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Symposium on Civil Engineering Structure Management Brussels – Paris, 1981 and An Example of an Ancient Bridge Rehabilitation

Colloque sur la gestion des ouvrages d'art Bruxelles – Paris, 1981
et Un exemple de rénovation d'un pont ancien

Kolloquium über die Verwaltung von Bauwerken Brüssel – Paris, 1981
und Ein Sanierungsbeispiel einer antiken Brücke

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SUMMARY
This article first presents a summary of the Symposium in Brussels and Paris, which took place on April 13 – 17, 1981 and was dedicated to the civil engineering structure management. It further presents an example of a rehabilitation of a bridge from the 18th century, the Wilson bridge, in Tours.

RESUME
Cet article donne d'abord une synthèse du colloque de Bruxelles et Paris, qui a eu lieu du 13 au 17 avril 1981, et était consacré à la gestion des ouvrages d'art. Il donne ensuite un exemple de réhabilitation d'un pont du 18ème siècle, le pont Wilson à Tours.

ZUSAMMENFASSUNG
Dieser Artikel enthält zuerst eine Übersicht über das Kolloquium in Brüssel und Paris, das vom 13. bis 17. April 1981 stattfand und der Verwaltung von Bauwerken gewidmet war. Anschliessend wird ein Sanierungsbeispiel einer Brücke aus dem 18. Jahrhundert, der Wilson Brücke in Tours gegeben.

The subject of this symposium was the management of civil engineering structures. It was intended to make the searchers and builders of several countries acquainted with the experiments and results in this field, of the utmost actuality, and to enable them to draw comparisons and conclusions.

Even though the problems may not be identical in the various countries where the need for more thorough and extensive knowledge is felt, they are similar enough. Such a growing internationalism of requirements and techniques should therefore be met by a corresponding development of the international cooperation in this field.

The international character of the organization of the French-Belgian symposium was very marked, since six countries besides France & Belgium were represented : Germany, U.S.A., United Kingdom, Italy, Holland and West Germany,

— either in the Program Committee, entrusted with the definition of the general organization of the symposium and the control of the technical level of the contributions and sessions,
— or in the functions of session chairmen or secretaries.

The symposium consisted in two parts :

— technical visits in Belgium, distributed over two days,
— the symposium proper, the conclusions of which are the subject of this paper, held in Paris for three days.

The organization of Washington symposium emphasizes the great interest of such international exchanges.

INTEREST OF THE SUBJECT – GENERAL RESULTS OF THE SYMPOSIUM

Numerous investigations and researches about the control, maintenance, repair and reinforcement of bridges have been carried out in several countries. The development of these works can be explained both by the high number of such structures, which, moreover, are key points in road networks, and by the evolution of technical, economic and political conditions.

The capital of civil engineering structures of our world is huge because they are a very ancient product of human intelligence. They are therefore invaluable, both as economical assets and as historical and cultural marks. Besides, the effectiveness of communications and exchanges, hence the economy of any country, depend to a large extent on the safety and quality of these structures, and heavy political or economic consequences may result from their being damaged or out of service.

The evolution of general conditions appears mainly :

— technically, in the ever increasing aggressiveness of loads and actions, and in the relatively rapid evolution of technology ;
— economically, in the restriction of investments, leading per force to some optimization of management ;
— politically, in an increased users' need for safety, leading to a definition of a balance of the accepted hazards and the efforts necessary for their limitation.

The wide extent and interest of this subject was demonstrated by the very high number of contributions from 20 different countries, which exceeded 110.

Though the major part of the contributions (90, out of which 50 were French) came from 10 countries of Western Europe, interesting contributions from North and East Europe, North America, South America, Africa, Asia and Oceania were presented.

More than 320 attendants, from 30 foreign countries, some of them very far, came from the whole world. The presence of over 200 foreigners clearly shows that the proposed themes actually correspond to present preoccupations of the persons in charge with the execution and management of the structures.

Six themes were studied :

- Safety and bearing capacity of structures.
- Checking and auscultation.
- Pathology and strengthening.
- Special techniques.
- Design and management.
- Management policy : present conditions and prospects.

Thus it is not only the various technical aspects but also the political aspect of the management of structures which have been dealt with, with the problems of organization and means, and the interaction with design, which emphasized the general character of the proposed subjects.

MAIN CONCLUSIONS

The technical conclusions drawn by the chairmen for the above six subjects have been published in the symposium report, third book.

The main general conclusions developed hereinafter stress some important notions which step out of the numerous results of the symposium and are fundamental for the attitude and general policy. They regard :

- the improvement of knowledge,
- the need to foresee and prevent events,
- the organization principles of a policy of maintenance.

The need of knowledge and the duty of information.

To assess the condition of a structure is not an easy task, as this condition is forever evolving along with the wear of materials and structures and the evolution of loads. As a whole, the behaviour of a structure is a complex phenomenon, but the evaluation of its safety is one of the main targets of the Engineer's action. Our ignorance is still very great in this field, hence the high interest of new techniques, notably auscultation (and specially the development of non-destructive procedures), and of thorough studies of the principles and methods of assessment of the bearing capacity of existing structures, which must take into account both the actual behaviour of the structure and economic restraints.

Likewise, information must be spred in order to prevent difficulties met too often by managers. This need must be emphasized the more as it has often been underrated.

It has two aspects :

- regarding structures, the necessity of constituting proper engineering structures files, and uppermost of adequate management of the constitution and development of files and data banks ;
- regarding structure behaviour. The wide field of existing structures is an invaluable field of in-situ experience. While acknowledging the difficulty of using such experience with a sufficient scientific spirit, we must not forget that there lies a source of improvement of our knowledge, which is at the root of any management rationalization process and technical progress.

Forecasting and preventing.

It is generally assumed that a structure must have a long lifetime, while retaining relatively constant, sufficient service conditions to ensure the intended safety. In this field, errors and inadequacy are highly expensive.

Besides, a good management policy is a whole, starting at design level and proceeding throughout the structure lifetime. As numerous decisions must be made during that period, which imply choices the consequences of which are felt both immediately and in the future, the questions should forecast these consequences in order to get some optimization of the costs.

Prevention must be present at all stages :

- Design : this notion was dealt with in a specific theme, with much information on the steps to be taken or advocated in a project, as they are most effective when taken at that stage.
- Control : one of its main objects being to make it possible to carry out, in due time, the most adequate utilization and maintenance measures.
- Maintenance : it must be mostly preventive, as it is regular, scheduled maintenance only which enables to tend to economic optimization, by reducing technical hazards, improvised works and service breaks.

Organization – Financial requirements.

Several interesting notions were evoked in the discussions about management policy, many of which were general enough to be usable within the different frames of the organization structures of the various countries.

As regards organization, the basic notion is the uniqueness of the manager's responsibility. The manager of a road network should be held responsible for the structures of such a network. He must not leave technical specialists to deal with the choice of the applied methodology, the technical criteria for decision, the schedule of systematical rehabilitation of the structures, etc. Besides, it is important for a good understanding of all, and for a clear application of decisions, that a common language should be devised.

As regards the ever insufficient financial means, their limitation leads to an ever-increasing need of as effective and as rational a management as can be.

The problem of men has been stressed. In this field where technical progress cannot substitute the Engineer's craft, or the technicians' qualities, the adequacy of men is essential. This adequacy may result from specialization or from experience, but it is usually rare enough to call for an important effort, to develop a policy based on personnel stability and on training and teaching actions at every level, and intended to retain and promote competence.

Research

The present effort for studies and researches, regarding both theories and methodology, and techniques proper, clearly appeared in the symposium. This already important effort must be developed, and the following is to be noted :

- One should not hesitate, when dealing with ancient bridges restoration, to apply the most modern procedures, and techniques, as is already done with data processing, radioactive analysers, synthetic materials, etc...
- Generally, quality must be the major goal. Almost often, a compromise must be found between safety and quality requirements, and economic restraints. But in this compromise, technical progress is the tool to be used to meet economic requirements.
- The extent of this subject calls for international cooperation regarding researches and the works to be performed. The road is opened by O.C.D.E. works, A.I.P.C. actions, and the various symposiums, among which BRUSSELS-PARIS and WASHINGTON'S.

CONCLUSION

Through its various contributions and discussions, this symposium promoted a new advance in every aspect of the management of the structure capital : knowledge of structure behaviour, requirements and techniques to be applied in this difficult craft, necessary policy.

It was doubtless useful to all attendants, as each of them could benefit by the contact of the others and their experience, and the importance of the symposium's subject for the Engineer. Structure management is a field in which the Engineer's craft must apply, responsibilities must face a complex reality and difficult technical problems, and it must be kept in mind that the decisions can have very important economic and political consequences.

Finally, the symposium was successful in permitting information and experience exchanges, and in showing the need for further cooperation in this field.

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AN EXEMPLE OF AN ANCIENT BRIDGE REHABILITATION : TOURS BRIDGE

Tours' bridge was built in the 18th century, from 1765 to 1777, by Bayeux Sr., Ingénieur Général des Ponts et Chaussées, with the assistance of Vallée Sr., Bugey, de Voglie, Cadet de Limay and Vallée Jr.

This structure crosses the river Loire over 436,60 m from one abutment to the other. It includes 15 ellipse-shaped arches spanning about 24,50 m, with a span-to-rise ratio of three. It was thought, when completed, the most beautiful bridge in the world, and was currently considered as one of the major four bridges in France by the end of the 19th century.

The 14 piers rested on a series of vertical wood piles, hammer-driven through sand deposits down to limestone. Some foundations have been protected, ever since the bridge's construction, by adjoining wood piles, originally a cofferdam during construction.

The history of this bridge has been very eventful. Even before completion, the 8th pier suddenly sunk down, and had to be built over, together with both neighbouring arches. Sand removal between the piles which led to instability under the action of transverse loads, accounted for this collapse. Jean-Rodolphe Perronet, « Premier Ingénieur du Roi », then advocated building protections made of adjoining wood piles blocked by riprap around piers 8 to 12. Thus the only piers left unprotected were piers 2 to 6, which had been built on the old St Jacques island, but at that time the flow was running along the right bank.

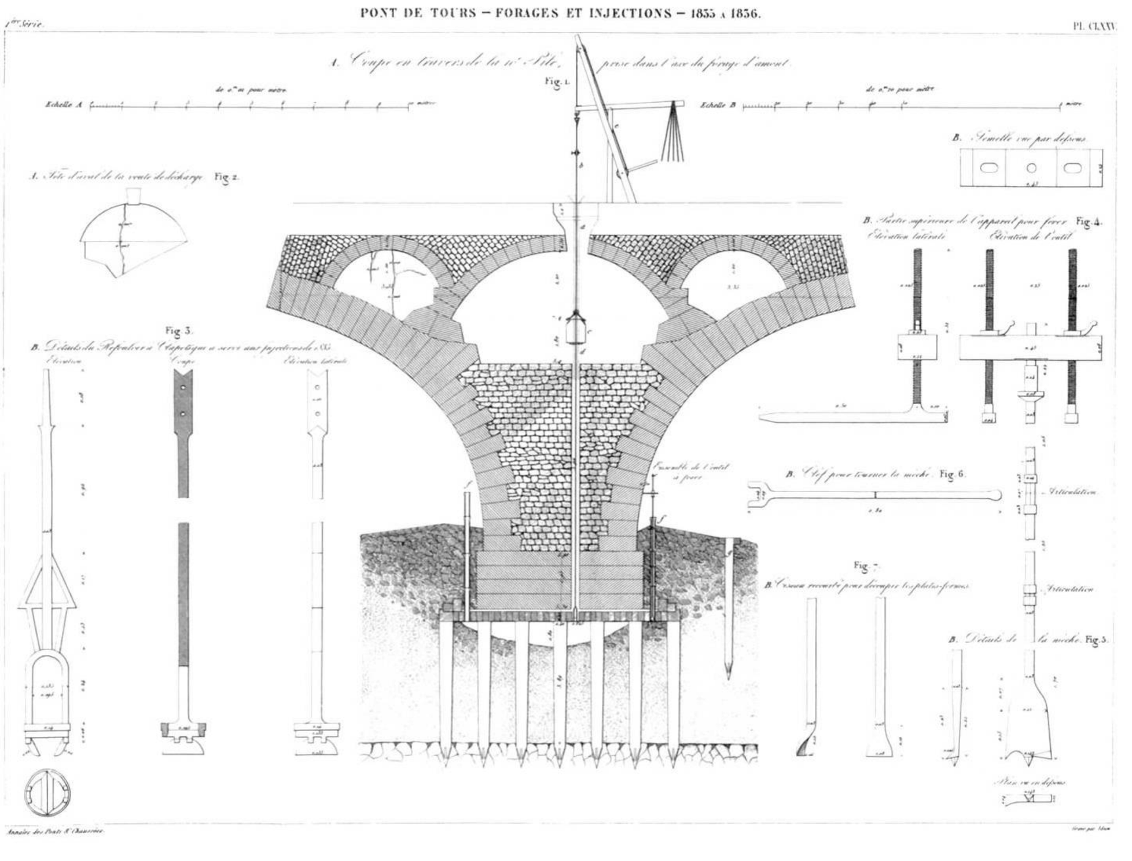


Fig. 1 : 1835 – Lime injections.
(drawing, in Annales des Ponts et Chaussées of that time).

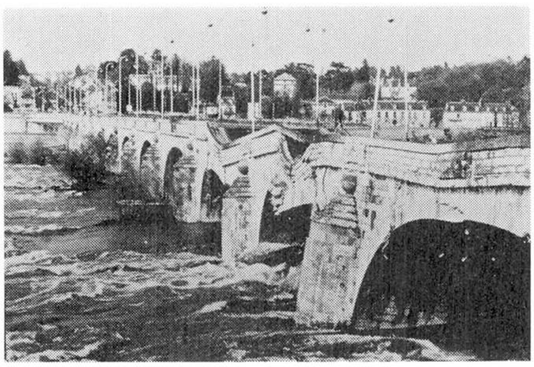
The collapse of the piers 12 to 14 and corresponding arches, on the 1789 river thaw, was also close to the right bank. Reconstruction works,slackened by the French Revolution,were completed in 1810 only.

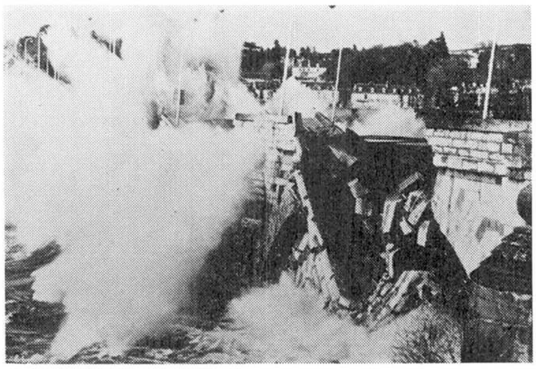
In 1835, piles 9 and 10 sunk noticeably, and disorders appeared in the masonry of arches 9, 10 and 11. Lime was injected to fill up cavities under the foundations of piers 9, 10 and 11.

In 1978, during borings performed to assess the condition of the foundations, elements of this history (pieces of the ancient wood plaftorms, masonry of the beds of the collapsed piers, lime injections ...) were found to confirm the information in the file records, even the measures mentioned in 18th and 19th century reports.

Finally, the bridge, called « Wilson bridge » between the two world wars, was injured by the second one. The French army destroyed the first arch in 1940 in order in hinder the German army's advance. It was reinstated later in the year. In 1944, in turn, the German army destroyed arches 9, 10 and 11, along with piers 9 and 10, to protect its flight. They were built over from 1946 to 1950, using slightly reinforced concrete, and the same ashlars as the original ones, though thinner with a somewhat different pattern, for economic reasons.

Then on April 9th, 1978, at 9.27 a.m., pier 2 sinks and brings down the upstream-faced part of the 2nd arch. At 2.15 p.m., the upstream-faced part of the 3rd arch collapses in turn. At 4.02 p.m., pier 2 sinks by one metre, and arches 2, 3 and 4 crash down. On april 10th, pier 4 sinks downstream, spans 5 and 6 fall and pier 5 tilts down. Finally, on May 3rd, pier 1's collapse induces span 1's fall. Most fortunately, there was no victim.





Photographs 1 & 2 : The collapse of the bridge, on April 9th, 1978, at 4.02 p.m. (Photographs by Pierre Fitou — La Nouvelle République)

The reason for this collapse was, once again, the removal of sand between the piers unprotected by adjoining wood piles, and the resulting transverse-force induced instability.

TEMPORARY STRENGTHENING

First of all, the engineers in charge with restoration works had to protect the part of the bridge still standing.

They had to clear the Loire's bed of all the masonry of the collapsed arches and piers, to prevent a shift of the flow which could endanger the remaining piers.

Much of the removed materials were used as a supporting shell built against pier 6, to enable it to resist the thrust of the 7th arch, left unbalanced after the fall of the 6th arch. However, as the thrust of an arch may range from 2,000 to 2,700 metric tons, depending on calculations and mainly on the masonry condition, this was not thought sufficient.

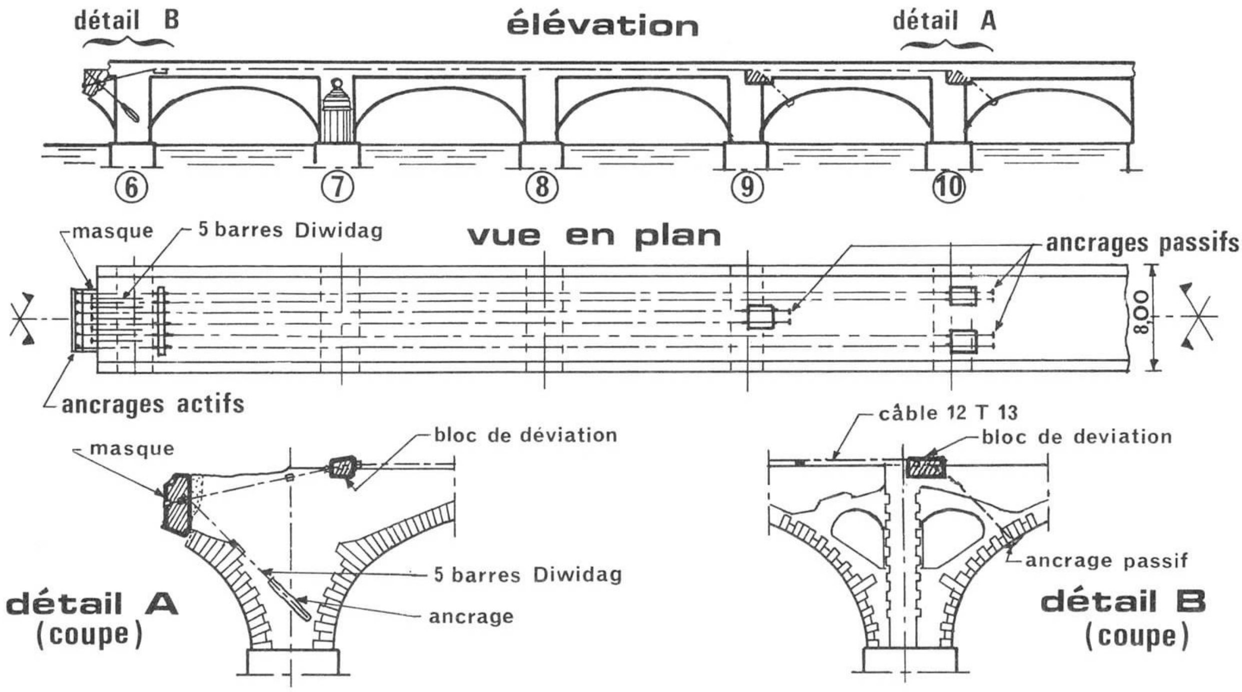
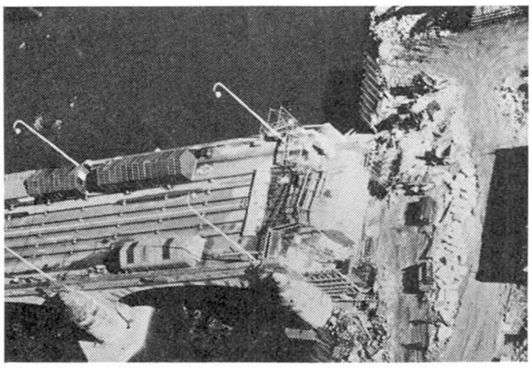
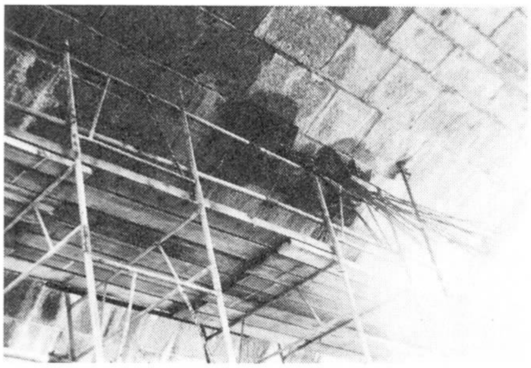


Fig. 2 : Pier 6 : temporary prestressing.

Six prestressing tendons, made of 12 strands of 13 millimeters, Freyssinet type, were therefore tensionned between the 6th and the 11th arches, and anchored in a reinforced concrete block cast against the standing part of the 6th arch, at the one end, and under the 10th and the 11th arches (2 tendons under the 10th, 4 tendons under the 11th) at the other end. They were laid on the deck and shifted down to the anchorages by deviators on either side. They were grouted with grease.



Photograph 3 : Temporary stabilization cables on the deck.



Photograph 4 : Anchorages under the 11th arch.

The stability of the anchor block of span 6 was ensured by a series of 5 embedded Diwidag bars.

This stabilization prestressing device reduced the thrust of the 7th arch by 650 tons approx.

Soil injections had previously been performed under piers 6, 7 and 8, in order to fill the largest cavities and to make the procedure safer.

FINAL STRENGTHENING OF PIERS 6 TO 14

But this did not constitute a lasting strenghtening of the still standing piers 6 to 14.

Since the Loire's bed in the bridge area is embarrassed with wood piles and masonry over some width on either side, the practical solution consisted in building a huge sheet-pile cofferdam, enclosing the remaining 9 piers and the right-bank abutment. The sheet piles (Larssen 3 S) were hammer-driven, throughout the sand, down to 1,50 m into the limestone.

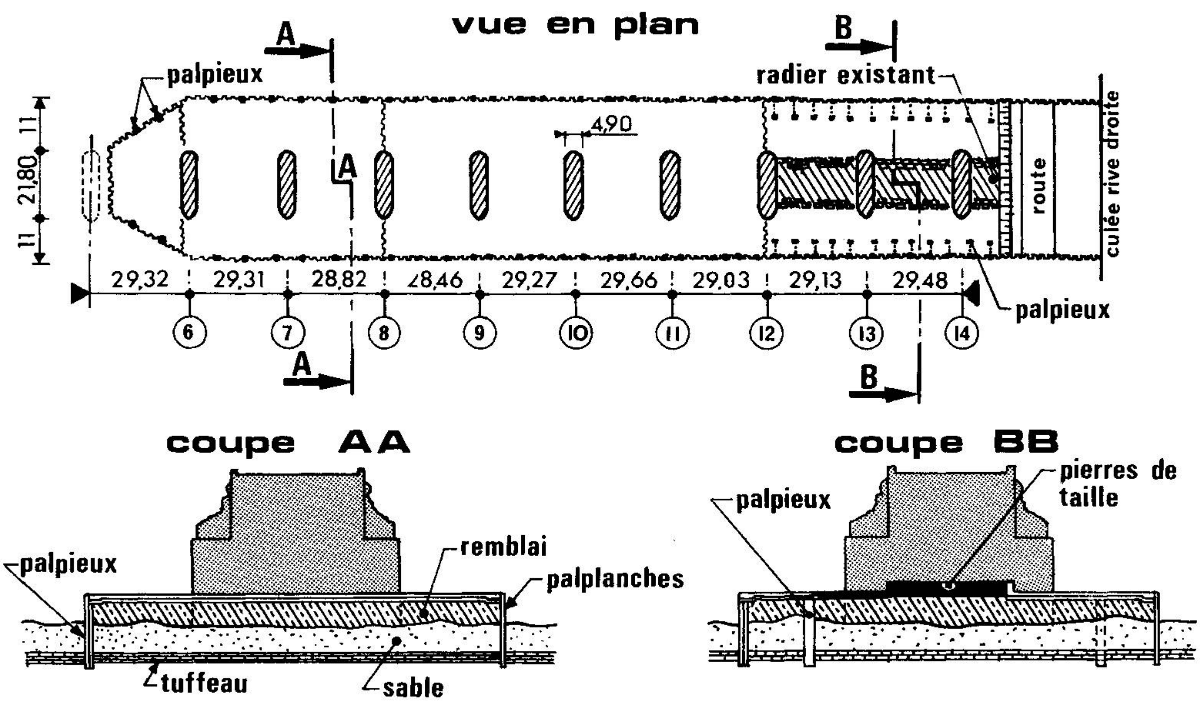


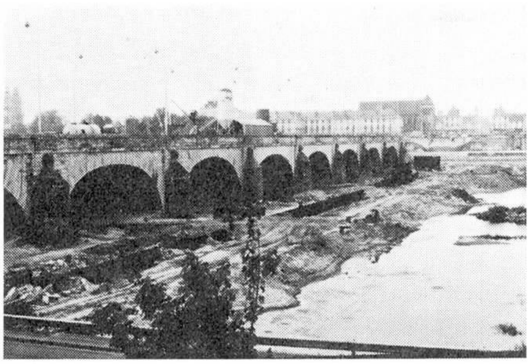
Fig. 3 : Drawing of the general cofferdam ensuring final strengthening of foundations.

An overall reinforced concrete slab, surrounding the piers, over the whole cofferdam, is intended to prevent the sand removal.

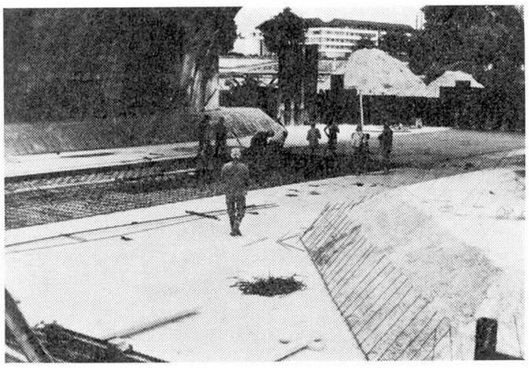
Under arches 6 to 12, the slab behaves as a tie between the upstream and downstream cofferdam walls. Moreover, these walls are stiffened by a pile box in sheet piling, every 6 metres.

Under arches 13 to 15, this solution was unpracticable because of high existing masonry raft. The concrete slab could not pass under the structure and it had to be interrupted. The stability of the sheet piling was ensured by frames, 4 metres apart, consisting of a pile box, included in the sheet pile wall, an 8 – m long tie, and a rear pile box, within the cofferdam.

After completion of this cofferdam, 40 metres wide and almost 300 metres long, and of the top slab, all the cavities under the piers were injected, even the small ones. The volume of injection could be reduced by a primary injection around each pier.



Photograph 5 : General view of cofferdam construction works.



Photograph 6 : Slab casting.

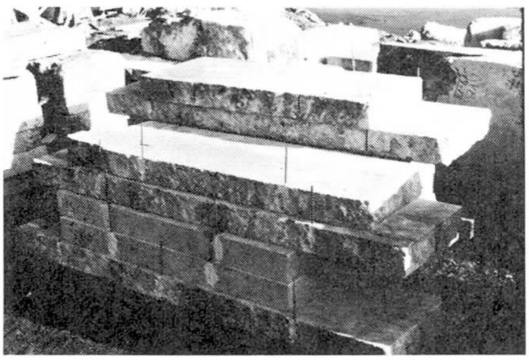
A lowered channel was built up, in order to provide for normal flow on low-water and, theoretically, for navigation.

RECONSTRUCTION OF ARCHES 1 TO 6.

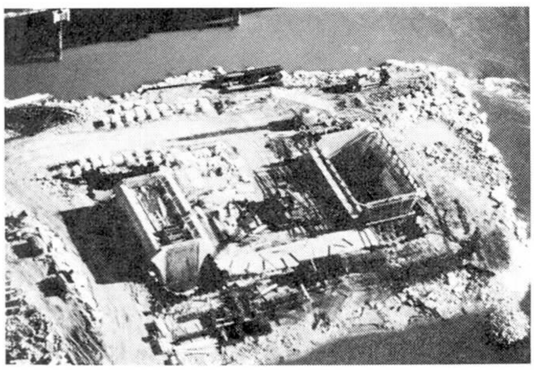
Finally, the collapsed 5 piers and 6 arches were to be reinstated.

It was decided, at the very beginning of the works, to build in reinforced concrete, with a thin stone facing. The concrete was poured direct onto the stone facings, laid on the bottom and sides of the formworks. Small stainless steel connectors, resin-bonded to the stone, provide for the stone facings and concrete adhesion.

The piers were conventionally built within sheet-pile cofferdams, using stone facings thick enough (min. 10 cm) to prevent too quick a flow-induced erosion.



Photograph 7 : Stone facings (from the soffit)



Photograph 8 : Piers 4 and 5 under progress.

For the deck, hinges at the springings of every arch are designed to prevent the important forces resulting from temperature shifts, and from concrete shrinkage and creep, from originating concrete cracking and possibly facing stone breaking.

The arch proper was cast in two steps, to reduce the centre size. The spandrels were built after arch completion.

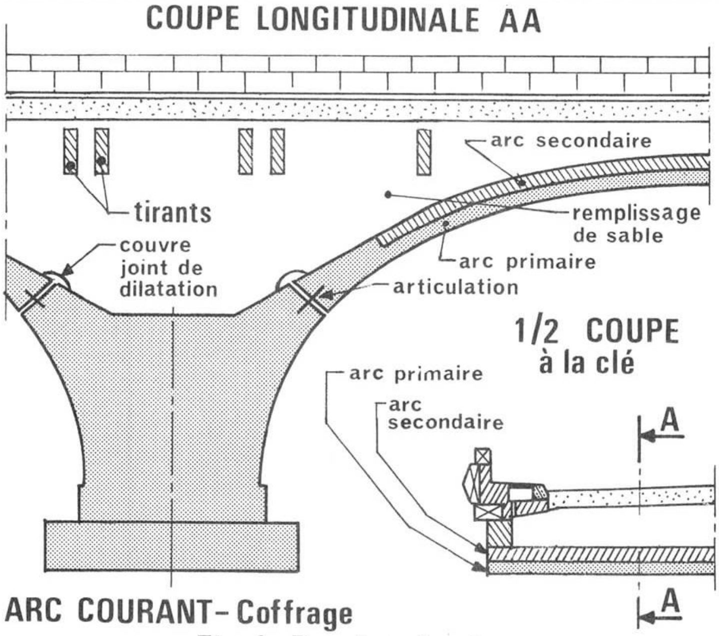
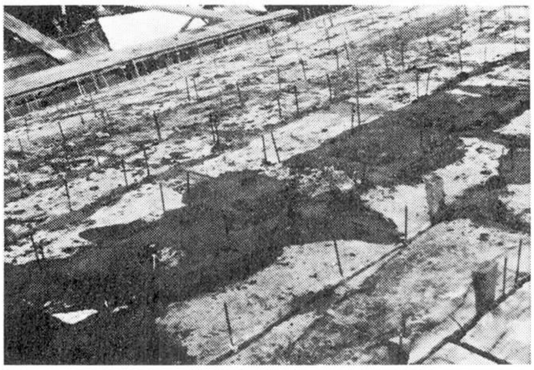
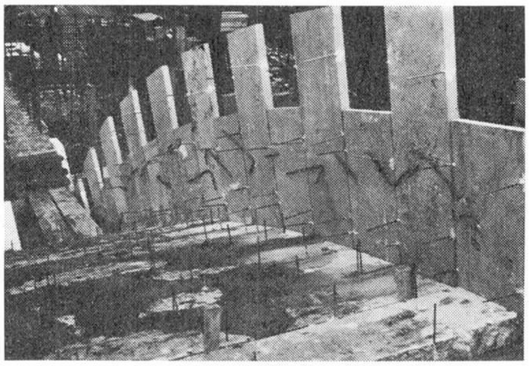


Fig. 4 : Drawing of arches.

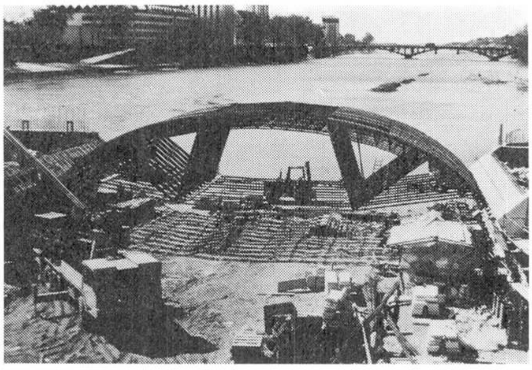




Photographs 9 & 10 : Installation of facing stones on the centre.

The center was made of several elementary beams, assembled in sets of 3 beams, resting at the pier tops, right beneath the hinges, on temporary supports, hanging using Diwidag bars. The 3 beam sets could be moved transversally on the supports, then placed over another span, without any need for dismantling.

After deck completion, the arch watertightness was ensured, and sand filling was provided as pavement support.



Photograph 11 : A centre of Tours' bridge.

The main difficulty lied in connecting the older and the new structures.

A huge counterweight block was built close by the abutment to balance the hinge-supporting corbel, the hinge being placed at the arch haunch due to the deck widening. As for the widenings on either side of this counterweight block, they were held in suspension by prestressing tendons, the need for which appeared suddenly when large cracks were found in the masonry of embankment walls.

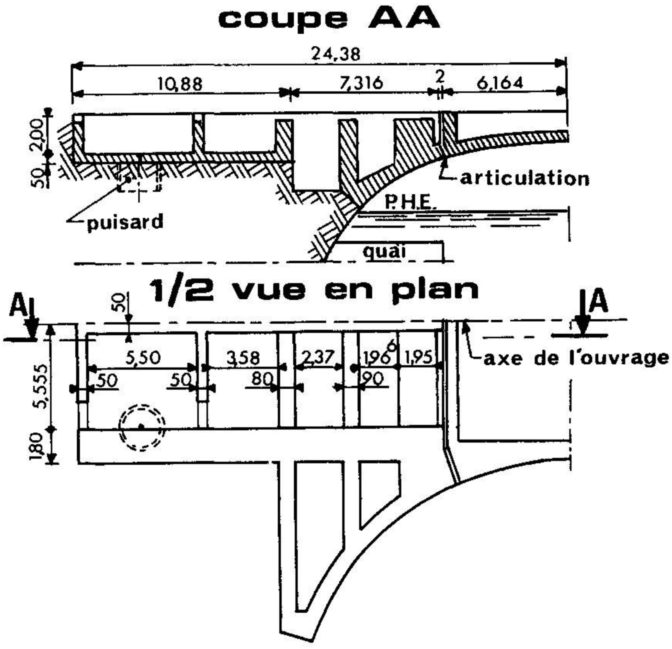


Fig. 5 : Abutment drawing.

Nevertheless, the most difficult problem was the connection to pier 6. It was necessary to have the new arch of span 6 supported by the existing pier, but the temporary stability prestressing could not be removed before, and the thrust of the new arch was to substitute to prestressing forces progressively.

The partly destroyed masonry was cleared away. On either side of the anchorage block of the temporary tendons, a supporting block was designed to bear the lateral ends of the new span. When this new span was built, the temporary prestressing was removed, its anchorage block still untouched ; then it was destroyed in turn, any damaged masonry was cleared off, the supporting block was extended to the whole deck width, and span 6, hinged over the supporting block on top of the former masonry, was finally completed.

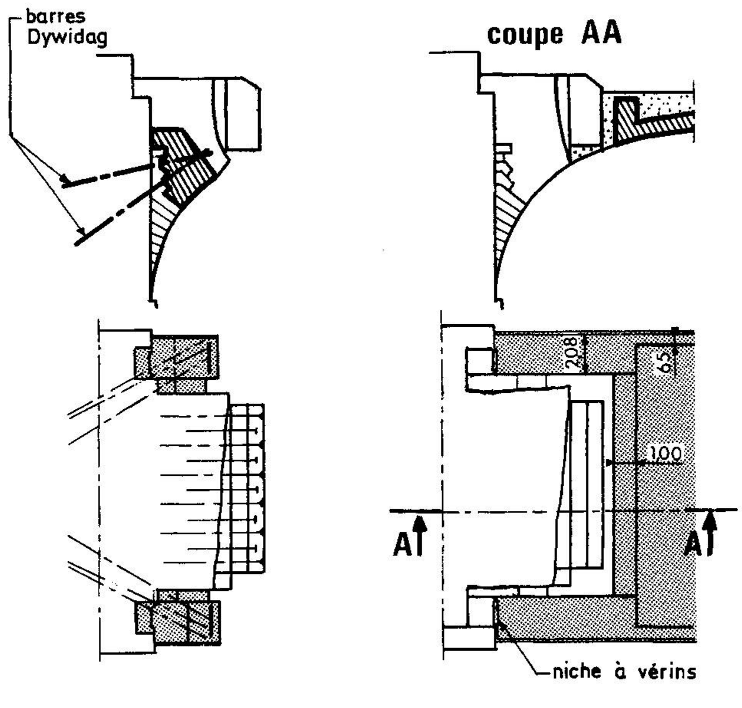
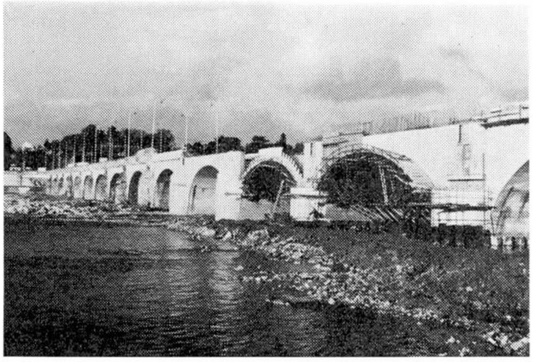


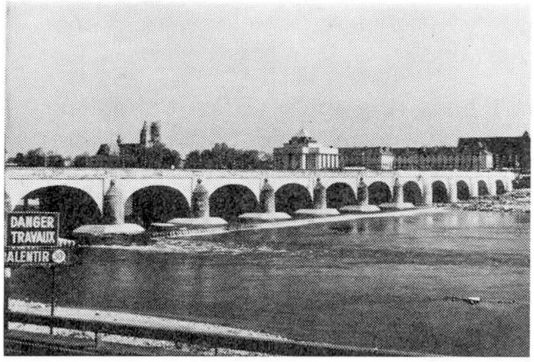
Fig. 6 : Connection to pier 6.

CONCLUSION

Now the reinstatement of Tours' bridge is over.



Photograph 12 : Completion of reinstatement works.



Photograph 13 : The restored bridge in Tours.

The overall cost of this operation, including the construction of two temporary bridges, is over 15 million U.S. $. The restoration of the 6 destroyed arches and the strengthening of the still standing piers, has been almost as expensive as a new bridge would have been.

But one of the most important of the 18th century bridges has been reinstated in its original appearence.

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