honfleur on the left bank. In 1988, it has been commissionned by the French Governement, with a special law in Parliament, to build a new toll bridge, the Pont de Normandie, 20 kilometres downstream from the famous Tancarville suspension bridge.

With a main span 856 metre long, this cable-stayed bridge will be one of the largest in the world.



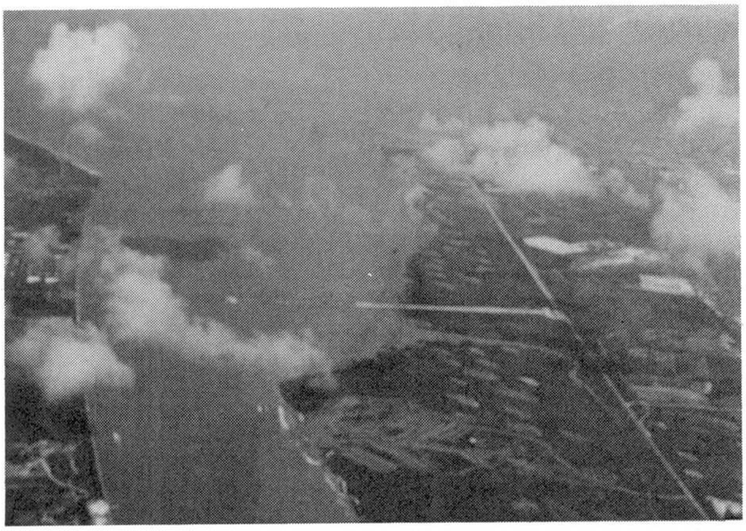


Fig. 1 (left): A view of the situation of the Normandie Bridge at the mouth of the Seine, on the highways from Channel Tunnel to South-west and Spain.

Fig. 2 (above): A general view of the Seine estuary with Le Havre harbour at the right (North) and Honfleur town at the left. Situation of works in summer 1990.

1.1. The Organization of the Design

The Normandie Bridge has been designed between September, 1986 and February, 1988, by a design team constituted by the Road Administration Design Office – the S.E.T.R.A. –, which was the pilot, and by several private design offices, mainly: SOFRESID, SOGELERG, QUADRIC and S.E.E.E. The design team worked with the help of two well-known institutes specialized in wind forces and aerostability: the ONERA, and the C.S.T.B. in Nantes.

As usual in France, the project presented to contractors for the call for bids, in March, 1988, was not a detailed project, but what is called an Avant-Projet Détaillé (Preliminary Detailed Project). It gives the structure static configuration – longitudinally and transversally –, the main dimensions, the principles for pre-stressing, and general principles for reinforcement. Of course, due to the project size, detailed analyses and computations had been developed, mainly for the evaluation of wind forces.

In addition – due to the high responsibilities of its services, S.E.T.R.A. and the Mission du Pont de Normandie –, the Ministry of Transport decided to create an expert group for the evaluation of the project. Project evaluation is normally done in France by S.E.T.R.A. for bridges on motorways and highways, but, as S.E.T.R.A. took a decisive part in the Normandie Bridge design, it could not play this role in this case. And, due to the importance of the bridge, this evaluation was an absolute necessity. The six experts were Professors Lacroix, Schlaich and Walther, and the general inspectors Brignon, Huet and Mathieu. They concluded, at different steps of the project, that it was safe and reasonable, and these external experts recommended some improvements in the design which were considered.

1.2. The Organization for the Call for Bids

The call for bids was organized according to a "combined" procedure aiming at a unique contract built from two separate bids: one for the concrete parts of the bridge, and one for the steel main span and the suspension. The goal of this separation was to avoid that steel contractors, which are of a much smaller size in France than the great contracting companies, could only work as subcontractors.

Only three groups of contracting companies could be selected for the concrete parts of the bridge. Two of these groups, piloted by Bouygues for one of them and by Campenon-Bernard for the other, gathered most of the major French contractors. The big European contractors – from Germany, Netherlands, Great Britain, Spain or Italy – had surprisingly not been interested by the competition.

For the steel part of the contract, seven contractors were qualified, from different European countries: France, Germany, Great Britain, Denmark... This more favourable situation led us to think that we had a greater competition for this part of the contract.

2. THE RESULTS OF THE CALL FOR BIDS THE ORGANIZATION OF THE CONSTRUCTION

The bids have been opened on August 8th, 1988, and the contracts for the bridge construction have been signed in May, 1990 for the concrete parts of the bridge, and in November, 1990 for the steel parts. The long time which has been necessary for the preparation of the contracts needs some explanations.

2.1. The Results of the Call for Bids

For the concrete parts of the bridge, the two most important groups of contractors joined. They presented two separate offers, but they very soon declared that they wanted to work together to limit technical and financial risks. Nearly all French major contracting companies are thus finally involved in the groupment in charge of the construction, called GIE du Pont de Normandie: Bouygues and Campenon-Bernard, who are pilots, Dumez, Grands Travaux de Marseille (G.T.M.), Quillery, Société Auxiliaire d'Entreprise (S.A.E. Borie), Société Générale (SOGEA), and Spie Batignolles CITRA.

This situation probably limited the competition, and partly explains that the prices in the three bids were much higher than expected.

For the steel parts of the bridge, two companies were in close competition: Eiffel Constructions Métalliques (the new name of the Compagnie Française de Construction Métallique – C.F.E.M.), and a Danish Company, Monberg and Thorsen. For this part of the job – which is of course the most innovative and difficult –, the prices were more in the line of the predictions.

This situation obliged the Client – the Chambre de Commerce et d'Industrie du Havre – to look for some amendments in the design in order to reduce the total price of the bridge, to match with its financial capacities. As the contractors proposed some improvements in their offers, they were analyzed by the design team which finalized the project as we shall explain later.

2.2. The Construction Organization

The Owner intended to build a unique contract after the call for bids, for both the concrete and the steel parts of the bridge. But the GIE du Pont de Normandie and Eiffel Constructions Métalliques did not accept this solution, considering that a concrete contractor could not take the place of a steel constructor if the latter is not able to achieve construction.

It was thus necessary to finalize two separate contracts for the bridge construction, what left open the problem of the coordination of detailed analyses and of short drawings. In addition, the concrete contractors limited their responsibility, in their offers, considering that they could not be responsible for the evaluation of the wind effects and for their consequences.

Due to the fact that the Normandie Bridge design is totally governed by wind and wind forces, accepting such a restriction of the contractors' responsibility would have meant that they would have had only a very limited real responsibility in the design.

The Owner – the Chambre de Commerce et d'Industrie du Havre –, the Project Manager – la Mission du Pont de Normandie –, the design team piloted by S.E.T.R.A., and the authorities of the Ministry of Transport decided then to abandon the classical French system: the design team – and through it the Owner – remains responsible for the bridge design, described as an "Avant-Projet Détaillé" in the contracts. It became its responsibility to amend its initial design to introduce the construction methods and techniques which were part of the offers from the contractors, and to reduce the cost as we already explained by some improvements and modifications, partly on the basis of propositions or ideas suggested by the contractors, and partly from its own ideas.

In this situation, the design team finalized a new Avant-Projet Détaillé – called Projet Détaillé de 1989, to avoid any confusion –, which has been achieved in November, 1989, and given to the contractors as the basis for their contracts.

The contractors still have to complete a detailed design, basis for the short drawings. But, due to the imbrication between the concrete and the steel parts of the bridge, this detailed analysis had to be done by a common team, called Groupement d'Etudes Générales (GEG), gathering the GIE du Pont de Normandie and Eiffel Constructions Métalliques. Eiffel has been later replaced by Monberg and Thorsen, associated with Cowi Consult, through a new separate contract. It was decided that the contractors should complete a detailed design – though they are not responsible for the general design – for three reasons:

- to have an external control of the design, going into all details;
- to avoid any misfit between structural analyses and construction methods and techniques;
- and to leave to contractors a real technical responsibility, corresponding to the establishment of the short-drawings, as always in France.

Due to this complex organization, the design team piloted by the S.E.T.R.A. has to solve – preferably in close cooperation with the contractors – the possible problems which can be evidenced by the detailed analyses: some modifications in the concrete dimensions, in the distribution of tendons, in the reinforcement... For example, we had to make some limited amendments to the 1989 Detailed Project, in the pylons.

This organization could look a bit curious, but we considered that it was better, for the Client's interest, that we could choose the solution to solve the possible problems – if any – since the client will be in all cases greatly responsible for their consequences, in the end, due to the prominent importance of wind forces.

Finally, the contractors are not directly responsible for the global design, but they have to give their opinion on this design, as professionals, if they consider it necessary.

This organization has been slightly complicated by the unsuccessful discussions with Eiffel Constructions Métalliques for the steel contract. The French contractor did not agree on some important technical and administrative specifications, and the Owner decided to search for an alternative. The construction contract was finally signed with Monberg and Thorsen, in November, 1990, as we said before.

3. EVOLUTION OF THE DESIGN

The 1987 Avant-Projet d'Ouvrage d'Art has been described in a previous paper [1], and the 1988 Avant-Projet Détaillé during the IABSE Congress in Helsinki [4, 6]. Unfortunately, the IABSE format does not leave enough place to detail here the evolution of the design between 1988 and 1990.

This evolution considered the technical propositions from the contractors, mainly concerning the construction techniques and methods; some amendments were also made to reduce the bridge cost; and finally some were also made to increase the bridge safety and to ease construction.

This evolution of the design has been presented during the Fukuoka Colloquium, devoted to cable-stayed bridges, in April, 1991.

Figure 3 gives the final distribution of spans, and an idea of the longitudinal static configuration. Figure 4 gives the typical cross-section, in the steel main span on one side and in the concrete access spans on the other side.

4. CONSTRUCTION PROGRESS

Of course, we are just beginning the construction of the main bridge. But many preliminary operations have already been conducted for a total cost of about 200 million French Francs.

4.1. Access Embankments

The access embankments have been built, on each side of the river, between May, 1988, and June, 1989.

On the South bank, this is a classical earthwork (up to 15 metres high), just to give access to the bridge last span.

But, on the North side, the access crosses the riverside muddy swamps at a rather low level. The road must then be protected from exceptionnal tides and from wave effects. The shape and the constitution of the embankment aims at producing these protections.

The North abutment is seriously protected from tide and waves by concrete blocks of standard types (up to 3.6 metric tons), imbricated as classical rocks.

The last point to note is the technique which had been used for the earthworks. As the soil quality is very poor in these swamps, the embankment has been created on a textile membrane, used to distribute the pressure on the ground and to favour drainage in the mud. This solution has been designed by the Mission du Pont de Normandie, the Laboratoire d'Hydraulique de France (LCHF), and the C.E.T.E. de Normandie for the geotechnical aspects.

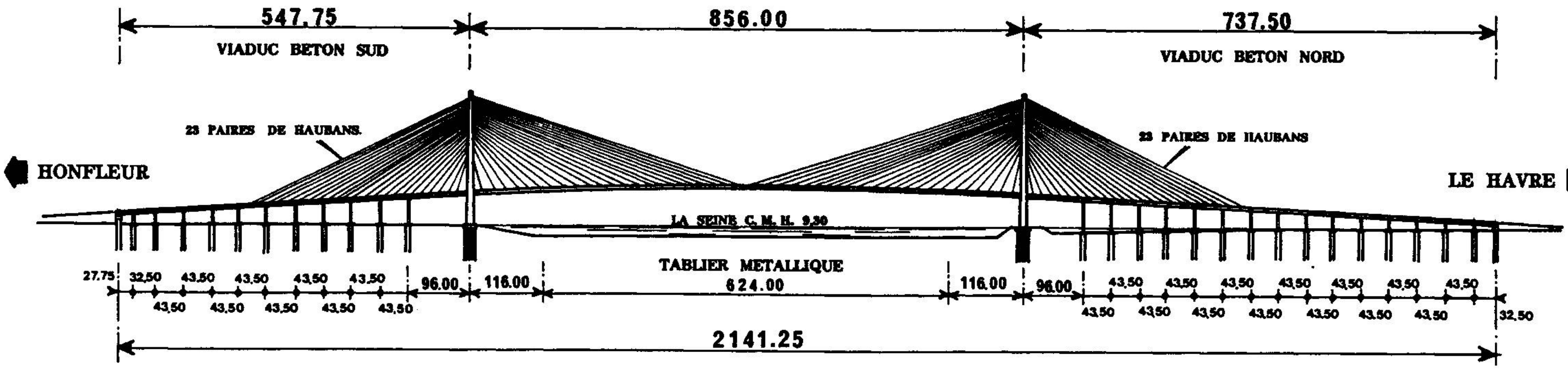


Fig. 3: Longitudinal static configuration of the Normandie Bridge (1989 Projet Détaillé). The central part of the main span, built in steel, is 624-metre long.

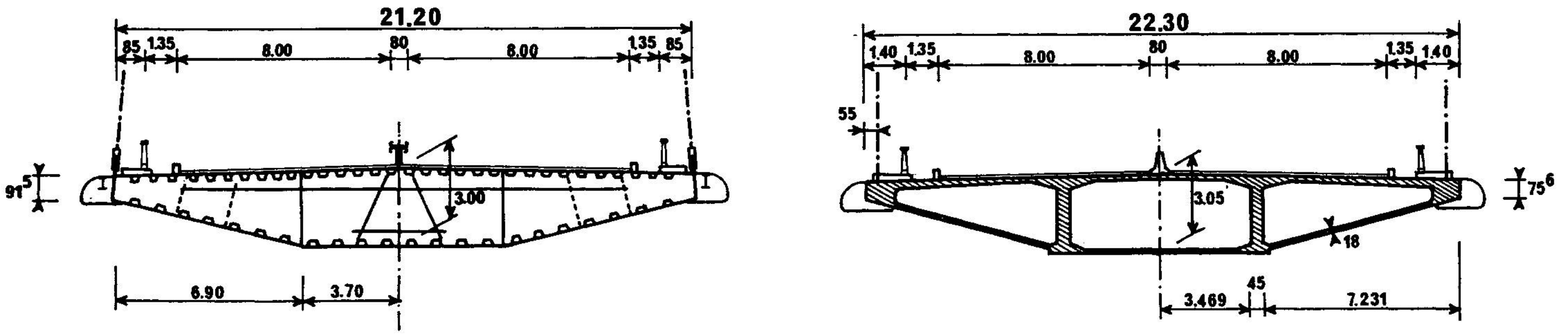


Fig. 4: Typical cross-section for the steel part of the bridge (left). The cables are directly anchored through open sockets on the lateral webs of the box-girder. Typical cross-section for the concrete part of the bridge (right).

The total cost of the Northern embankment – 1.2 kilometer long – is 50 million French Francs.

4.2. Temporary Bridge for the Access to the Piers of the North Access Spans and to the North Pylon

Due to their situation in the swamps, the piers of the North access spans cannot be reached, either by ship or by trucks, without creating very serious technical and ecological problems. The 1988 Avant-Projet Détaillé had then proposed the construction of a temporary bridge, to give access to these piers and – in the same occasion – to the North pylon in the river Seine stream which could have been only reached by ship otherwise.

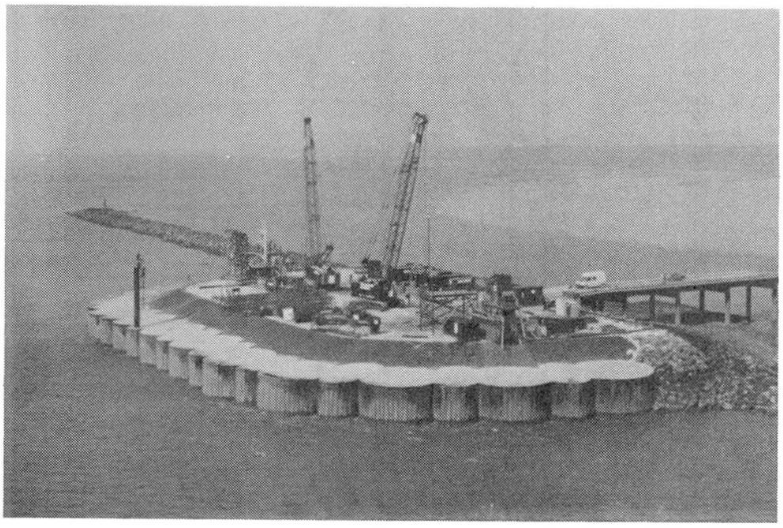


Fig. 5: Protection against ship collisions, supporting the foundation works of the North pylon (Winter 90-91)

Due to the very high price proposed by contractors in their offers, the Owner decided to design and build this temporary bridge with a separated contract, after a new special call for bids. This separated contract also had the advantage to allow for a quick construction of the temporary bridge, without waiting for the main contract, out of the operation critical path. Of course, the contractors for the main bridge had to prepare all the specifications corresponding to their needs: width, possible loads, crane track, etc... The competition was won by Chantiers Modernes, and construction began in June, 1989, to end in October, 1989.

This 750-metre long access bridge has a steel superstructure, made by two parallel I-shaped beams, supported by 210 steel tubes driven open in sand and gravels to their foundation level. These steel beams support a concrete slab made of precast elements, just connected by bolts to the beams. The successive spans are independent, and 10 metre long.

Lateral extensions are built at each pier level, both to allow for truck crossing and to permit the construction of the piers and of their foundations: the boring machine, for instance, will be placed on these extensions, pier after pier.

This access bridge has been designed by SOFRESID (Jean-Claude Foucriat and Michel Dufresne), and by the C.E.T.E. de Normandie for the foundations. Its total cost is 30 million French Francs.

4.3. Protection of the North Pylon Against Ship Collision

As we already explained it in previous papers, the North pylon is slightly in the stream, but more than 500 metres from the navigation channel. Nevertheless, it had been decided to protect it against a possible ship collision.

Jean Calgaro designed a huge concrete protection, made of two connected semi-circular beams, each of them surrounding one of the two pylon footings. These beams, 4 metres wide and 5 metres high, were founded on a series of long and thick piles.

In their offer, the contractors of the groupment piloted by Campenon Bernard – and mainly SOGEA – proposed an alternative: the protection is constituted of a curved line of sheet-

Fig. 6: A photo of the temporary bridge in the swamps at low tide

pile cofferdams, surrounding the whole foundation of the pylon. These cofferdams are filled with concrete to give them sufficient rigidity and strength.

The foundation level of the cofferdams, the water pressure behind them at low tide and many other points had to be discussed with the contractors. Finally, the diameter of the sheet-pile cofferdams was fixed to 8.90 metres, to ensure its stability, and it revealed necessary to protect the line of cofferdams by placing calibrated rocks in the stream when undermining appeared fantastic during construction.

The contractors in charge with the main bridge were not extremely interested in the construction of this protection, and their price was high. As for the temporary bridge, a separate contract was prepared, with also the advantage of a quick construction out of the critical path.

The local agency of Quillery – one of the contractors of the GIE du Pont de Normandie – finally had this contract and built the protection of the North pylon between October, 1988 and April, 1990.

4.4. Beginning the Main Bridge Construction

The construction of the main bridge itself began in September, 1990, with the construction of the piles of the North pylon, and of the South abutment. All the foundations – except for footings – are subcontracted to a German company: Billfinger Berger. The piles are bored with a Wirth equipment, 1.50 metre in diameter for the foundations of typical piers and abutments, and 2.10 metres in diameter for the foundations of the pylons. For the construction of the last ones, the length of the boring equipment reaches 54 metres.

The work is in progress now, and will end by the beginning of 1993 for the concrete parts of the bridge (access piers and spans; pylons; and main concrete cantilevers built from the pylons); and by mid-1994 for the steel deck with its Freyssinet cables.

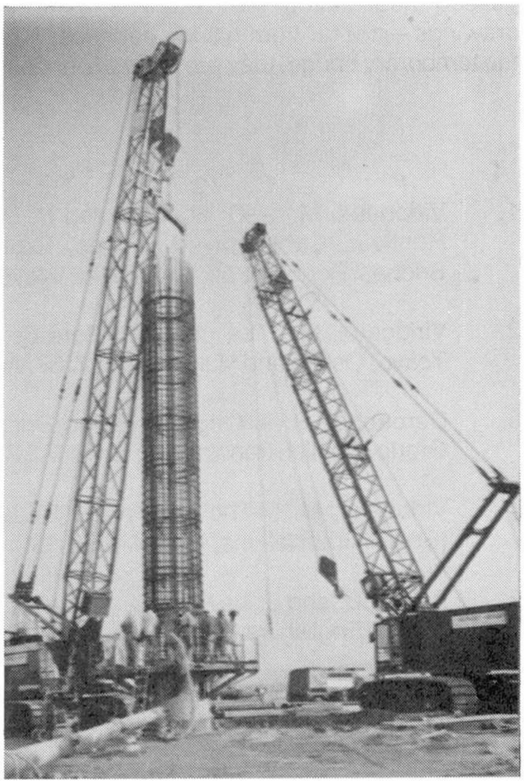


Fig. 7: A view of one of the four casings of reinforcement for the bored piles of North pylon (Winter 90-91)

5. CONCLUSION

Building very big bridges is always difficult. Specially when a new construction constitutes a great technical advance, as will be the case of the Normandie Bridge with its 856 metre main span, to be compared to the current world record of the Anacis Bridge, 465 metre long "only".

Many problems have to be solved, and the purely technical ones are not always the most difficult.

Despite the fact that the Owner's design team bears the greatest part of the bridge's technical responsibility, some engineers – who are not directly involved in the Project but who belong to one of the contractors – question the project safety. Some newspapers interested in these informations evoked their opinion, and obliged us to give clear answers to the different question, thus wasting much time and energy.

– For example, they very soon gave an evaluation of the settlement of the pylon foundation, that they estimated to 20 centimetres. This value was in complete contradiction with the opinion of our foundation experts, Luis Angel Millan, Olivier Combarieu et Jean Renault. We had to consult an external expert, François Baguelin, who confirmed that the settlement will be limited to 3, or at the maximum 5 centimetres, a small part of it only after the closure with the access spans.

– But, most of all, the wind analysis has been questionned by an engineer who considers in a recent note that the wind forces had been underestimated by a factor 2 ! Of course, such a position is extremely unpleasant for everybody involved – two years after the call for bids –, and could have produced a stop in the bridge construction without the engineers' determination and the Owner's confidence in the design, in his wind experts, and in the advice from the six experts in charge with the Project evaluation. The out-of-scale evaluation of wind forces by this engineer is also a reassuring factor, as is, above all of course, the wide safety margin that we created as compared to the design wind forces. Nevertheless, in the same time as the construction progresses, an expertise of wind forces has been asked for by the Owner to give an end to this debate. Professor Alan Davenport is in charge of this expertise since October, 1990, and he will give his final report in March or April. But his preliminary report already assures that the evaluation of wind forces has been done following the safety principles widely accepted all around the world for large bridges, and that the necessary measures and tests have been done, mainly due to Jacques Bietry's competence.

Building big structures needs both technical competences – coming from very wide design teams, gathering all necessary experts –, and nerves of steel, due to technical competition and to the importance of the costs involved.

Finally, the most important is that the construction progresses, and that these two last years – which passed negociating the contracts, performing detailed analyses and establishing a part of the short drawings – are far from having been lost ! In addition to the construction of the North pylon protection and of the temporary bridge, they proved that our design of the Normandie Bridge is reasonable and safe.

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