BII3: Special erection methods

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BII 3

Typical methods of erecting four bridges across main rivers in the Netherlands

Méthodes caractéristiques de montage pour quatre ponts sur des rivières principales aux Pays-Bas

Besondere Montageverfahren für vier Brücken über grosse Flüsse in Holland

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The Hague Utrecht

(a) ROAD BRIDGE OVER THE RIVER LEK NEAR VIANEN

The river crossing at Vianen was first completed in 1936 as shown in fig. 1(*c*). To allow international and other traffic to pass during erection a passage of 60 m. was kept in the trestlework. To assemble the arch, with a span of 160 m., 28 m. above the flooring a movable tower-swing-crane with the underside of the arm 3 m. above the top of the arch was used.

The main span was destroyed in 1944; the spans at the south side of the river were only damaged. The traffic was kept going by a ferry and afterwards over a Bailey-bridge on barges. During ice-drift traffic was diverted over the railway bridge at Culembourg, 12 km. upstream. The increasing railway traffic made it necessary to remove the temporary wooden flooring on this bridge, and so the rebuilding of the original bridge at Vianen had to be completed in a very short time.

No girders or spans were available for building a trestlework with a suitable passage for navigation. The available time and the demands of navigation made it necessary to erect the main span in big units with floating cranes. These cranes, the Condor and the Heracles, shown in fig. 1(*a*), can lift 200 and 250 tons each.

The erection method is shown in fig. 1(*b*). Two auxiliary piers of steel sheet piling were driven in the river 60 m. apart. On these piers heavy reinforced-concrete blocks were made. The 30-m. high steel pillars were constructed of the floor-girders of the bridge.

At first four arch units, each with a weight of 180 tons, were placed with the above-mentioned floating cranes. The higher parts of the arch were built from both sides. For this assembly a floating crane had to be supplied with shear legs constructed of truss-jibs used on another work (fig. 1(*d*) and fig. 2).

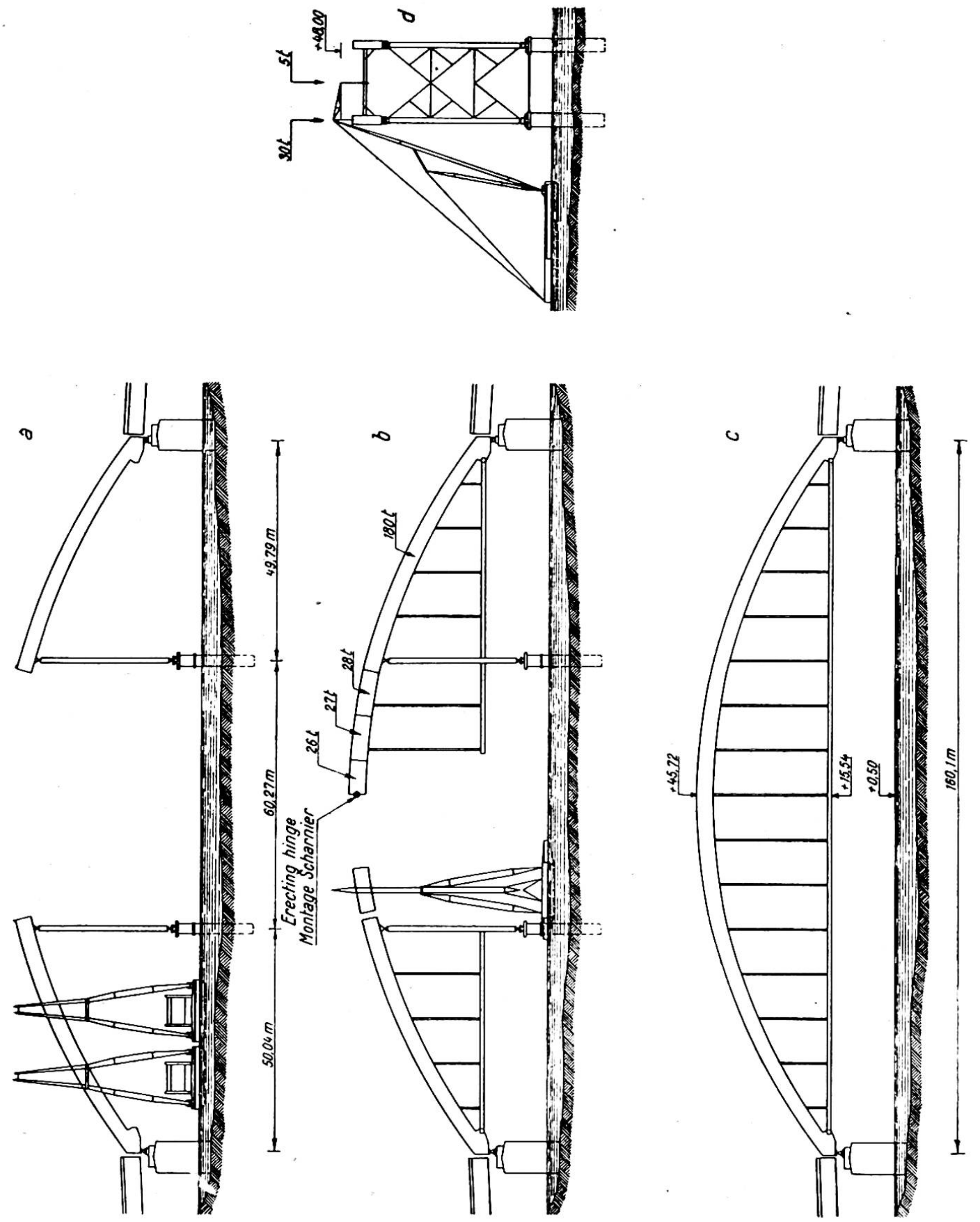

Fig. 1. Bridge over the River Lek near Vianen

In the top of the arch a temporary hinge was constructed, an opening of 300 mm. being left for this hinge; afterwards one of the bridge parts had to be rolled in to bring the two parts together. After completing the concrete flooring the two parts of each arch were joined by gusset plates thus putting the hinge out of action. Thus the main span is a three-hinged arch for the dead weight only. Special calculations were made to give the bowstring the right camber.

In September the first arch parts were placed. In the middle of November the pillars could be removed. In a short time the crossbeams and some of the floor-girders were erected; over this flooring a Bailey-bridge was laid 1·80 m. above the concrete flooring (fig. 3). Traffic could pass over the Bailey-bridge on the same day

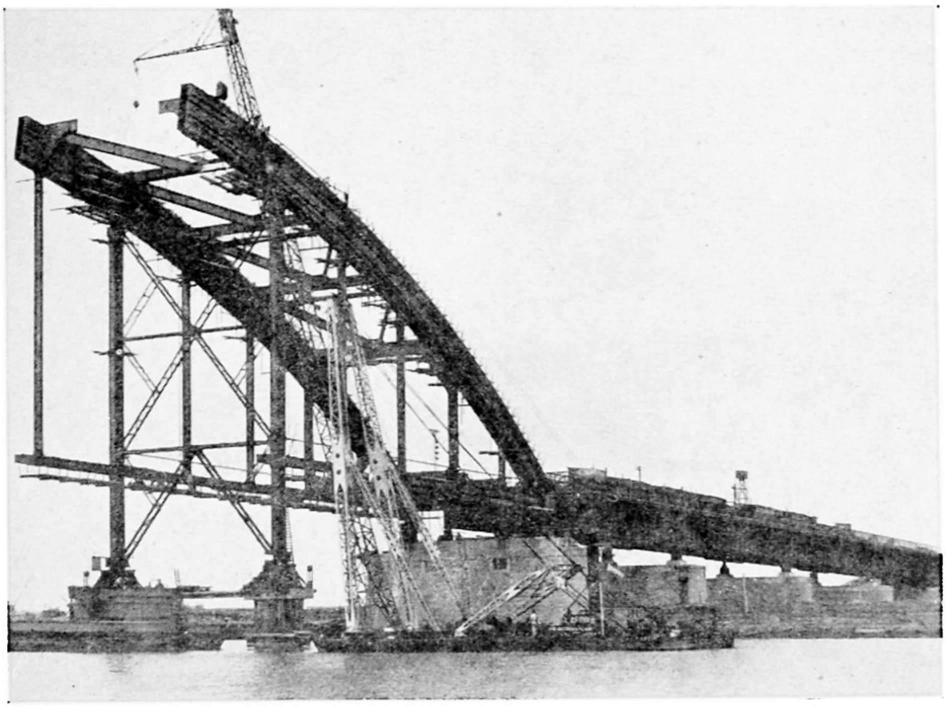

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Fig. 2. Vianen Bridge

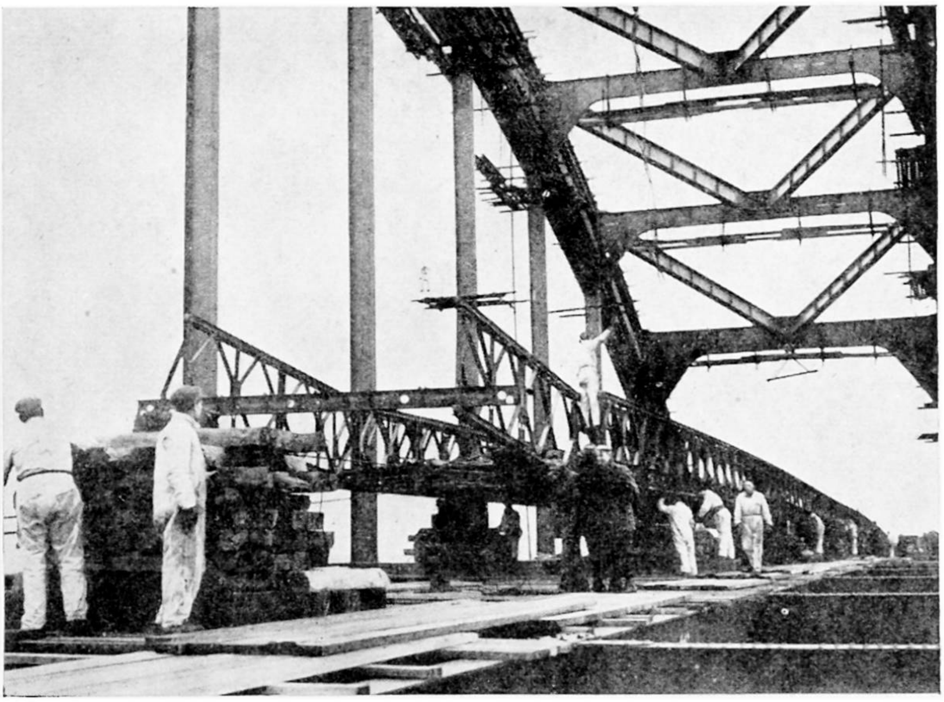

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Fig. 3. Vianen Bridge

as the floating bridge had to be removed, on 23 December 1948. The concrete floor had to be completed while traffic continued.

(b) ROAD BRIDGE OVER THE RIVER RHINE AT ARNHEM

The main span of the bridge at Arnhem has been designed as a bridge on four supports, with spans of 50 m. at either side of the middle span of 120 m., stiffened with an arch. The total weight of these three spans is 4,600 tons, including the concrete slab. This bridge was first destroyed in 1940, and a second time in 1944. The procedure of the erection of these arch bridges by using only a few temporary supports in the river was given in the Preliminary Publication of the Third Congress of the I.A.B.S.E.

The second reconstruction had some interesting features, as on the piers of the bridge two double-triple Bailey-bridges were laid. To reduce the span of the Bailey-bridges two auxiliary piers were placed in the river (figs. 4 and 5 (*a*)).

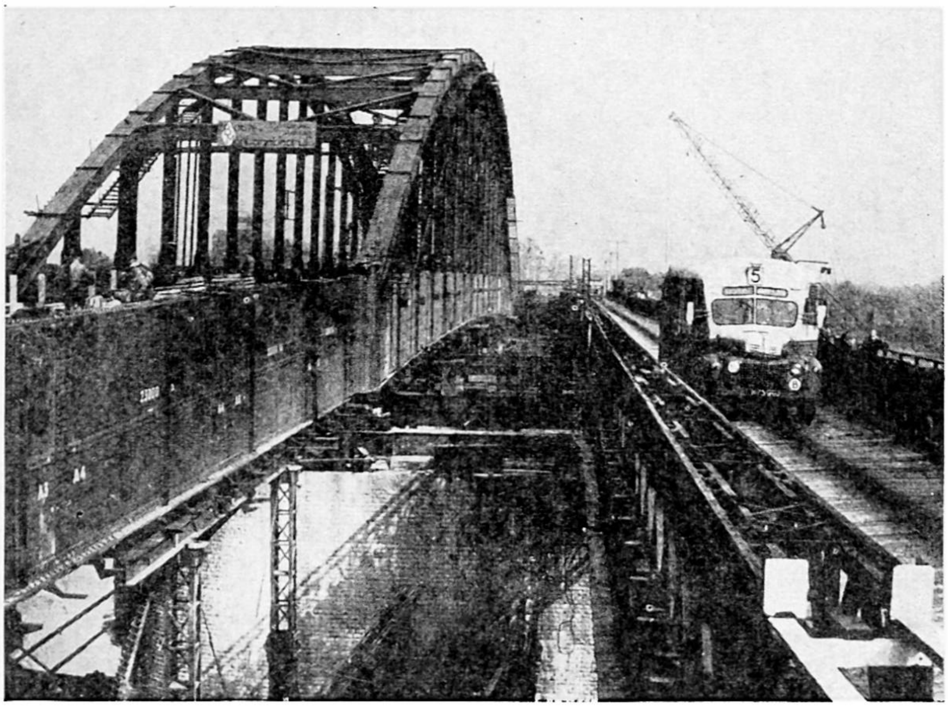

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Fig. 4. Arnhem Bridge

These piers were designed for the erection of the main girders of the permanent structure at either side of the Bailey-bridges. To fulfil this project the Bailey-bridges had to be lifted for 4·75 m. and the erection of the floor would have met considerable difficulties.

The contractor therefore proposed to build the new bridge downstream of the Bailey-bridge by enlarging the auxiliary piers and driving two piers of steel sheet piling at the downstream side of the river piers. Difficulties were met during pile driving, as parts of the destroyed steel structure were buried in the river bed at a depth of 3 m.

As the maximum weight was limited by the piling, the concrete slab could only be completed for one traffic lane (fig. 5(*b*) and (*d*)). The footway at the side of the

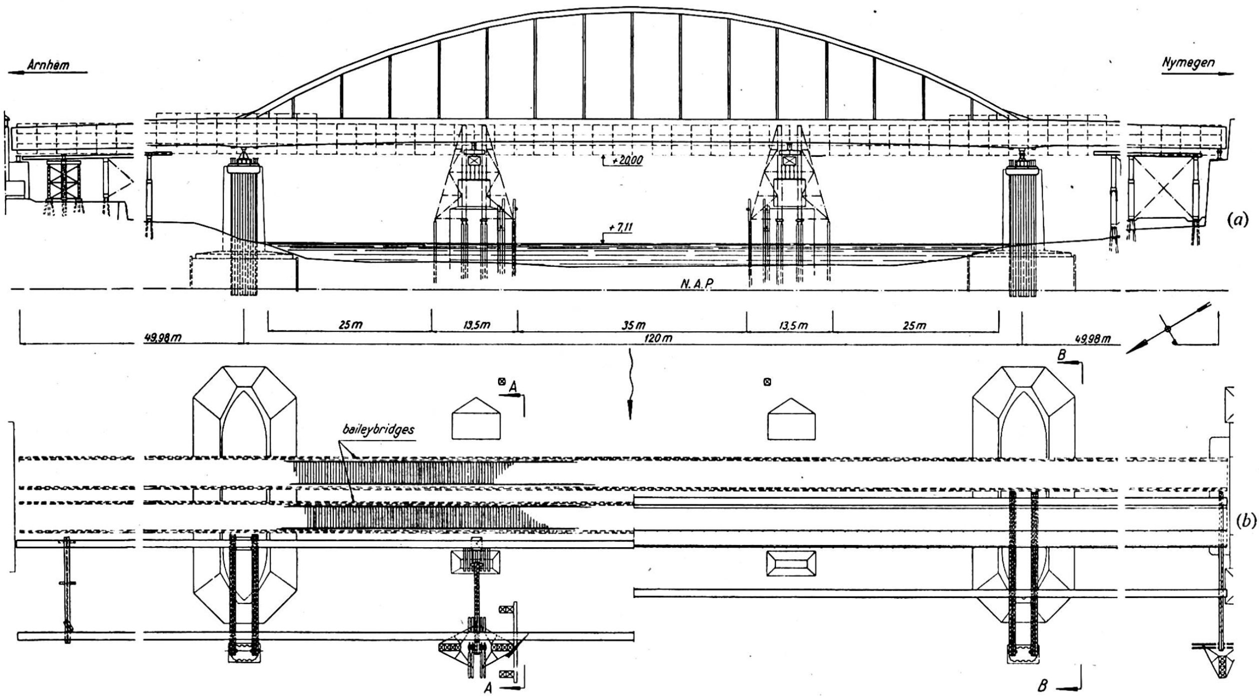


Fig. 5. Bridge over the River Rhine at Arnhem

Bailey-bridges was not yet built and the footway at the other side was partly completed and provided with a wooden floor as a temporary passage. At this stage the Bailey-bridge downstream was removed and the new bridge was pushed sideways by hydraulic jacks over a distance of 7·40 m. Traffic could now use one Bailey-bridge and the concrete floor. The second Bailey-bridge was removed and the permanent construction pushed into the right place while traffic continued. The total distance of rolling was 14·80 m. The force needed to roll the bridge totalled 75 tons divided over four jacks. Finally the concrete floor and the footways were completed.

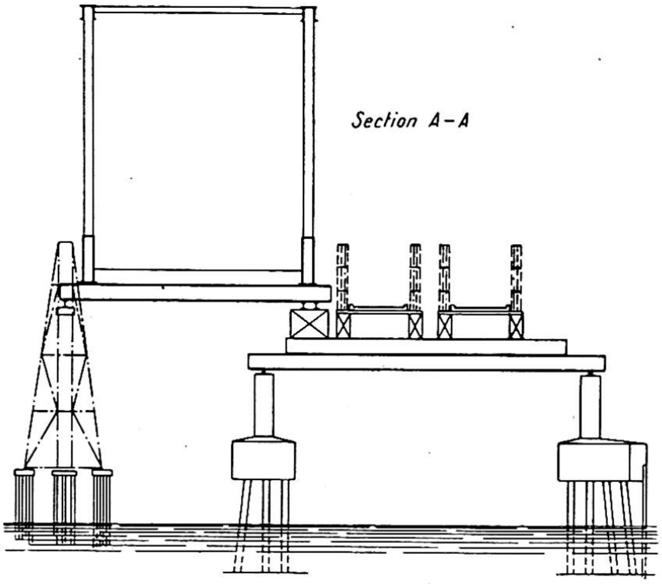


Fig. 5 (*c*).

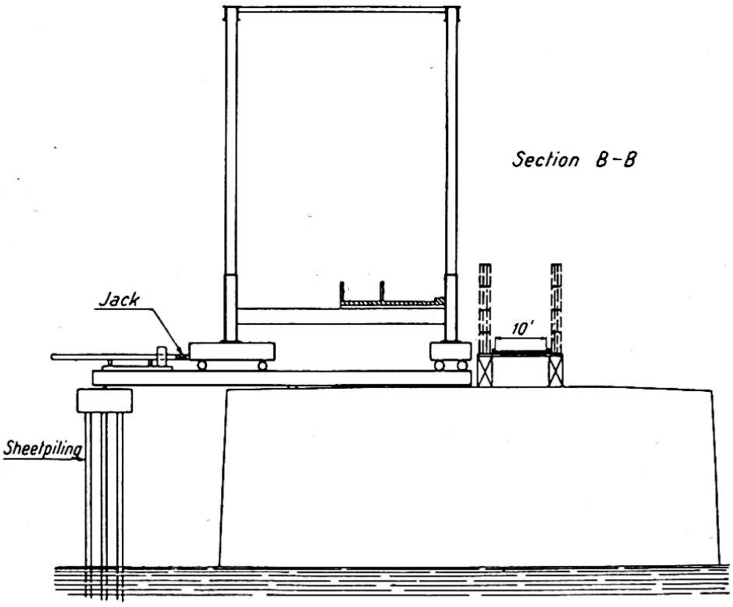


Fig. 5 (*d*)

(c) RAILWAY BRIDGE OVER THE RIVER OUDE MAAS NEAR DORDRECHT ON THE ROTTERDAM–DORDRECHT SECTION

During the provisional repair in 1945–46 of the bridge over the River Oude Maas near Dordrecht, both the double-track truss-bridges that lay originally between the two swing-bridges were replaced by a single-track span, released from the temporary arrangements used during the construction of the new Waterloo Bridge in London, and a single-track Type D Callendar-Hamilton span with triple main girders. Both these spans were erected in the downstream track, that is, the track nearest to the road bridge.

In the final reconstruction in 1949–50 these auxiliary spans had to be replaced by a double-track span on three supports. This bridge was assembled on the upstream side and then rolled in. The temporary spans had to be rolled out at the same time.

As the traffic on this section is very dense and many international trains coming from Amsterdam or the Hook of Holland cross this bridge, the inevitable interruption of the traffic had to be restricted to a minimum. It was possible to execute the replacement in eleven hours, from Saturday evening, 5 August 1950, at 21.30 hours, until Sunday morning, 6 August, at 8.30 hours, by observing the following procedure:

(1) the erection programme had to be planned in such a way that it was possible to put the bottom castings of the bearings of the new bridge into position *before* it was rolled in, and

(2) the height by which the new bridge had to be jacked down upon its final supports after it had been rolled in had to be kept as small as possible.

In addition to the above, it was obligatory to avoid any obstructions in the navigation channel in the form of temporary supports. For the same reason also, the use of floating cranes had to be restricted to as short a duration as possible. Finally, no speed restrictions at all were allowed over the bridge.

The erection was executed in the following sequence:

(1) The uppermost parts of the three piers were replaced by reinforced-concrete slabs, the top of which had to be kept at a lower level in order to get the necessary room for the bearings of the new bridge which are much deeper than the old ones.

(2) On the upstream as well as on the downstream side of each pier temporary steel trestles were erected on the existing foundations.

(3) As all the spans were to be rolled in or out, roller paths were constructed of wide-flange beams at the same level as the top of the bottom castings of the bearings. For the middle pier three such paths were constructed (one for the new span and two for the temporary ones) and one for each of the two other piers.

(4) Each of the main girders of the new span was erected in two parts by floating cranes (fig. 6). The first part of each main girder was placed on roller-frames that were already mounted on two of the roller paths, and the second part was connected at the points 1 and 2 with the first part by means of pins and then lowered by the floating cranes till its other end came to rest upon the third roller-frame (fig. 7). The four big parts of the main girders were riveted in the factory and the rivet holes of the connection-points 1 and 2 were reamed there also. By executing the erection in this manner it was possible to induce into the members of the main girders the same dead-load stresses as provided for in the calculations. The downstream main girder was fastened to the temporary spans and the upstream main girder was coupled to the downstream one.

(5) The cross-girders, the stringers and the bracings were erected with a crane moving on rails laid on the top chords of the new span.

Dordrechtsch Nieuwsblad

Fig. 6. Dordrecht Bridge

(6) In order to enable the rolling out of the temporary spans, the rails and the electric-traction conductors were disconnected, the spans were jacked up, their bearings were replaced by roller-frames and the spans lowered on to them.

(7) The rolling in of the new span (1,600 tons) and of both the temporary spans (600 tons each) was accomplished simultaneously by means of two 10-ton and two 5-ton hand-winches, all mounted on the floor of the new span near the middle pier. With each of the smaller winches one end of the new span was pulled sideways, with both the bigger winches pulling at the centre. The new span rested on six and

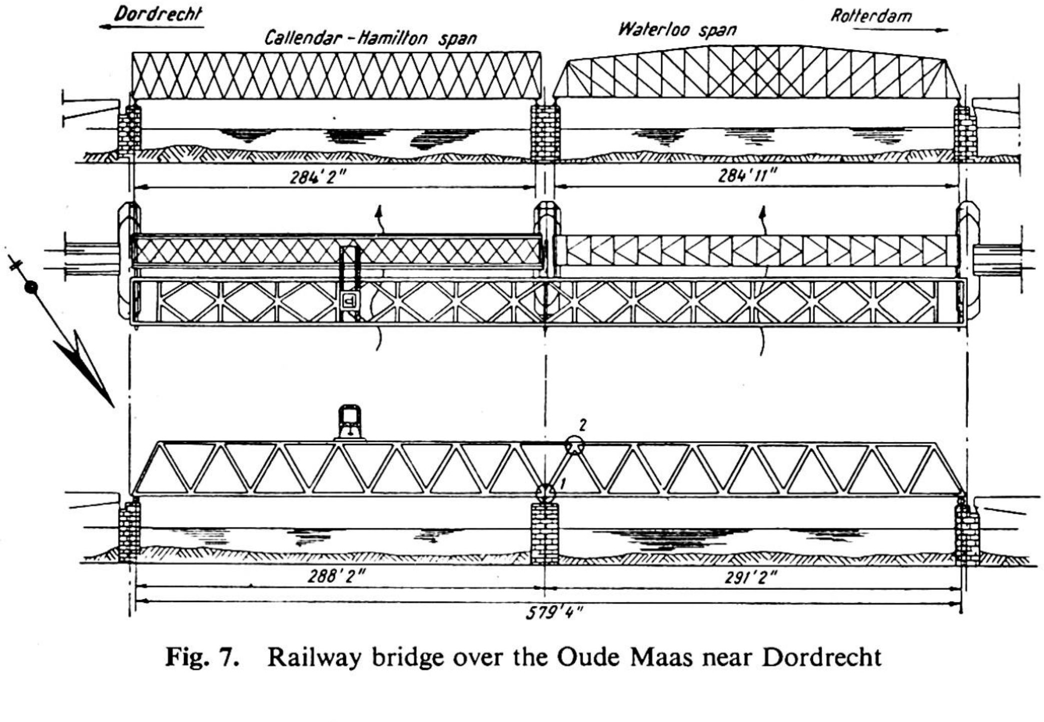


Fig. 7. Railway bridge over the Oude Maas near Dordrecht

each of the two temporary spans on four roller-frames. These two spans were pushed aside by the new span. In order to be able to control the movement, signal-lamps that could be worked from all the piers were mounted near the winches, and telephone connections were made between the piers and the post of command near the winches. In addition an arrangement was made by which a rod, suspended in the middle of the new span, moved out of its normal horizontal position as soon as one of the ends of the new span moved faster than the other.

(8) After the new span had been rolled into position it was jacked up, the roller frames were rolled out, the new bearings were mounted on the bottom castings and the span was lowered upon its bearings. In order to speed up the mounting of the heavy bearings they were rolled in sideways on small rollers. Then they were jacked up and lowered upon the bottom castings.

(9) Finally the tracks and the electric-traction conductors on the swing-bridges and the new span were connected. This took rather a long time, as the new span is situated between two swing-bridges, which necessitates rather complicated connections. The work described in (6) above was accomplished between 21.30 and 23.55 hours, that described in (7) between 23.55 and 3.00 hours, that described in (8) between 3.00 and 3.45 hours and that described in (9) between 3.45 and 8.30 hours. Provision was made for an adequate reserve of winches, jacks, lamps and electric generators.

After the new span was opened to traffic both the temporary spans had to be removed. This was impeded by their being situated in the rather narrow space between the road bridge and the new railway span, which made it impossible to use big floating cranes. The removal was accomplished in the following sequence:

(1) The floors and the bracings were taken away by the crane running on the top chords of the new span; the downstream main girders, which still rested upon the roller-frames, were rolled inwards and fastened to the upstream main girders. This made it possible to remove the downstream girders piecemeal by the crane.

(2) After the upstream triple girder of the Callendar-Hamilton span had been fastened on the new bridge, two of its three girders could be removed in the same manner, the remaining part always being strong enough to support its own weight. The last of the three girders had, of course, to be suspended on the new span before it could be removed piecemeal by the above-mentioned crane. Its weight was so small that this could be done without overstressing the new span.

(3) The upstream main girder of the Waterloo span, which could be considered as scrap, was securely fastened to the new span at a point situated at one-third of its span. A small floating crane having taken over a part of the dead load, this girder was flame-cut into two pieces, a small one, slung from the crane, and a big one, still suspended on the new span and resting on the pier. Then the middle of this big part was fastened to the new bridge, and this part was cut into two pieces that were removed one after the other by the small floating crane. By dismantling the last main girder in this manner there was no uncertainty about the extra stresses induced in the new span. These extra stresses could be permitted, provided that two heavy trains were not allowed to be on the bridge at the same time.

(d) RAILWAY BRIDGE OVER THE RIVER WAAL NEAR ZALTBOMMEL ON THE UTRECHT–'S-HERTOGENBOSCH SECTION

Before the war this bridge consisted of two rows of single-track spans resting on common piers and abutments. Looking from the south each row consisted of three 408-ft. curved-flange trusses over the river, and eight 196-ft. truss spans, with straight top chords, over the land between river and dike. At the time of liberation all the spans, except one small span, and the north abutment were found to be destroyed.

In 1945–46 all the spans of the western row were permanently repaired, except the big one over the northern channel of the river. For want of steel, the southern part of this span was replaced by a Type D Callendar-Hamilton span with double main girders and its northern part by the only small span left intact, which was moved from its original position on the adjoining opening of the eastern row of bridges. This solution necessitated the construction of a temporary pier, which has still not been removed. The eight small spans of the western row were replaced by three spans, two on four supports, and one on three supports.

In order to complete the repair of the whole bridge, four big spans had to be built, one to replace the two small temporary spans in the western row of spans and three for the eastern row, in which the land between river and dike was bridged by one new span on three supports, five old spans that could be repaired, and the span that had been temporary used in the western row of bridges. Two of the big spans were erected in 1950 and two in 1951. To avoid interference with the navigation—the upstream river traffic uses the middle channel and the downstream traffic the southern one—all the spans were assembled over the northern channel (fig. 8).

The first span was assembled on a falsework under the future eastern track by means of a floating crane. After completion it was rolled sideways clear of the eastern row of spans; this was executed in the night of Saturday/Sunday 29/30 July 1950. On that Sunday the Callendar-Hamilton span was put on four coupled barges by two floating cranes, and the small span was first rolled eastward and

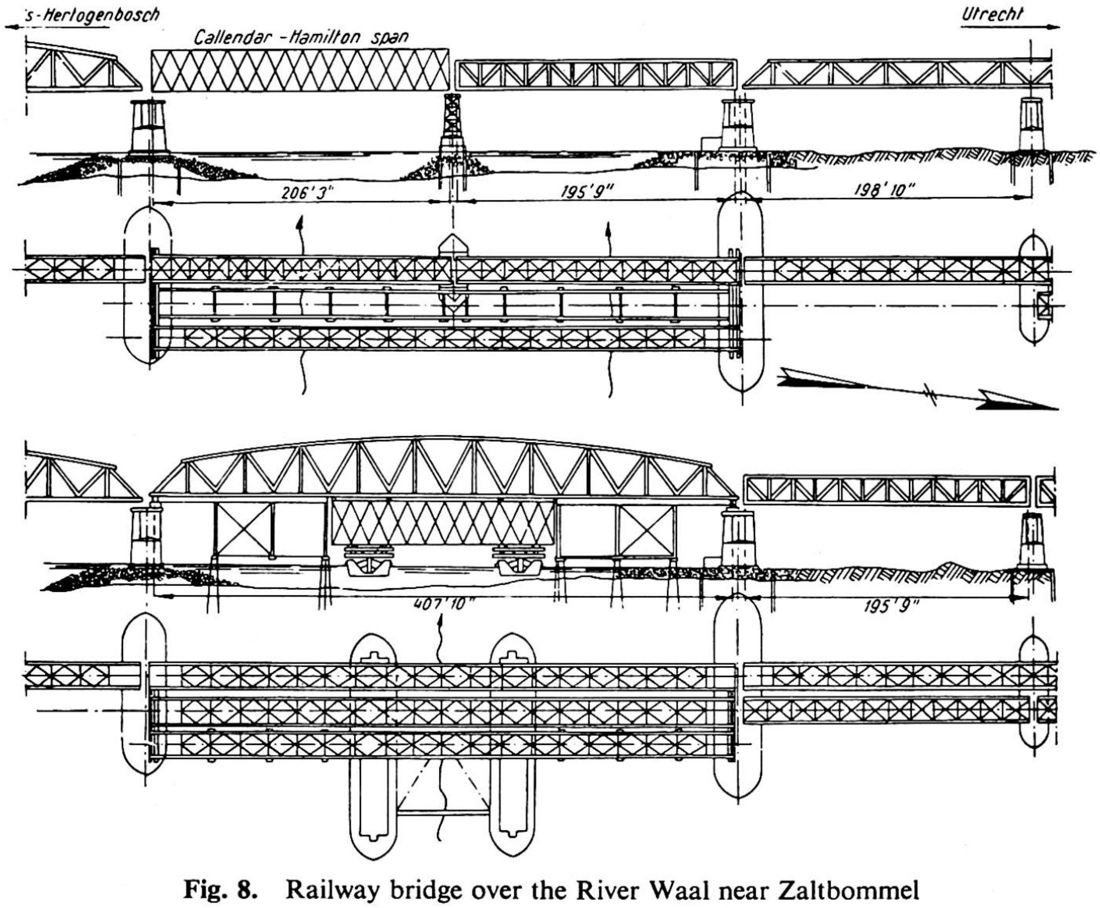


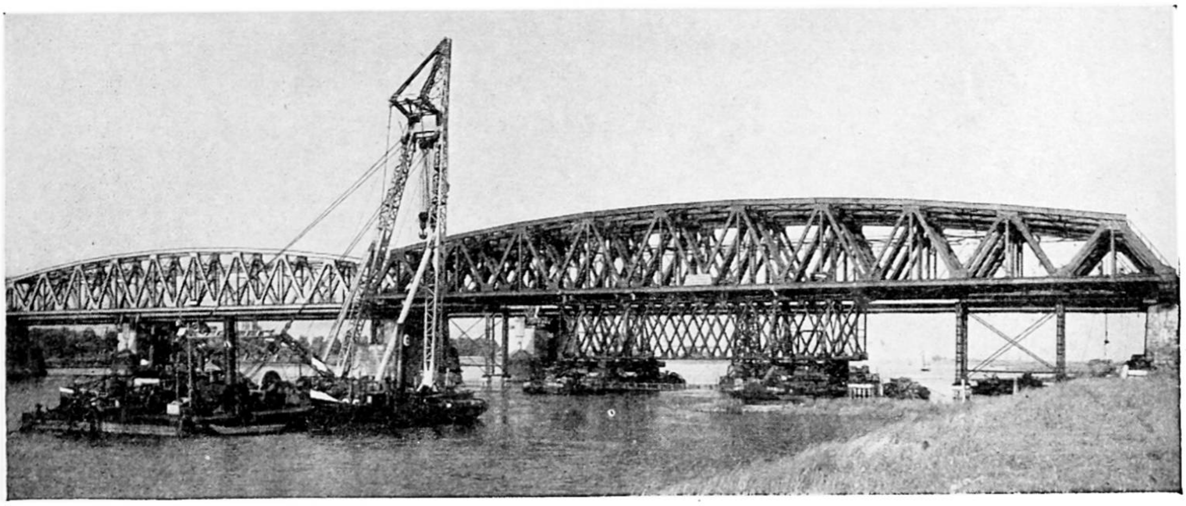
Fig. 8. Railway bridge over the River Waal near Zaltbommel

then northward into its original position in the eastern row of spans. To enable this, roller paths were constructed on the northern part of the falsework as well as on the land. On the roller-frames, moving on the last-mentioned paths, trestle supports were erected on which the span—for obvious reasons—was supported at its last-but-one bottom-chord connection points. Then, the same day, the big span was rolled westward into the western row of spans.

It was planned to lower the span on its bearings in the night from Sunday to Monday and to connect the rails and the electric-traction conductors in the early morning of Monday, 31 July, but this did not succeed, because of the following reasons: the wooden packing under the jacks was too soft for the rather heavy load and the large lift (3 ft. approximately); neither of the electric pumps worked satisfactorily; there were only hand-pumps in reserve, and their working was very slow and strenuous and beyond the capacity of the workmen present. Traffic could only be resumed on Tuesday morning, 1 August, at 7.30 hours.

After the assembly of the second big span on the same falsework, this falsework, which was not allowed to remain in the river during the winter, was removed in the beginning of December 1950.

In the early spring of 1951 new falsework was constructed eastward of the eastern row of spans (fig. 9). The central part of this falsework consisted of the shortened and stiffened Callendar-Hamilton span, so as to provide room for the barges which were to carry the second and the third big spans. On completion of the assembly of the third big span, there were at this stage three big spans over the northern channel, only one of which—on the west—was in use. The second and the third span were floated on barges to the middle and the southern channel on 12 and 14 June 1951 by means of five tugs and a floating crane. This crane anchored in the river and pulled the barges loaded with the span very cautiously upstream with its steam winches and then weighed anchor, and the whole convoy was pulled by the tugs across the river. Then the crane dropped anchor again and allowed the barges to float very slowly downstream to their destination. To control the sway of the barges in the openings hand-winches were mounted on the piers.



N. V. Werkspoor

Fig. 9. Zaltbommel Bridge

Before the second span was floated out, it was rolled eastwards in the place vacated by the third span. This was done because it was considered advantageous to repeat the manœuvre as exactly as possible and also because the temporary pier under the western span would have interfered with the movement.

Each of the barges, with a carrying capacity of 1,000 tons, had a watertight compartment of a volume of 500 m.^{3} The compartments were filled with water and the barges floated under the Callendar-Hamilton span. The supports on the Callendar-Hamilton span which carried the new span during assembly had been removed after jacking up the new span, which had left quite a large gap between the two spans.

The barges, after being positioned under the Callendar-Hamilton span, were raised by pumping 200 m.^{3} of water out of each water-filled compartment, thereby lifting the Callendar-Hamilton span free of its bearings, which were then removed. The watertanks were filled again.

Across the Callendar-Hamilton span eight wide-flange beams in four groups of two were laid, on which the big span came to rest through the medium of teak packings of different thicknesses, chosen so that none of the spans was overstressed when they were lifted together.

As the big span (1,160 tons) is heavier than 1,000 m.^{3} water, pumping out of all the water would not suffice to lift it. So it had to be jacked down under its bearings to get it free of its supports. For the same reason, after the spans had been floated to their new position they had to be jacked up to free the barges.

The reason why no bigger barges were used, which would have made unnecessary the lowering and the lifting of the spans, is that the steel supports through the medium of which the load was transmitted to the barges and by which the barges were stiffened were already available, and it would have been uneconomical to replace them.

Finally, after that the Callendar-Hamilton span was replaced as part of the falsework the fourth big span was assembled and rolled westward into the eastern row of spans. The completed bridge in the eastern track was tested on 16 October 1951 and opened to traffic on 22 October 1951.

The advantages of the method of erection chosen were that the navigation had to be interrupted only on 12 and 14 June 1951, and the trans-shipment equipment could do all its work with an interruption of only one day (13 June 1951).

Summary

The paper gives in detail a description of:

(*a*) the erection of the big arch span of the road bridge over the River Lek near Vianen;
(*b*) the replacement of the Bailey-bridge over the River Rhine at Arnhem by a stiffened arch;
(*c*) the replacement of two temporary single-track spans of the railway bridge over the River Oude Maas near Dordrecht by one double-track span on three supports; and
(*d*) the erection of four big spans of the railway bridge over the River Waal near Zaltbommel.

Résumé

Une description détaillée est donnée:

(*a*) du montage de l'arc avec tirant du pont route sur le Lek près de Vianen;
(*b*) du remplacement du pont Bailey sur le Bas-Rhin à Arnhem par un pont Langer;

(*c*) du remplacement de deux travées temporaires à voie unique du pont de chemin de fer sur l'Ancienne Meuse près de Dordrecht par une travée à double voie sur trois appuis; et
(*d*) du montage de quatre grandes travées du pont de chemin de fer sur le Wahal près de Zaltbommel.

Zusammenfassung

Eine ausführliche Beschreibung wird gegeben:
(*a*) der Aufstellung der grossen Bogenbrücke mit Zugband über die Lek bei Vianen in der Strasse Utrecht-Herzogenbusch;
(*b*) der Ersetzung der Bailey-brücke über den Rhein zu Arnhem durch eine Langersche Brücke;
(*c*) der Ersetzung zweier einzelspurigen behelfsmässigen Fachwerkbrücken der Eisenbahnbrücke über die "Oude Maas" bei Dordrecht durch eine doppelspurige Fachwerkbrücke auf drei Stützen; und
(*d*) der Aufstellung vierer grossen einzelspurigen Fachwerkbrücken der Eisenbahnbrücke über die Waal bei Zaltbommel.

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BII 3

Procédés originaux de relevage et de montage d'ouvrages métalliques

Special methods for raising and erecting steel structures

Besondere Verfahren zur Hebung und Montage von Stahlkonstruktionen

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Les opérations militaires de la guerre de 1939 à 1945 ont entraîné la destruction de la grande majorité des ouvrages d'art français essentiels et notre Pays s'est trouvé à la Libération, avec toutes ses voies de communication ferroviaires et routières coupées.

En raison des conditions tout-à-fait particuliéres dans lesquelles nous avons dû travailler, après la cessation des hostilités, pour faire face aux nécessités pressantes du rétablissement de ces voies de communication, en dépit de la pénurie des matières premières, des difficultés de reconstituer l'outillage, nous avons été amenés, pour les relevagés et les montages d'ouvrages métalliques, à nous écarter des solutions classiques employées communément sur les chantiers.

Parmi les nombreux travaux que nous avons exécutés, nous choisirons quelques exemples de réalisations montrant que l'esprit inventif permet d'aboutir à des solutions originales, économiques et rapides malgré les difficultés matérielles rencontrées, solutions qui pourront, pensons-nous, servir d'exemple pour d'autres travaux.

I. PONT ROUTE DE BRAGNY SUR LA SAÔNE

Pont de 159 m. de longueur totale en trois travées continues de 47–65–47 m. de portée avec poutres de hauteur variable à âme pleine, hauteur variant de 1 m. 10 sur culée à 3 m. 80 sur piles et 2 m. 20 au milieu de la travée centrale. C'est une réalisation particulièrement légère et élégante, puisque la hauteur des poutres est seulement du 50ème de la portée au milieu de la travée centrale et du 40ème sur culée. Il avait été construit en 1937 en acier chrome cuivre en conservant les piles d'un ancien pont suspendu. A cette époque, il avait été monté sans interrompre la circulation en utilisant, pour la mise en place des poutres, des chalands munis de mâts de levage (fig. 1).

Il fût détruit par explosifs en 1944 et pour permettre la réutilisation des maçonneries et du tronçon récupérable du tablier, le type de l'ancien ouvrage fût conservé avec seulement des renforcements pour permettre la passage des camions de 25 t., par application de la circulaire ministérielle du 29 août 1940.

Pour le montage du nouvel ouvrage, il fût impossible de trouver les chalands nécessaires à l'ancien mode de montage et la violence du courant au confluent du Doubs et de la Saône ne permettait pas l'établissement d'échafaudages en rivière. Il fallut improviser un système de montage totalement nouveau par lançage sur berceaux en raison de la courbure prononcée de la membrure inférieure des poutres.

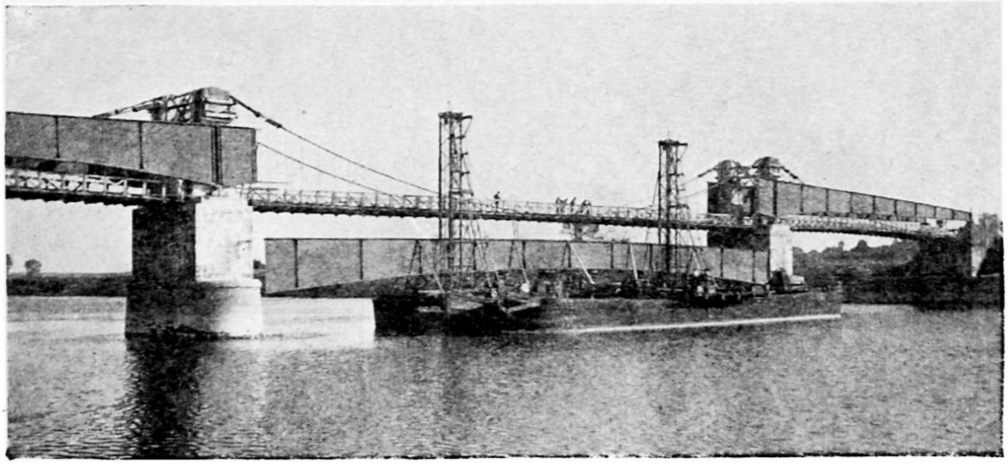

Fig. 1. Pont route de Bragny—montage des poutres sur chalands (1936)

Le chantier de montage fut établi sur la rive coté Verdun, les éléments du tablier furent assemblés à un niveau supérieur de 4 m. environ à leur niveau définitif. Sur les piles des chevalets métalliques furent établis pour servir d'appuis provisoires.

Le lançage s'est effectué par phases successives, au fur et à mesure du montage. Un avant-bec léger de 18 m. de longueur et quelques renforcements locaux des poutres principales ont permis d'éviter toute fatigue excessive du métal, en particulier pendant le franchissement de la grande travée de 65 m.

Quinze opérations successives de lançage s'échelonnèrent sur trois mois (fig. 2):

1*ère opération*—Montage sur culée et lançage sur 10 m.

2*ème opération*—Montage de 18 m. 50 de pont et lançage sur 18 m.

3*ème opération*—Montage de 13 m. de pont.

4*ème opération*—Mise en place du 1er berceau et lançage sur 14 m. jusqu'à la première pile.

5*ème opération*—Montage de 11 m. de pont et lançage sur 13 m.

6*ème opération*—Montage de 11 m. de pont, mise en place du 2ème berceau et lançage sur 37 m. 50.

7*ème opération*—Montage de 37 m. 50 de pont, mise en place du 3ème berceau abaissement de 1 m. 50 des galets sur pile et lançage sur 13 m. 50.

8*ème opération*—Montage de 15 m. 50 de pont, déplacement du 1er berceau et lançage de 11 m.

9*ème opération*—Montage de 10 m. 50 de pont, déplacement du 2éme berceau et lançage sur 11 m.

10*ème opération*—Montage de 10 m. 50 de pont, déplacement des ler et 2ème berceaux et lançage sur 11 m.

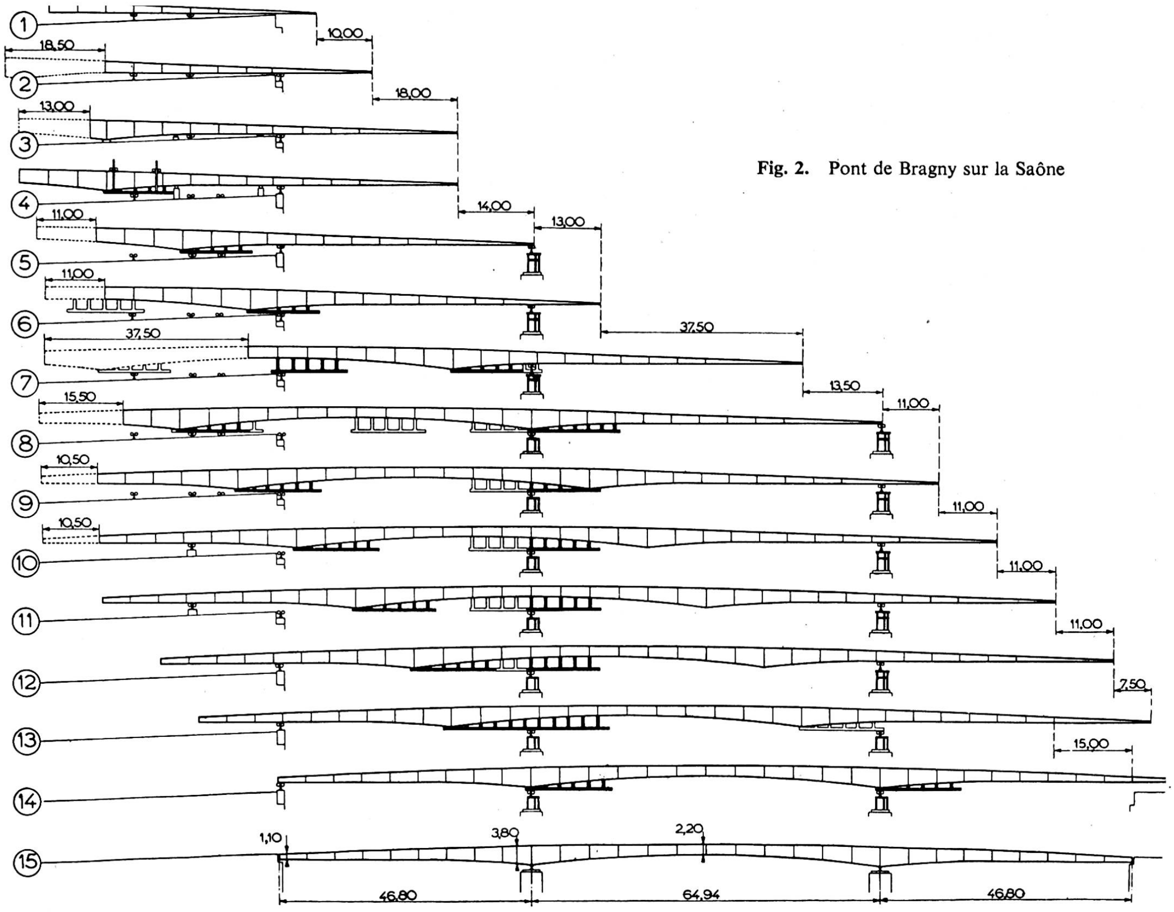

Fig. 2. Pont de Bragny sur la Saône

11*ème opération*—Déplacement des 1er et 2ème berceaux et lançage sur 11 m.
12*ème opération*—Déplacement des 1er et 2ème berceaux et lançage sur 7 m. 50.
13*ème opération*—Déplacement du 1er berceau, abaissement de 1 m. 50 des galets sur 2èmes piles et lançage sur 15 m. (fig. 3).
14*ème opération*—Démontage de l'avant-bec et descente sur appuis.
15*ème opération*—Mise en place des appareils d'appui et réglage du pont (fig. 4).

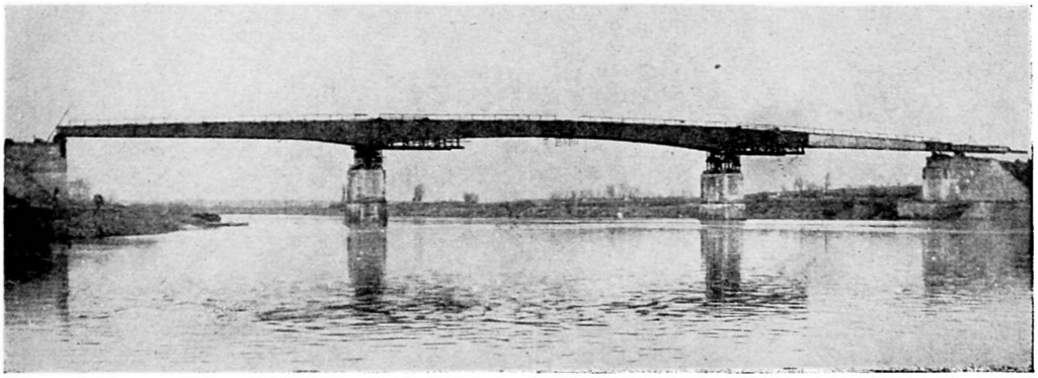

Fig. 3. Pont route de Bragny—Mise en place par lançage en 1950 sur berceaux (fin du lançage)

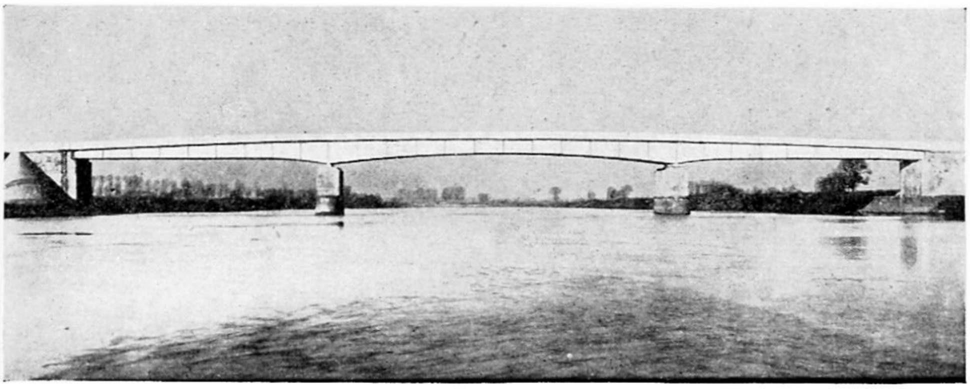

Fig. 4. Pont route de Bragny en acier 54—Vue d'ensemble

Pour compenser la variation dans la hauteur des poutres, on établit un chemin de roulement horizontal fixé sous chacune d'elles, et constitué par des poutrelles de 450 mm. de hauteur. Des madriers verticaux en chêne de 320×320 taillés à la demande assuraient l'appui des poutres sur le chemin de roulement.

Les berceaux étaient déplacés au fur et à mesure de l'avancement du lançage sous le tablier, de façon à rester à l'aplomb des appareils à galets disposés sur piles et sur culées.

II. VIADUC DE SERROUVILLE

Pont rail à trois travées continues de 60–90–60 m. de portée avec poutres en treillis, construit sur une vallée profonde.

Il fut détruit par charges d'explosifs disposées; les unes dans une pile qui s'effondra

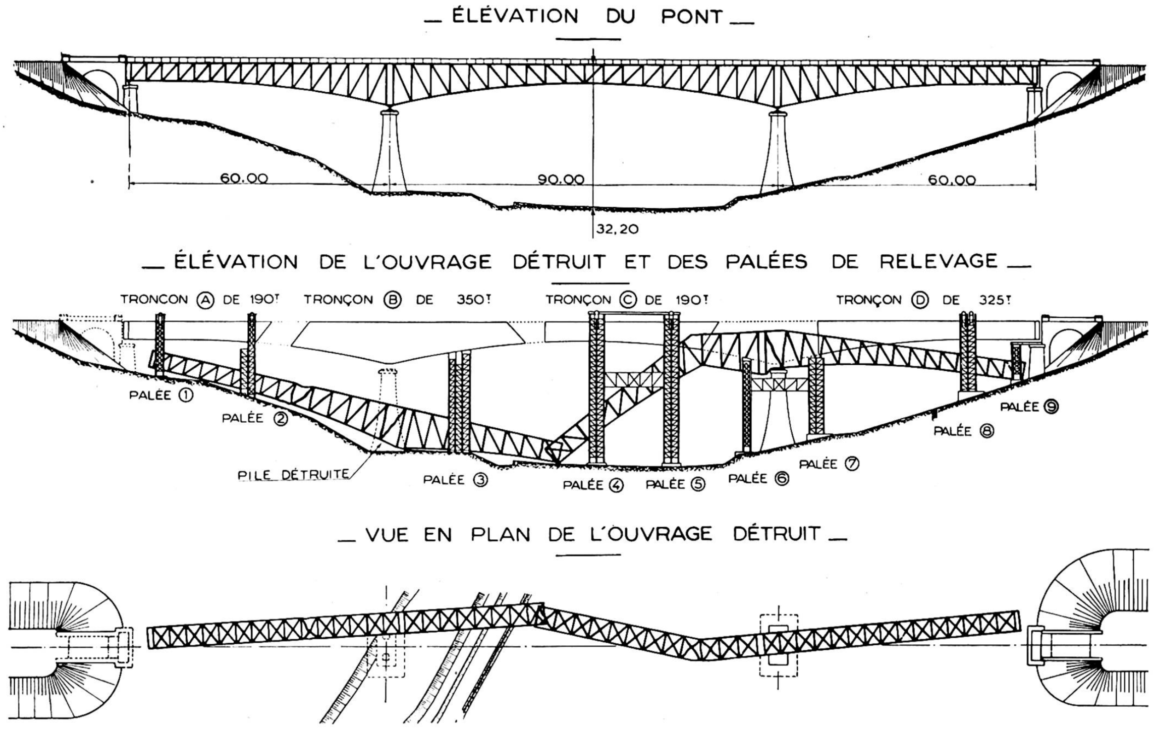

Fig. 5. Viaduc de Serrouville

totalement, les autres sur le tablier, qui fut sectionné en trois points, suivant schéma ci-joint (figs. 5 et 6).

La reconstruction de cet ouvrage est le prototype de récupération maximum de métal avec un minimum de démontage.

Fig. 6. Viaduc de Serrouville. Destruction—détail de la lère cassure côté Conflans

Les palées de relevage avaient été prévues en premier lieu en bois, mais la fin des hostilités ayant libéré des palées anglaises, un tonnage de 600 t. a pu être affecté à ce chantier, ce qui permit de réaliser une solution très économique.

Plusieurs procédés de relevage furent mis en œuvre simultanément sur ce chantier et il est intéressant de les décrire d'une manière détaillée:

(1) *Opérations préliminaires*

Calages des divers éléments et découpages des parties détériorées pour séparer le pont en quatre tronçons.

(2) *Remise en place du tronçon d'extrémité A de* 190 *t.*

Ce tronçon était tombé sur le sol, déversé et déporté transversalement et longitudinalement:

1*ère opération*—Suppression du dévers sur calages au moyen de vérins hydrauliques.

2*ème opération*—Ripage transversal sur chassis de rouleaux.

3*ème opération*—1er ripage longitudinal de 5 m. vers culée.

4*ème opération*—Relevage de 8 m. 50 au moyen des treuils électriques avec moufles de 50 t.

5*ème opération*—2ème ripage longitudinal de 2 m. 90.

(3) *Relevage du tronçon médian B de* 350 *t.*

Ce tronçon était tombé de 20 m. de hauteur par suite de la disparition de la pile, il avait en outre glissé longitudinalement et transversalement, et enfin s'était déversé.

1*ère opération*—Suppression du dévers par vérins.
2*ème opération*—Ripages longitudinaux et transversaux.
3*ème operation*—Relevage sur palées anglaises et calages pour le mettre horizontal et permettre la construction du soubassement de la pile.
4*ème opération*—Relevage de 17 m. avec construction simultanée de la pile.

Les opérations se sont déroulées comme suit pour le relevage par vérins (un de 300 t. sur pile, le 2ème de 100 t. sur palée anglaise), en utilisant des blocs de béton de 1 m. × 1 m. × 0,5 m. de hauteur coulés à l'avance (fig. 7).

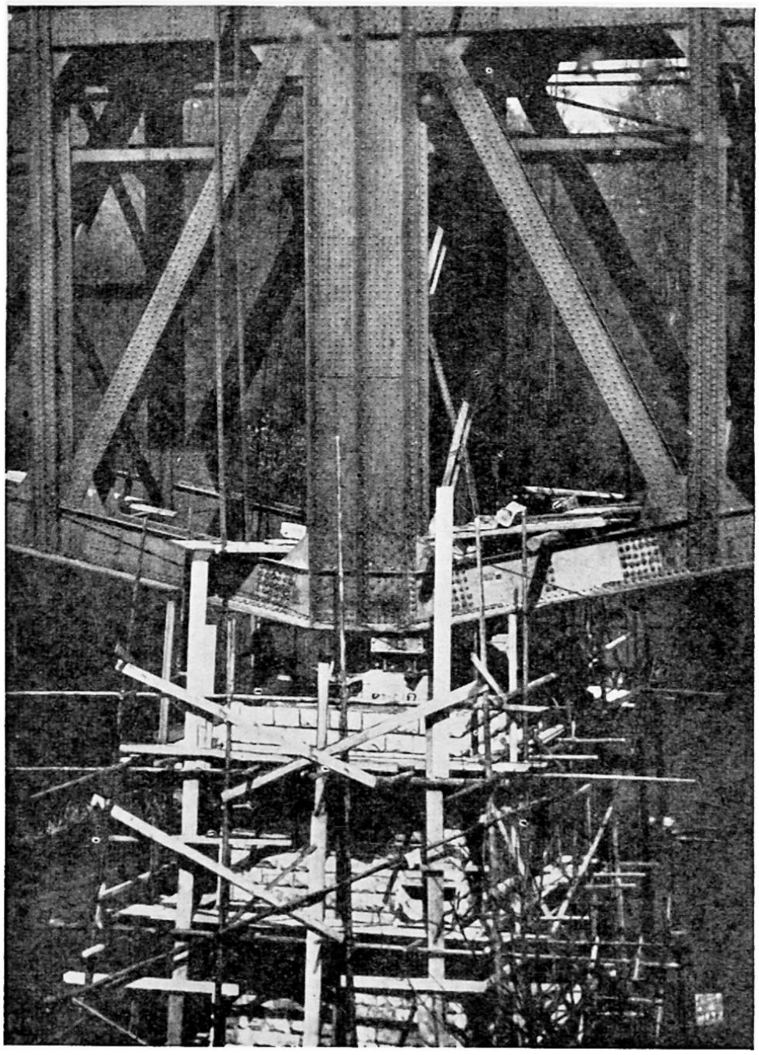

Fig. 7. Viaduc de Serrouville—Reconstruction de la pile sans le tronçon B en cours de relevage

Une assise de deux blocs par poutre étant en place, le vérin était disposé sur un des blocs avec calage de sécurité et l'on relevait jusqu'à ce que l'on puisse mettre en place le 1er bloc de l'assise suivante sur lequel on venait poser le vérin ce qui permettait alors de mettre en place le 2ème bloc et ainsi de suite.

(4) *Relevage du tronçon médian C de* 190 *t.*

Ce tronçon était incliné à 45° et sa liaison à la partie haute avec le tronçon suivant était précaire. Aussi ne pouvait-il pas être question de le relever en soulevant seulement l'extrémité fichée en terre (fig. 8).

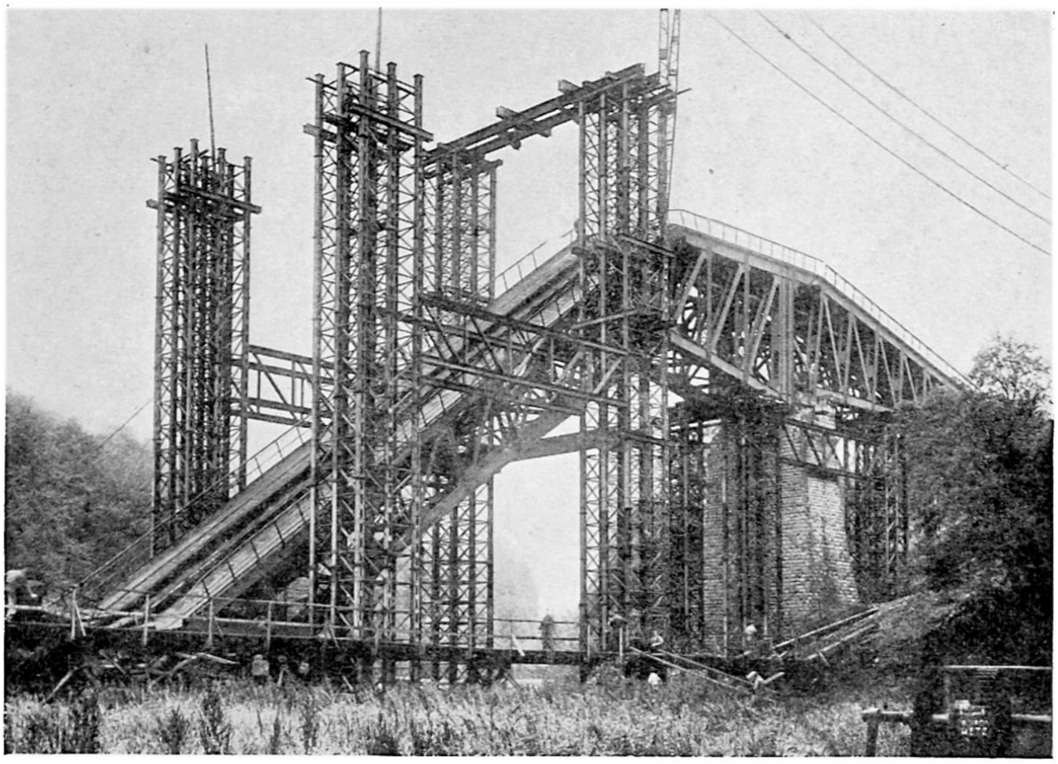

Fig. 8. Viaduc de Serrouville—Palées de relevage

1*ère opération*—Calage sur éléments de palées anglaises, puis découpages des pièces détériorées à la liaison des deux tronçons.

2*ème opération*—Suspension du tronçon à des mouflages et descente sur le sol, l'extrémité basse ayant été posée sur articulation et galets, de manière à la rendre mobile et obtenir ainsi que la suspension reste toujours sensiblement verticale.

3*ème opération*—Levage de l'ensemble du tronçon au moyen de mouflages de 50 t. avec treuils électriques. Le levage de ce tronçon de 190 t. sur 24 m. de hauteur fut réalisé en une matinée.

Enfin le tronçon relevé fut calé sur les palées de relevage.

(5) *Remise en place du tronçon d'extrémité D de* 325 *t.*

Comme les autres il était déversé et tombé de la culée, mais en outre les éléments au droit de la pile étaient profondément détériorés ainsi que la partie en avant de la pile, qui était à peu près en porte à faux, étant donnée la précarité de la liaison avec le tronçon suivant.

1*ère opération*—Calages sur palées anglaises en trois points.

2*ème opération*—Démontage des éléments sur pile et au délà de la pile au moyen d'un derrick placé sur le tablier, manœuvre osée qui s'effectua sans aucun incident.

- 3*ème opération*—Relevage de l'extrémité coté culée au moyen de treuils en pivotant sur l'autre extrémité, puis relevage d'ensemble par treuils d'un coté, sur vérins de l'autre coté.
- 4*ème opération*—Ripage longitudinal de 4 m. 61 pour ramener le tronçon sur la culée.

(6) *Opérations complémentaires*

Il ne restait plus alors qu'à rétablir la continuité du pont en remontant, au droit des trois brèches, des éléments neufs ou réutilisés après réparation (fig. 9).

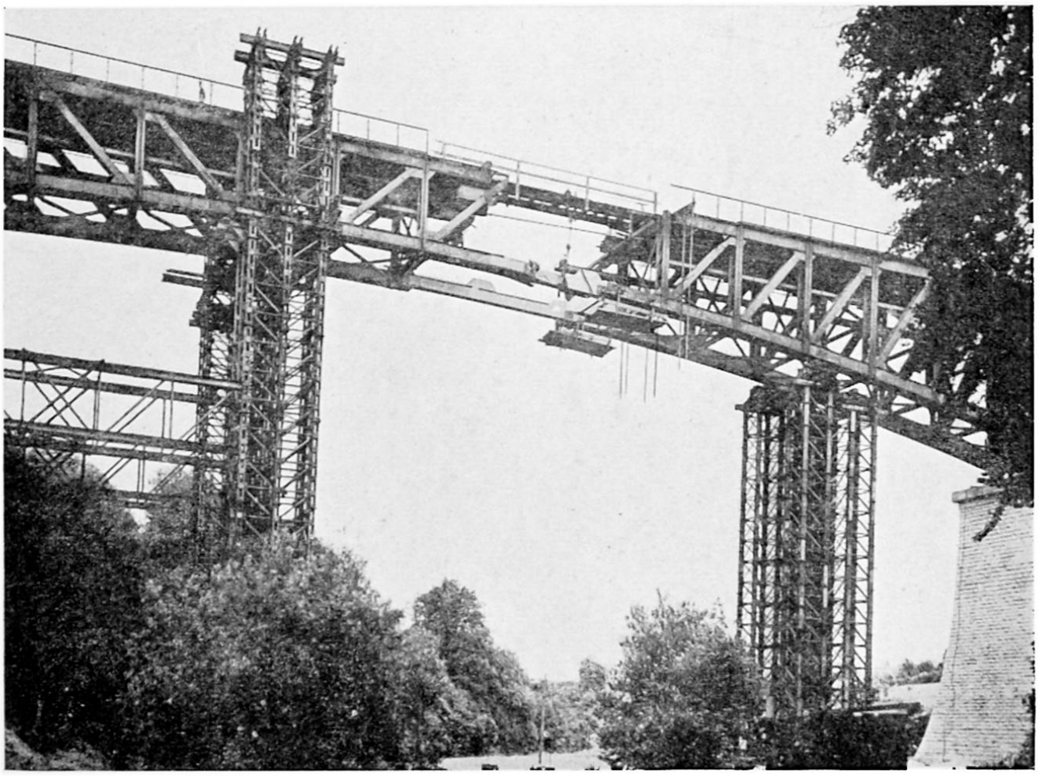

Fig. 9. Viaduc de Serrouville—Montage des éléments nouveaux au droit des brèches

III. PONT RAIL DE BOLLÈNE SUR LE CANAL DE FUITE DE DONZÈRE MONDRAGON

Pont à trois travées continues avec poutres à treillis multiples. Etant donné le biais du pont par rapport au canal (42° 48′), les piles sont parallèles au canal, par contre les culées sont restées perpendiculaires à l'axe de l'ouvrage. Les rails et traverses sont posés sur ballast supporté lui-même par des dalles en béton armé, ce qui assure la continuité de la voie.

Les portées des travées sont respectivement de 70 m. 63, 95 m. 85 et 80 m. 72, en tout 247 m. 20.

L'ossature métallique pesant 2 700 t. devait être mise en place en moins de 60 jours afin de laisser, jusqu'au dernier moment, le passage libre aux dragues qui creusent le canal, entre l'amont et l'aval.

Il n'était donc pas question de monter le pont sur échafaudages ou en porte à faux à l'avancement, et la mise en place a été effectuée par lançage après montage sur plateforme en deux phases, en raison de l'insuffisance de longueur de la plateforme.

Nous avons réalisé ces travaux en utilisant les procédés modernes de lançage mis au point pour les viaducs du Manoir, Pont Royal et Collonges, basés sur les principes suivants:

1° Recherche d'un point fixe solide sur lequel prend appui le dispositif de traction car l'effort maximum dépasse au démarrage 5 % de la charge à déplacer.
2° Traction par treuils électriques puissants démultipliés reliés à des points fixes par mouflages.
3° Egalisation des tractions par palonnier intermédiaire ou autre dispositif similaire.
4° Appareils de lançage à 16 galets, très robustes de construction soudée, avec galets en acier moulé, ayant une charge portante admissible de 50 t. par galet.
5° Lançage en plusieurs phases suivant longueur de plateforme disponible.

Le point d'ancrage établi en arrière de la culée avait été calculé pour un effort de traction de 200 t. En fait, au démarrage cet effort atteignit 180 t. et s'est maintenu aux environs de 150 t.

Fig. 10. Pont rail de Bollène—Ouvrage en cours de lançage

Le système de traction comprenait essentiellement deux treuils de 10 t. munis de câble de 30 mm. mouflées à 10 brins.

Les moufles avaient une force de 75 t. construits spécialement pour cette opération, pièces pesant 1,5 t. chacune avec 2 m. de longueur.

Le palonnier intermédiaire réunissant les deux moufles transmettait les efforts à un câble de 70 mm. de diamètre allant jusqu'au point d'ancrage et fixé sur un axe, au moyen de culots et d'étriers coté palonnier, et par mordaches coté ancrage.

Les sommiers du dispositif de traction étaient fixés sur le tablier; les câbles des treuils bien qu'ayant 650 m. de longueur ne permettaient pratiquement que des avancées de 50 m., après chacune de celles-ci on raccourcissait le câble de traction de 50 m.

L'avant-bec de 30 m. de portée a permis de réaliser le lançage sans renforcement des poutres malgré l'importance du vide à franchir de 95 m. de travée centrale. Toute fois, pour ne pas dépasser une réaction de 800 t. par appareils de lançage sur la 1ère pile, un appui intermédiaire provisoire avait été prévu à 8 m. avant la 2ème pile, réduisant à 87 m. le porte à faux maximum (fig. 10).

Pour gagner du temps, le coffrage de la dalle et une partie du ferraillage avaient été mis en place à l'avance, de sorte qu'avec l'avant-bec de 60 t., c'est un ensemble de plus de 3 000 t. de 277 m. de longueur qui était à déplacer de 300 m., dépassant largement nos réalisations antérieures.

L'avancement a été réalisé à une vitesse de 25 m. à l'heure, la progression du pont se faisant sans à coup, mais en raison de l'importance des réactions sur les galets, qu'il était très difficile d'égaliser en raison du biais du pont, des contreflèches et de la variation des épaisseurs des semelles, des arrêts furent effectués de distance en distance pour mesure des réactions au moyen de vérins à huile de 200 t. et 300 t. munis de manomètres.

Le spectacle du déplacement de cette masse énorme, en silence, sans aucun effort humain, nous faisait souvenir de premiers lançages d'autrefois, par galets moteurs commandés par de grands leviers avec cliquets que manœuvraient péniblement et combien lentement des équipes nombreuses d'ouvriers que peinaient à la tâche, et cette comparaison prouvait que, dans ce domaine comme dans d'autres, de grands progrès techniques ont été réalisés en quelques décades.

Le souci du gain de temps était si grand et la sécurité de manœuvre si complète que les ferrailleurs de la dalle continuaient leur travail tandis que le pont se déplaçait.

IV. PONT DE LA MULATIÈRE SUR LA SAÔNE À LYON

C'est un ouvrage métallique à deux voies et à trois travées continues de 44,67–89,34–44,67 m. de portée entre axes des appuis, construit en 1912.

Il est essentiellement constitué de deux poutres latérales à treillis, de hauteur variable, supportant les voies par l'intermédiaire de pièces de pont et de longerons. Des contrepoids s'opposent à tout soulèvement sur culée.

Les Allemands en retraite, coupèrent à l'explosif la travée centrale, séparant ainsi l'ouvrage en deux tronçons. En outre, côté Lyon, la pile était détruite sur toute sa largeur et le tronçon pesant 1 000 t. s'était incliné vers le fleuve. Côté Roanne, la culée et la pile étaient détruites du seul côté amont et le tronçon de 1 200 t. s'était incliné transversalement de 42% (fig. 11).

Dans sa chute sur la pile, la poutre amont agissant à la manière d'un coin avait désorganisé la partie supérieure des maçonneries non détruites par l'explosion en repoussant dangereusement les pierres vers l'extérieur.

Le premier travail consista donc à ceinturer ces maçonneries par un "corset" en béton armé s'opposant à tout mouvement des pierres disjointes.

Après cette première consolidation, on procéda au redressement transversal du tronçon de la manière suivante:

Sur la pile Lyon, la poutre amont fut munie d'une forte console recevant la réaction des vérins et calages par l'intermédiaire de sommiers dont l'horizontalité était rétablie à chaque levée. Les vérins et calages reposèrent eux-mêmes sur des éléments préfabriqués en béton placés au fur et à mesure de la montée (fig. 12).

Un dispositif analogue prenant appui directement sous la poutre amont avait été disposé au droit du nœud voisin de la culée. Une béquille à articulation roulante fixée sous la poutre amont assujettissait l'ouvrage à tourner autour d'un axe, à peu près horizontal, passant par le pied de la béquille et l'appareil d'appui aval sur pile. Ces multiples travaux préparatoires au redressement nécessitèrent un délai de cinq mois.

L'opération proprement dite fut effectuée en deux mois (du 10 octobre au 12 décembre 1945). Après redressement, le relevage de l'ouvrage fut effectué par les procédés classiques de vérinage et de calage. La réparation ne présenta pas d'autres difficultés que celles inhérentes à ce genre de travail.

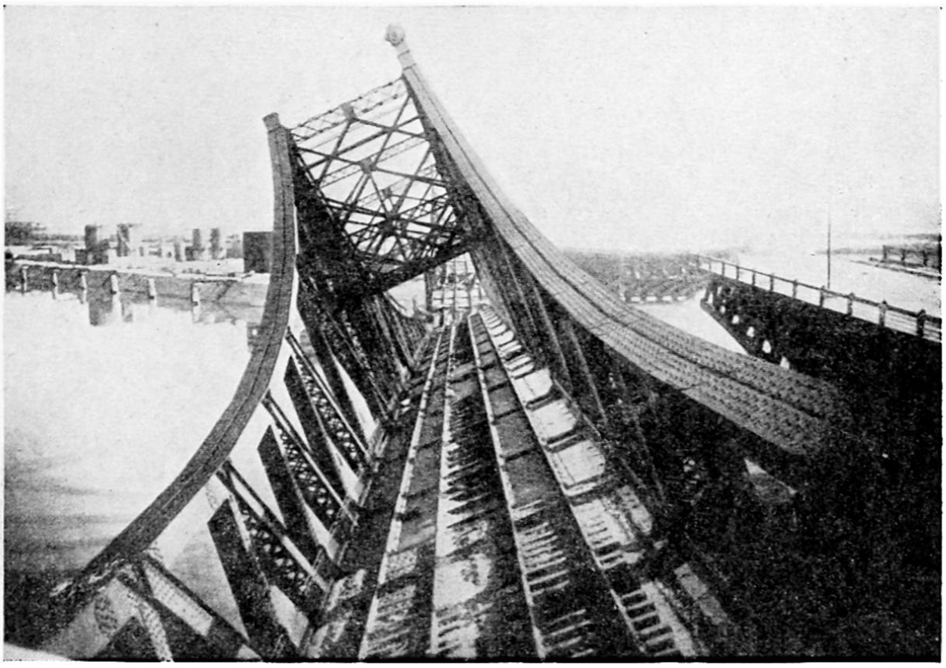

Fig. 11. Viaduc de la Mulatière à Lyon—Destruction en 1944

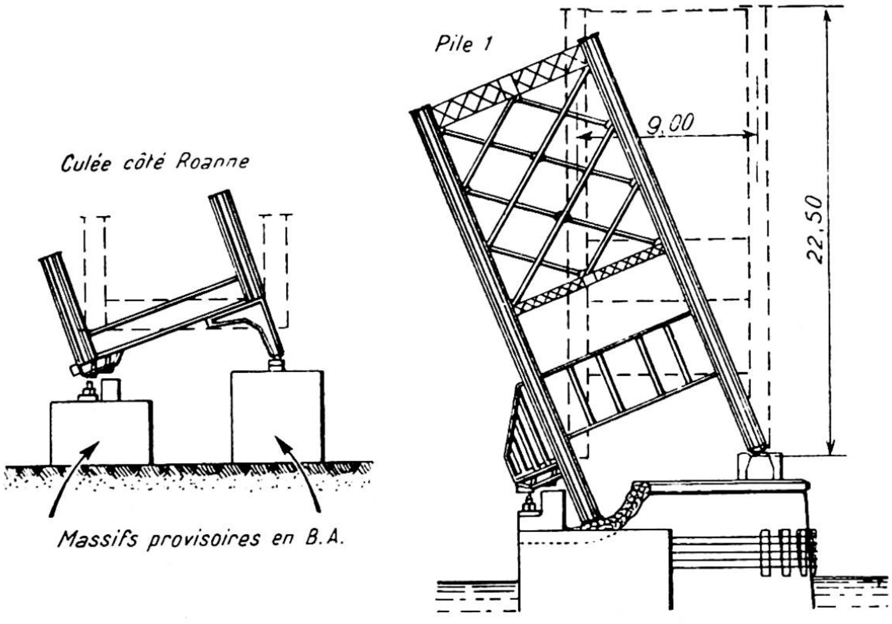

Fig. 12. Viaduc de la Mulatière sur la Saône—Relevage du tronçon côté Roanne

V. PONT DE CUBZAC SUR LA DORDOGNE

Cet important ouvrage de 1 420 m. de longueur comprend entre autres, un groupe de huit travées solidaires au-dessus de la Dordogne (deux travées de rive de 60 m. et six travées intermédiaires de 73,00 m.).

Ces travées sont du type tubulaire; poutres latérales à treillis de 8 m. de hauteur reliées à leur partie inférieure par le tablier et à leur partie supérieure par un contreventement longitudinal. Les poutres reposent, sur des culées en maçonnerie et sur sept piles métalliques de 15 m. de hauteur avec soubassements en maçonnerie.

En août 1944, le Génie Allemand coupait les deux premières travées intermédiaires côté Cubzac à 8 m. environ des piles. Le tronçon de 72 m. compris entre les coupures basculait autour de la 2ème pile et se fichait profondément dans les enrochements disposés au pied de la pile suivante après avoir glissé horizontalement de 8 m. La membrure de la poutre inférieure côté aval, était restée accrochée au couronnement, la poutre amont restant en porte à faux. Il en résultait, en outre, une torsion notable du tablier, le niveau de la poutre amont étant de 1 m. environ plus bas que celui de la poutre aval. La pile, elle-même, sous l'effet du choc avait rompu ses attaches et avait pris un faux aplomb de 80 cm.

L'équilibre de l'ensemble, constitué par le tronçon tombé et la pile, était des plus précaires. Il n'était, en fait assuré que par le contact de quelques centimètres de membrure sur le couronnement. Ces éléments étaient, du reste, partiellement désorganisés par l'explosion et la chute du tablier.

Le tronçon de 125 m., compris entre la culée et la première coupure, après avoir amorcé son mouvement de basculement, avait été arrêté dans sa chute par les maçonneries surmontant la culée; cette situation put immédiatement être consolidée par des ancrages.

La pénurie de métal imposait la récupération du tronçon de 72 m. en majeure partie intact. Par ailleurs, la force du courant et la hauteur rendaient difficiles l'établissement des classiques palées de relevage que la position des tronçons paraissait imposer. Après étude de différentes solutions, il fut décidé de se servir de la pile préalablement remise en état et du tronçon en porte à faux sur la pile suivante comme appuis de relevage. Les travaux furent conduits de la manière suivante:

(1) *Redressement de la pile* (fig. 13)

On utilisa un procédé original consistant à se servir du poids du tronçon lui-même comme moteur.

La pile préalablement calée à son pied pour prévenir tout mouvement intempestif fut munie au droit de chacune des poutres d'une forte console.

A l'aide de vérins, on put alors reporter sur ces consoles la réaction du tablier, ce qui eut pour premiers résultats de lui fournir un appui stable et d'annuler sa poussée sur la pile.

On procéda alors à un premier levage sur la console, côté amont, de manière à remettre les poutres au même niveau, puis à un deuxième levage simultanément sur les deux consoles jusqu'à pouvoir prolonger les membrures inférieures au-dessus de la pile par des éléments provisoires.

On disposa ensuite, sous ces prolongements, des galets destinés à rouler sur le sommet de la pile et disposés au plus près du bord, côté Bordeaux. Le redressement proprement dit put enfin être obtenu en enlevant les calages de pied de pile. Pendant cette opération, la pile reprenait progressivement sa place définitive, son sommet roulant sous le tablier.

Les ancrages détruits furent alors remplacés et les éléments détériorés du pied de pile remis en état.

(2) *Relèvement du tronçon de 72 m.*

Il fut effectué à l'aide d'un important appareil de levage (fig. 14) déjà utilisé pour des travaux analogues et prenant appui sur les membrures supérieures. L'extrémité, côté Bordeaux du tronçon, y fut suspendue au moyen de chaînes à maillons démontables par l'intermédiaire de sommiers sur vérins, la montée du tronçon provoquant son roulement sur la pile et sa remise en place progressive. A noter qu'après plusieurs essais de levage infructueux, on dut couper, sous l'eau, la partie de travée ancrée dans les enrochements.

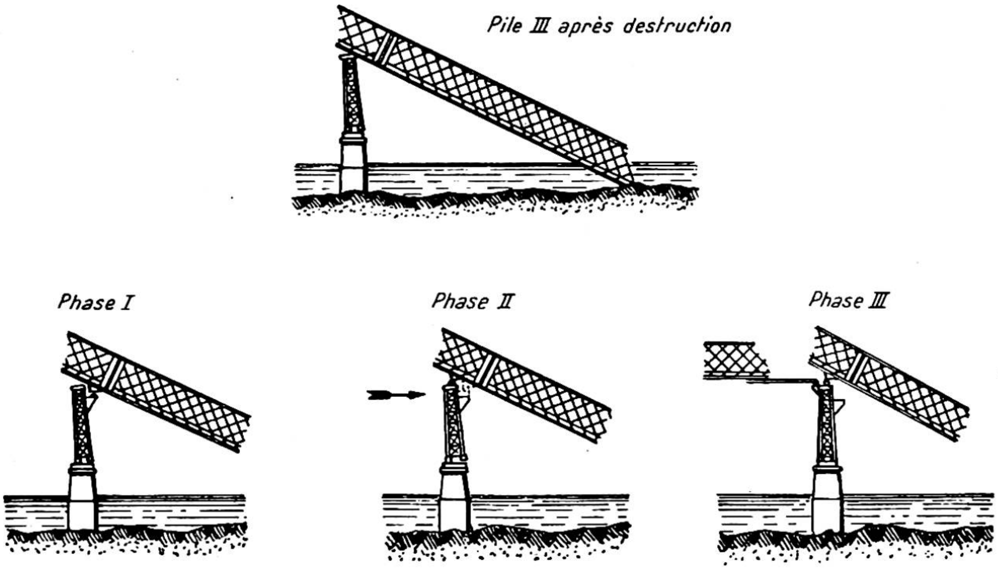

Fig. 13. Pont de Cubzac sur la Dordogne—Redressement de la pile III

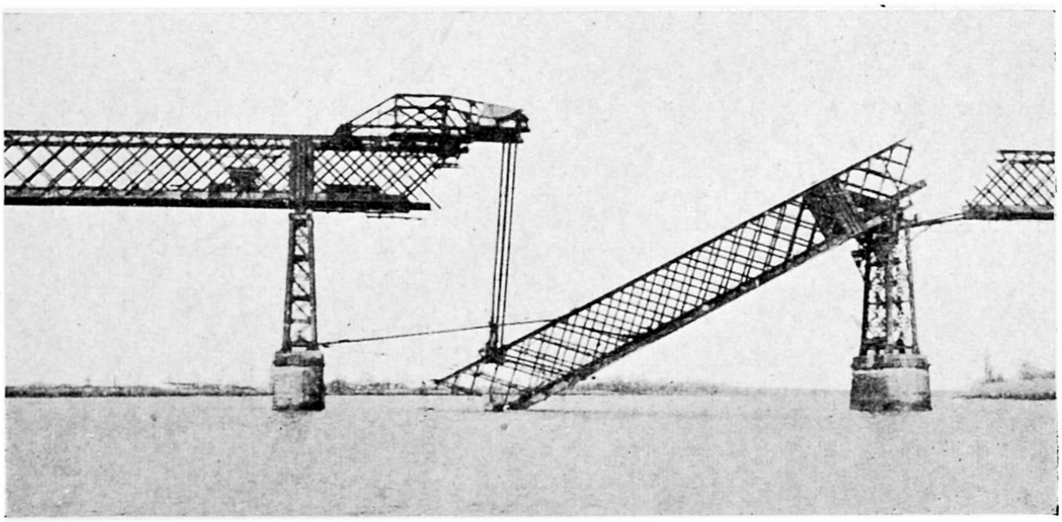

Fig. 14. Pont de Cubzac—Levage du tronçon

(3) *Rétablissement de la continuité*

Après fin du levage et remise en place du tronçon, il fut procédé à la réparation de la brèche, côté Bordeaux, les éléments manquants ou détériorés étant remplacés par des éléments neufs.

La brèche, côté Cubzac fut réparée ensuite, l'extrémité en porte à faux du tronçon précédemment raccordé soutenant celle du tronçon suivant. Pendant chacune de ces opérations, l'appui sur la 2ème pile fut dénivelé de la quantité voulue pour rétablir après remise à niveau définitive, les efforts dus à la charge permanente.

Sans cette précaution prise d'ailleurs par la S.N.C.F. pour toutes les opérations de raccordement, les contraintes permanentes se seraient trouvées sensiblement modifiées (3 à 4 kg./mm.^{2}). Il est d'ailleurs à noter que si ces dénivellations sont correctement déterminées, les extrémités des tronçons en présence se raccordent sans point anguleux.

VI. VIADUC DE CARONTE SUR L'ETANG DE BERRE ET PONT DE ROPPENHEIM SUR LE RHIN

Les travaux de ces deux ouvrages qui présentent un caractère d'originalité très marqué pour leur mise en place ont déjà fait l'objet de communications dans diverses revues. Nous projetterons de courts films tournés au cours des travaux qui illustreront, mieux qu'un long exposé, les techniques mises en œuvre.

Les schémas et photographies ont été mis à notre disposition par les Constructeurs de ces ouvrages, Ets. Fourès, Daydé, Dunoyer et Compagnie de Fives-Lille.

Résumé

Les auteurs se sont proposés de montrer que la construction métallique offrait une grande souplesse de mise en œuvre sur le chantier, tant pour les constructions neuves que pour les ouvrages sinistrés par faits de guerre.

Les procédés originaux imaginés et les outillages modernes employés ont permis de réduire au minimum les échafaudages et de récupérer au maximum l'acier des ouvrages détruits.

Quelques exemples montrent que l'esprit inventif permet, en dépit de toutes les difficultés matérielles rencontrées, de réaliser des travaux intéressants tels que:

Lançage du pont route de Bragny à membrure inférieure courbe.
Relevage et réparation d'une pile et du tablier du viaduc de Serrouville tombé d'une grande hauteur.
Lançage rapide du pont-rail de Bollène.
Redressement du pont de la Mulatière incliné transversalement à 42%.
Relevage d'un tronçon de 72 m. du pont de Cubzac resté en équilibre instable sur une pile métallique déversée.

Summary

The authors intend to show that steel construction offers great flexibility of erection on site, both for new constructions and those damaged in war.

The original methods conceived and the modern equipment used have made it possible to reduce the scaffolding to a minimum and to salvage the maximum of steel from the wrecked elements.

A few examples show that an inventive spirit enables, in spite of all the material difficulties involved, some interesting work to be done, such as:

Launching the Bragny highway bridge, with a curved lower boom.
Raising and repairing one pier and the deck section of the Serrouville viaduct, which had collapsed from a great height.
Quick launching of the Bollène railway bridge.
Reconditioning the Mulatière bridge, transversely inclined at 42%.
Raising a 72 m. section of the Cubzac bridge, resting in unstable equilibrium on a leaning steel pier.

Zusammenfassung

In diesem Beitrag soll gezeigt werden, welch grosse Arbeitsgeschwindigkeit auf dem Bauplatz der Stahlbau sowohl für Neubauten als auch für Wiederherstellungsarbeiten an im Krieg zerstörten Bauwerken bietet.

Die selbst entwickelten Methoden und die verwendeten modernen Geräte erlauben, die Gerüste auf ein Minimum zu reduzieren und möglichst viel Stahl der zerstörten Bauwerke zurückzugewinnen.

An den folgenden Beispielen soll gezeigt werden, dass der erfinderische Geist es ermöglicht, trotz allen angetroffenen materiellen Schwierigkeiten interessante Arbeiten auszuführen:

Vorschieben der Strassenbrücke in Bragny mit gekrümmtem Untergurt.
Heben und reparieren eines Pfeilers und der aus bedeutender Höhe eingestürzten Fahrbahn des Viadukts Serrouville.
Schnelles Vorschieben der Eisenbahnbrücke in Bollène.
Geraderichten der bis zu 42% seitlich geneigten Brücke Mulatière.
Heben eines Bruchstückes von 72 m. der Brücke in Cubzac, welches in labilem Gleichgewicht auf einem geneigten Stahlpfeiler liegen geblieben war.

BII 3

Influence of erection methods on design of steel bridges

L'influence des méthodes d'érection sur la conception des ponts métalliques

Der Einfluss der Montage-Methode auf den Entwurf von Stahlbrücken

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INTRODUCTION AND HISTORY

To get the best results and the greatest economy, it is essential that the method of erection of any bridge should be considered when the design is prepared and that the design should be modified as may be necessary in order to conform to it.

Difficulties in erection have largely controlled the development of bridges. From the time of the construction of the Menai Suspension Bridge in 1818–26 until the Forth Bridge was completed in 1890 the longest single span was always of the suspension type, on account of the comparative ease of erecting the cables or chains compared with the difficulty of erecting girder or arch bridges.

In the middle of the nineteenth century suspension bridges fell into disrepute because of the failure of engineers to stiffen them adequately against the aerodynamic effect of wind forces, with their consequent failure in storms and under oscillating or rhythmic loads. The onset of the railway age brought further problems in the form of heavier and more concentrated loading and impact effects. John Roebling, however, by means of diagonal ties above and below deck and the incorporation of stiffening trusses, produced a design in the Grand Trunk Railway Bridge at Niagara which carried railway traffic, although not without difficulties, for some forty years and continued to keep suspension bridges in the lead. The collapse of the Tay Bridge in 1879, however, set up a clamour for bridges of sturdy design that would stand four-square to the wind and so ushered in the era of the great cantilever bridges.

In his well-known treatise *Long Span Railway Bridges*, in 1867, Benjamin Baker states: "Of the numerous practical considerations and contingencies to be duly weighed and carefully estimated before the fitness of a design for a long-span railway bridge could be satisfactorily determined, none are more important than those effecting the facility of erection." This was written only a few years before he and Sir John Fowler began work on the design of the Forth Bridge. Thereafter cantilever bridges held the lead in span until the growth of road traffic led to the construction of the long-span suspension bridges of today.

METHODS OF ERECTION

The following methods of erection may be adopted:

(1) Falsework or temporary staging
(2) Floating out
(3) Service girder
(4) Cantilever
(5) Rolling out
(6) Suspension

Let us see in what ways these methods may affect the design of a bridge.

(1) *Falsework*

Falsework is most suitable for erection of trusses over a dry river-bed or in shallow water where staging can easily be provided. It may also be used for the erection of the anchor arm of a cantilever bridge as in the Quebec and New Howrah Bridges

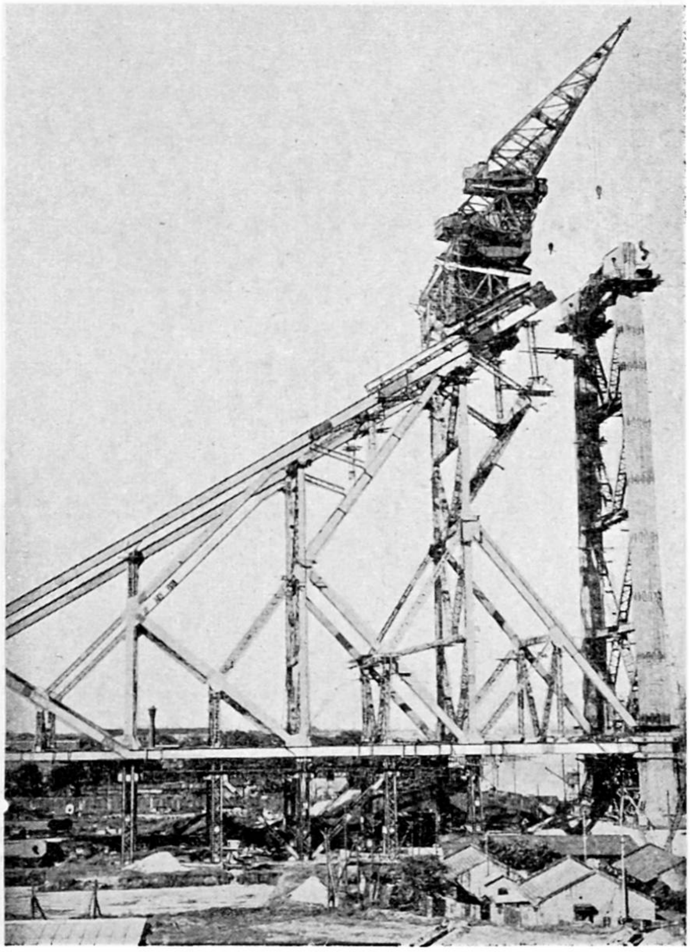

Fig. 1. New Howrah Bridge, Calcutta. Erection of anchor arm on falsework. Note fleeting tracks for creeper crane and temporary members supporting top chord

(fig. 1). It provides easy conditions for carrying out any desired prestressing,* but otherwise does not affect the design of the bridge, except possibly in the location of the connections. It was probably the provision of temporary supports immediately below panel points that originally led to the practice of locating splices in the lower chord some feet to one side of the intersection to facilitate riveting. It is more economical to locate splices at panel points, if possible, because the main gusset plates can then be included in the cover material. If there is any change of angle or depth of member at the panel point, fabrication is simplified by locating the splice there.

(2) *Floating out*

Floating out may be adopted for the erection of spans of 150 ft. or more, over a river that is too deep or otherwise unsuitable for staging, and where there are facilities for assembling the spans on pontoons, moored close to the shore, e.g. the Willingdon Bridge in Calcutta and the bridges over the Hawkesbury River, N.S.W. (fig. 2). It does not affect the design of the spans, except in so far as special details may be required at the ends for subsequently hoisting or lowering them into place. It is noteworthy that the first two substantial girder bridges, Britannia and Saltash, built a hundred years ago, were both floated into position and thereafter raised by hydraulic rams to their final level. This method may also be used for the erection of the suspended span of a cantilever bridge, as at Quebec.

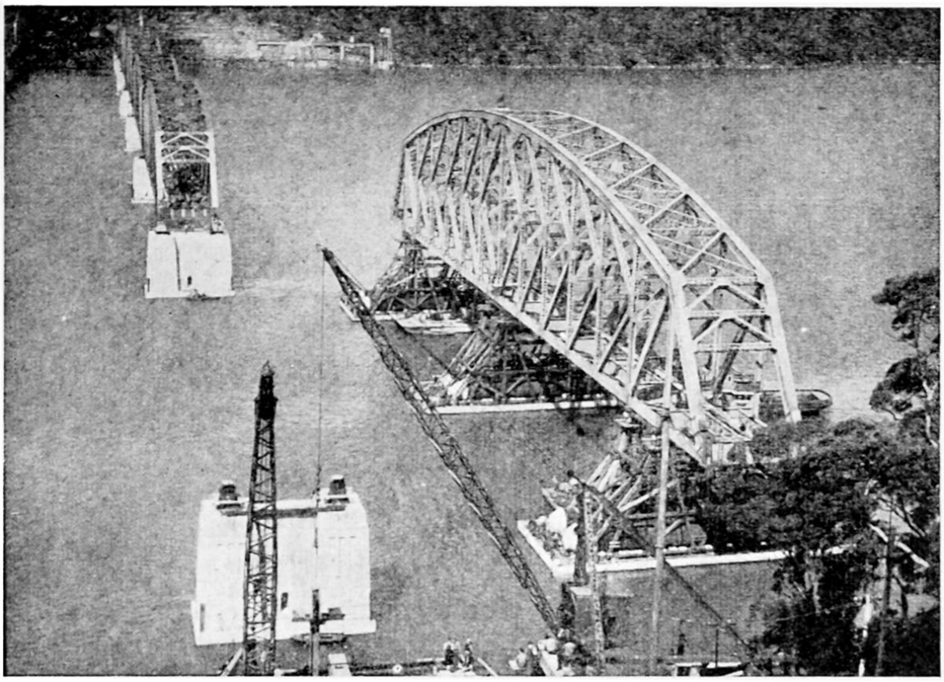

Fig. 2. New Hawkesbury River Railway Bridge. Floating in 445-ft. span

It is usually cheaper, however, to cantilever out the suspended span, even though extra material may have to be used in the end chords and diagonals, rather than to

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* *Prestressing*. The members of the trusses are fabricated to such lengths and their intersections to such angles, that under dead and (if desired) live load, the trusses would assume their correct geometric shape and all members would be straight. During erection, therefore, individual members have to be "prestressed," that is, temporarily strained or bent into position. By this means the secondary bending stresses that would otherwise occur under the predetermined load are largely eliminated.

float it out. This remains true even though prestressing is facilitated by the floating-out method.

(3) *Service girder*

Erection on service girders (fig. 3), e.g. Vila Franca Bridge, is similar in its effects to erection on staging and facilitates prestressing.

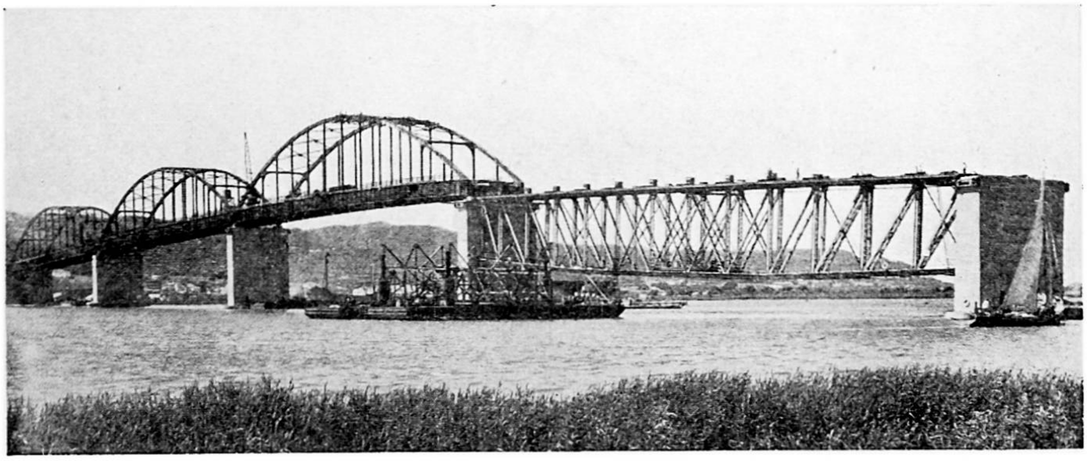

Fig. 3. Vila Franca Bridge over the Tagus near Lisbon. Service girders floated into position ready for erection of fourth span

(4) *Cantilever*

The first notable example of cantilever erection was that of the St. Louis Bridge over the Mississippi by James B. Eads in 1874. It is remarkable that this method was first used for an arch and not for a cantilever bridge. Since this date all big steel arches have been erected by this method with one notable exception, the Bayonne Bridge, which was temporarily supported on trestles. Spandrel-braced arches such as the Victoria Falls Bridge or Sydney Harbour Bridge are more suited to cantilever erection than crescent-shaped arches or ribs of uniform depth, as the anchorage cables can be attached to the ends of the upper chords and, on account of the depth of the truss, need not be moved further out as erection proceeds. Nevertheless extra material will generally be required to reinforce the upper chord and a number of the web members to enable them to resist erection stresses. N-type bracing also lends itself very well to cantilever erection and has been used in practically every long-span arch bridge. The effect of wind stresses during erection must be carefully investigated, particularly if the bridge is slender. In the Birchenough Bridge it was considered advisable to anchor the bearings of the arch against possible uplift arising from wind forces during erection.

The most economical way of erecting a cantilever bridge, if the site is suitable, is by means of balanced cantilever erection, as on the Forth Bridge. In this method the anchor and cantilever arms are built out equally from the main pier and no falsework or temporary foundations are required. After the ends of the anchor arms have been tied down, the erection of the cantilever arms and suspended span proceeds to the centre (fig. 4). No extra material is required on account of erection stresses, except in the ends of the suspended span if it is erected as two cantilevers. Provision, of course, must be made for closing the bridge at the centre and subsequently "swinging" the suspended span, so as to convert it to a freely supported structure. This method has also been used on cantilever bridges which have single end-posts, by employing one or more temporary trestles close to the main pier and so providing a base from which to cantilever.

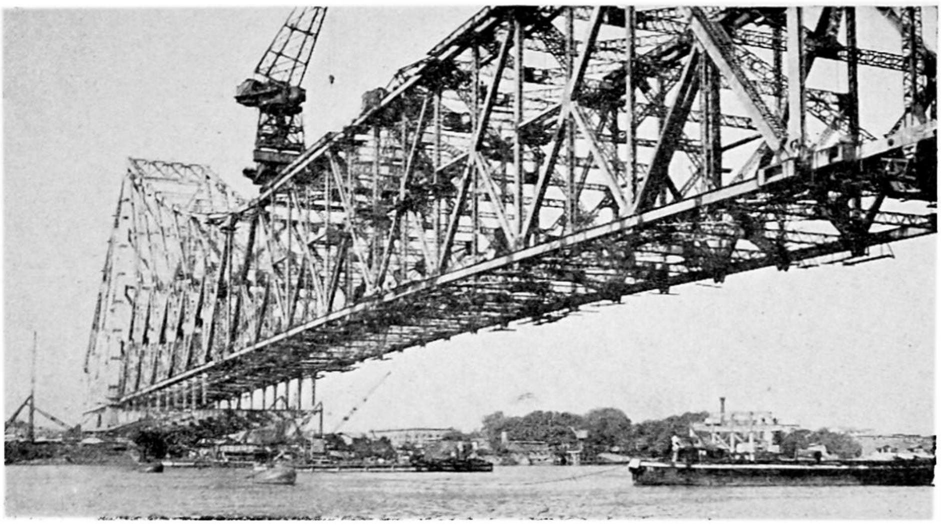

Fig. 4. New Howrah Bridge, Calcutta. Junction of suspended span after erection as two cantilevers

The prestressing of a cantilever arm is not very difficult but certain items of special plant may be needed. On the New Howrah Bridge two adjustable jacking members (fig. 5) had to be designed for this purpose. These members were telescopic and had 200-ton jacks incorporated in them, to enable the lower chord panel points to be forced upwards, so that connections in the diagonals above them could be made.

The cantilever method of erection may be used for simple spans, as, for example, on the Beit Bridge over the Limpopo River. In this bridge of 14 spans, the first was erected on falsework and all the other spans were built as cantilevers; this enabled erection to proceed independently of floods. Extra material will, of course, be needed at the ends of the spans to resist erection stresses, and temporary ties between the spans are required. Great difficulty may be experienced if a simple span of high-tensile steel is erected as a cantilever, and has also to be prestressed. The reason for this is that the erector has a dual task in that he has first to eliminate the distortions of the truss as a cantilever and then to impose the distortions necessitated for prestressing.

(5) *Rolling out*

The method of rolling out is more applicable to short than to long spans. Its most extensive civilian use is in the reconstruction of railway bridges, where in a week-end occupation the old bridge may be rolled out sideways on temporary trestles and a new one, which has been assembled beside it, may be rolled into position.

The method of balanced launching "end-on" was considerably developed in the erection of Bailey bridges during World War II. In one method the bridge was built on rollers on the river bank with a temporary extension piece or nose on the end of the bridge. It was then launched out on two or three sets of fixed rollers, and before the centre of gravity of the span had moved beyond the last set of rollers on the near side, the nose end reached the far bank. If this could not be contrived, the "derrick

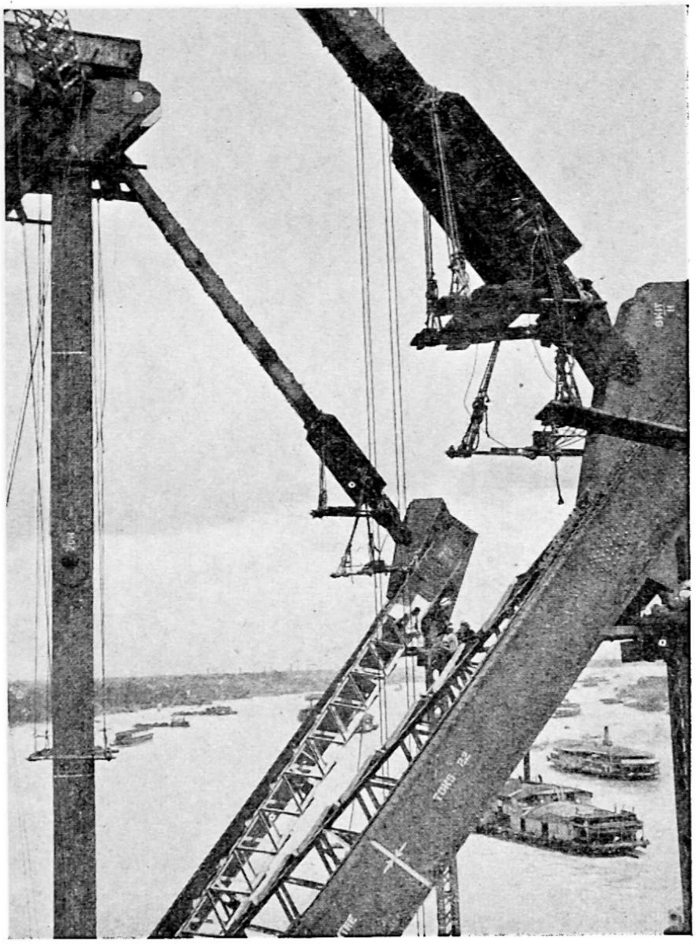

Fig. 5. New Howrah Bridge, Calcutta. Temporary adjustable members with 200-ton jacks being used for prestressing of cantilever arm

and preventer" method was used. In this system the span was prevented from overbalancing by supporting the nose end by means of tackle suspended from a pole on the far shore. The forward pull was resisted by means of preventer tackle attached to the near end of the span to hold it back. Alternatively, counterweights might be used, if available, on the near end to prevent overturning. In all these methods the truss has not only to be designed to resist the effects of cantilevering to the extent required, but the lower chord has to be capable of resisting in bending the reaction from the rollers.

(6) *Suspension*

The design of a suspension bridge as a whole is not much affected by the method of erection of the cables. These may consist of parallel wires spun in place, squeezed together and bound, as in standard United States practice; or they may be composed of a number of prestressed stranded ropes or locked-coil cables that permanently maintain their individual character. Alternatively, links may be used, as in the reconstruction of the Menai Suspension Bridge.

The most significant difference in design occurs in the method of connection of the cable to the anchorage. The loops of wire forming parallel wire cables are connected by passing them round the curved ends of the strand shoes so that the wire remains continuous and is in a state of tension, bending and compression. Cold-drawn high-tensile wire, unlike heat-treated wire, appears to suffer no harm in this condition, The ends of individual strands in the stranded-rope cable, however, are usually connected by means of white-metal into a cast-steel socket which is bolted to the anchor bars. Each wire remains virtually straight and is in a state of tension only.

An interesting innovation in the Otto Beit Bridge was to use parallel wire cables but to pull each strand across in the form of a flat ribbon made up of a number of wires side by side. Strands were socketed at the ends for connection to the anchorages and retained their individuality to some extent at the tower saddles, which were specially shaped to accommodate the layers of wires; but throughout the remainder of their length they were squeezed together and bound (fig. 6).

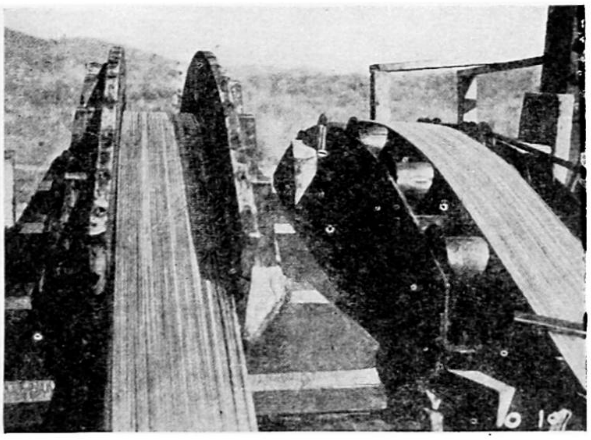

Fig. 6. Otto Beit Bridge, Rhodesia. Erection of cable strands in the form of ribbons of parallel wires. Note tower saddle on left with new strand about to be placed

Suspenders may be either socketed at the ends, so that the wires remain straight or they may be looped over the top of the cable bands as in United States practice.

Towers may be either fixed or hinged at the base. The usual practice today, particularly on long spans where the towers are massive, is to fix the base. After erection the cables are also fixed to the top of the tower, which is thereby subjected to slight bending, but not enough to be of any significance. To facilitate the erection of straight backstays on a fixed tower the saddle is usually moved back to enable the backstays to be connected, and subsequently jacked forward and bolted in its permanent position centrally on the tower. A recent example of hinged towers is the new Chelsea Bridge in London.

Very wide variety is found in the arrangement of deck and stiffening trusses. Greatest economy is gained by bringing the sag of the cable as low down as possible relative to the deck and thus achieving the maximum sag with the shortest tower. In a number of early suspension bridges, such as Brooklyn Bridge and Clark's famous bridge at Budapest, this was done by bringing the cable down below the upper chord of the stiffening truss. This arrangement was also successfully adopted on the Otto Beit Bridge. There the ends of the cross girders were suspended from the cables and the stiffening trusses were subsequently erected on the cross girders. The deck could thus be erected before the truss and the truss material could be laid out on the deck stringers right along the span before erection, thereby avoiding severe distortion of the cables (fig. 7).

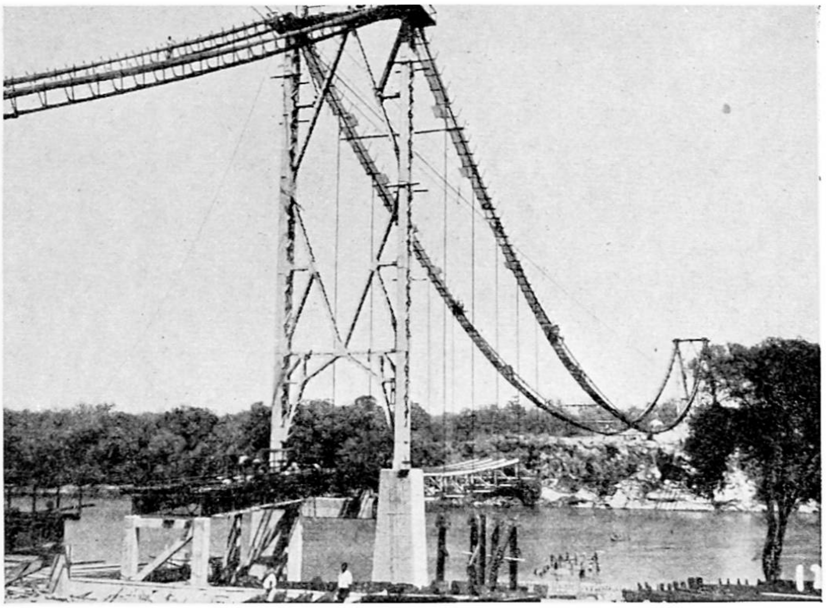

Fig. 7. Otto Beit Bridge, Rhodesia. Erection of deck cross girders. Note opening in tower bracing for Blondin on Bridge centre line

The usual modern practice in the United States is to put the cables and stiffening trusses in the same plane, so that the suspenders directly connect the top of the truss to the cable. In this arrangement taller towers are required; moreover the erection of the stiffening truss, which has to be built before the deck, or together with it, is complicated by distortion of the cables. This distortion is particularly severe if the stiffening truss is built out continuously from the towers, as on the Golden Gate Bridge. In the Bay Bridge the deck steel was erected by means of tackle suspended from the main cables and in units weighing from 75 to 203 tons. Erection was begun at the centre of the main spans and at the ends of the side spans (fig. 8).

EFFECT OF ERECTION CRANE ON DESIGN

Cranes may be situated:

1. On the bridge, i.e. Scotch derrick, or creeper crane.
2. Independent of the bridge, i.e. on the ground on staging, on service girders, or floating cranes.
3. Blondins.

(1) *Cranes on the bridge*

(*a*) Creeper cranes

Early bridges, such as the St. Louis Bridge and the Forth Bridge, were erected piecemeal with very light cranes that travelled on the bridge. At the beginning of this century the tendency to use heavy creeper cranes for assembling large units developed. On the Hell Gate Bridge pieces were erected weighing up to 180 tons each; the heavy traveller on Quebec Bridge weighed 920 tons and was equipped with four

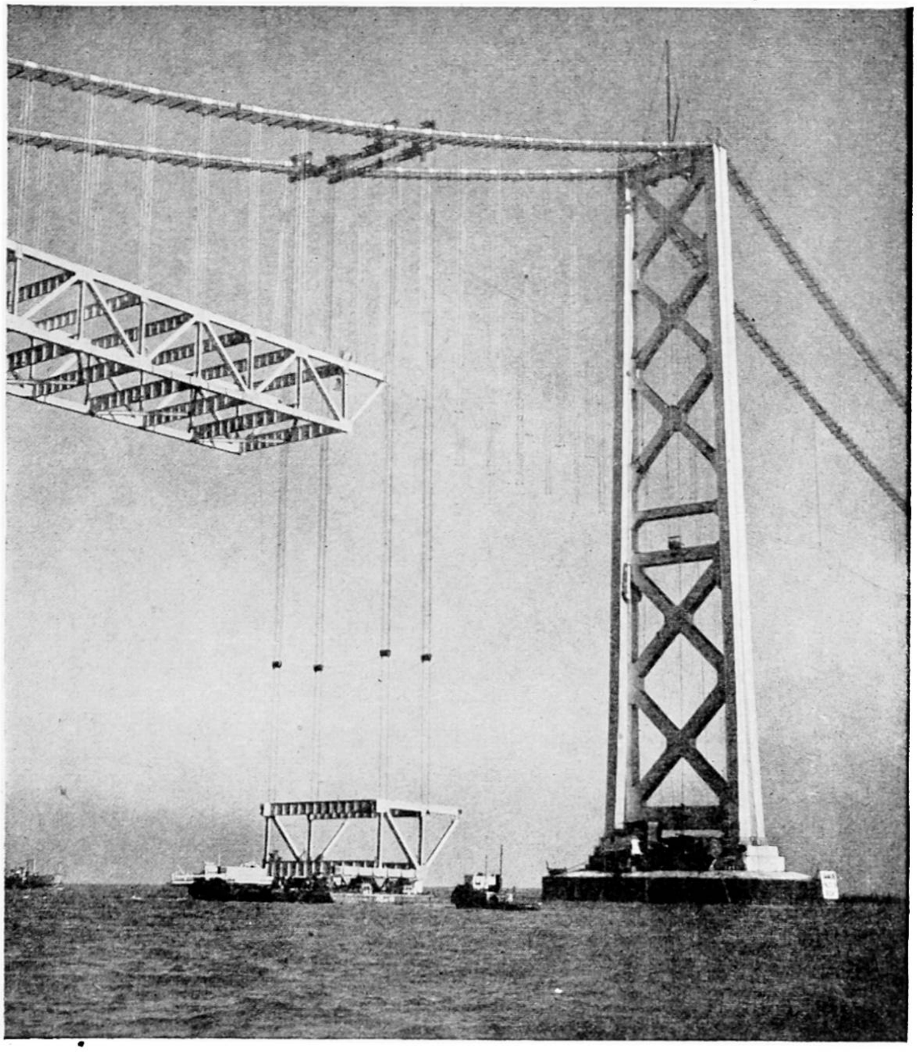

Fig. 8. San-Francisco–Oakland Bay Bridge. Erection of heavy units of deck steelwork

55-ton and four 20-ton hoists, in addition to numerous light derricks of 5- and 10-ton capacity.

On Sydney Harbour Bridge the heaviest chord member weighed more than 500 tons. In order to keep the weights of individual lifts to a reasonable figure all the chords were subdivided longitudinally and most of them were given one or more field splices in their length. By this means a fairly uniform range of lifts was obtained, all within the capacity of the 120-ton creeper cranes. It is generally more economical to reduce the heaviest lifts by means of splices in this way than to provide a crane capable of lifting the heaviest member in one piece. If by this means the capacity of the crane can be halved, as it well may be, its weight and cost will be very substantially reduced and it will be quicker in use. Moreover, the cost of temporary trestles, foundations and fleeting tracks will all be substantially less.

On arch bridges, creeper cranes generally run on the upper chord, which is usually sturdy enough to carry the weight. No reinforcement was required in the Sydney Harbour Bridge or Birchenough Bridge. On through cantilever bridges creeper cranes may be run over the top chord as on the New Howrah Bridge or a tower traveller may be used running on the deck. The disadvantage of running a creeper crane over the top chord is that upper chord members of a cantilever bridge are seldom heavy enough to support its weight in bending. On the Howrah Bridge special fleeting tracks had to be bolted on to stools on the top chord and temporary members had to be inserted in the bracing to support the chord under the weight of the crane (fig. 9). Moreover, if the cantilever bridge is of conventional outline, special means have to be provided to haul the crane over the peak at the end post. The tendency in America today is to use comparatively light guyed-derricks, as on the San-Francisco–Oakland Bay Cantilever Bridge, in preference to heavy creeper cranes.

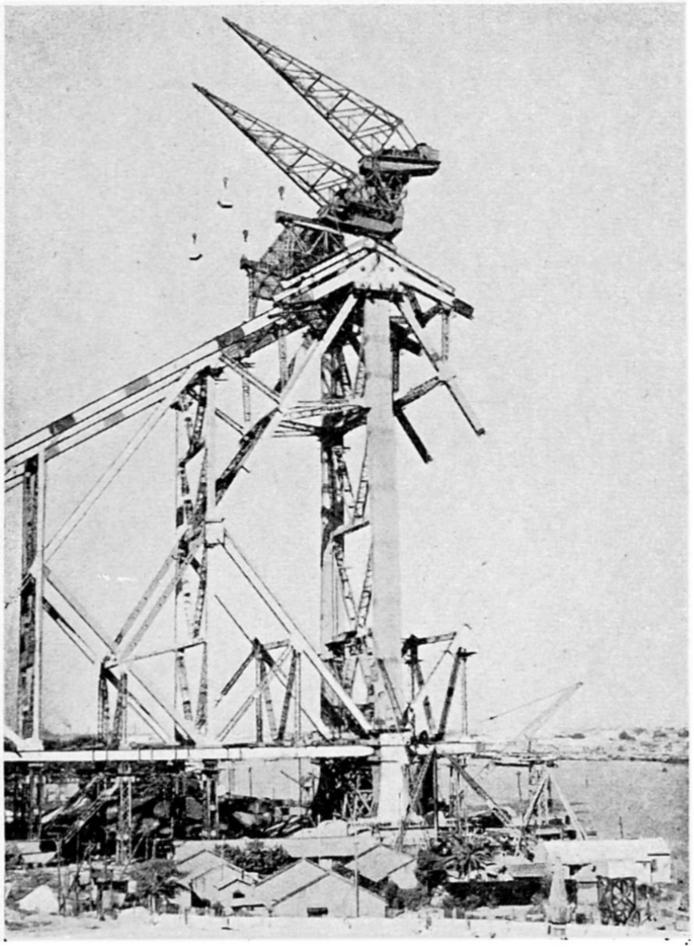

Fig. 9. New Howrah Bridge, Calcutta. Creeper crane moving off temporary cradle on which it had been hoisted up anchor arm on to fleeting tracks on cantilever arm

Cantilever bridges rarely require any strengthening of members to resist direct stresses, including those from the weight of the crane during erection, because the members adjacent to the piers are the most heavily stressed in the final condition. But on arch bridges the circumstances are entirely different. The ends of the upper chords of a spandrel-braced arch carry little stress in the final condition and substantial reinforcement is required in them during erection. On the Sydney Harbour Bridge part of the extra section needed was added in permanent material and part in the form of temporary side webs which were removed after the arch was closed.

(*b*) Scotch derricks

Instead of employing creeper cranes, Scotch derricks may be used in a kind of leap-frog, as on the new Tyne Bridge at Newcastle. In this method a derrick on the steelwork erects the members of the bridge as far ahead as it can reach and then erects a second derrick on the end panel. This derrick then proceeds with the erection and dismantles the first derrick and re-erects it ahead, and so on. The effect of this method on design is less than that of creeper cranes, in that the derricks themselves are lighter; no fleeting tracks are required, nor does the upper chord have to support the weight of the crane in bending.

(2) *Independent cranes*

(*a*) On the ground, on staging or on service girders

None of these has any direct effect on the design of the bridge, but it may be well to consider the circumstances under which the use of cranes on service girders becomes economical. In multiple-span bridges it will probably pay to use special plant, such as a Goliath crane travelling on a service girder, as in the Lower Zambesi Bridge, rather than to adopt cantilever erection which necessitates strengthening the bridge by using extra material in the end chords and web members of every span.

(*b*) Floating cranes

Erection by means of floating cranes generally has no effect on the design of the superstructure. In the Storstrom Bridge complete plate-girder side-spans weighing up to 500 tons each were hoisted up bodily by means of a huge floating crane and placed on their bearings on the piers at a height of 90 ft. above water level (fig. 10).

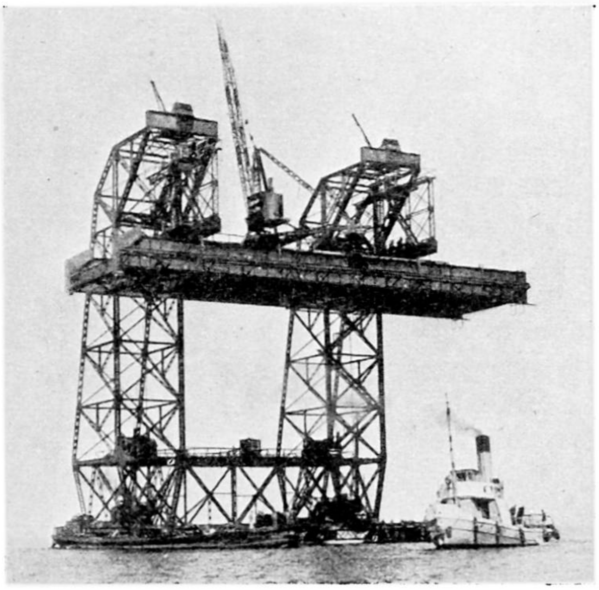

Fig. 10. Storstrom Bridge. Floating crane lifting 500-ton side span complete with erection crane on it

The main spans on this bridge consisted of tied arches with plate girders 12 ft. deep in the deck. The plate girders were erected in halves by the floating crane and joined on a temporary trestle at the centre (fig. 11). The arch rib was then erected overhead

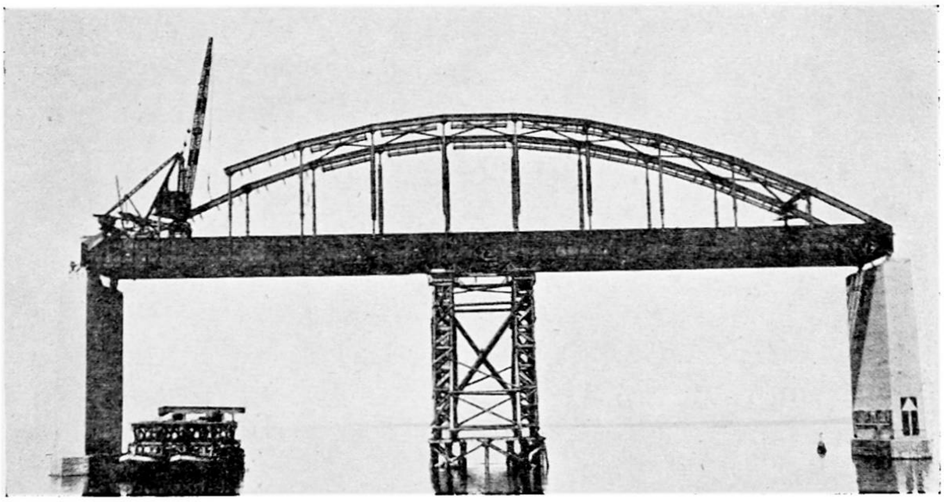

Fig. 11. Storstrom Bridge. Plate girders of navigation span assembled in two halves by floating crane and connected on temporary trestle. Arch rib and hangers erected by travelling crane

by means of a travelling crane running on the deck. This method enabled long-span plate girders to be erected on a bridge spanning deep water, and the arch rib to be built without using a creeper crane.

(3) *Blondins*

On certain sites, such as a gorge or river with good access only at one end, a blondin may be necessary to take the steel across the river or even to erect it. On the Birchenough Bridge a 7-ton electrically operated cableway was used alongside the bridge. Members were taken out on the blondin and transported to the crane in mid-air, a platform being provided for the erector around the cableway hook. The same blondin was subsequently used for the erection of the Otto Beit Suspension Bridge (fig. 7). Here it was assembled on the centre line and a large opening was provided in the tower bracing to leave space for it. The legs of the towers were erected by means of the blondin, two sections being assembled at a time, at the ends of a lifting beam which spanned the width of the bridge. Subsequently the blondin was used to erect the deck steelwork. The cross-girders and inner roadway-stringers were erected in sets of two each with only one bolt at each joint. This method of connection enabled the set to be folded up, as it were, so that it would pass through the opening of the tower. An erector was carried at each end of the cross-girders to make the suspender connections.

A blondin not only saves the necessity for a crane on the deck of a suspension bridge, but it also provides the means of laying out the stiffening truss along the whole length of the deck before erection (if the design permits this to be done) so as to avoid distortions of the cable.

ALL-WELDED BRIDGES

The development of all-welded trusses of substantial size is delayed by the following problems which have yet to be satisfactorily solved:

(1) Holding members securely in place during welding of the site connections.

(2) Making the correct allowance in advance for distortions that will occur during site welding. The distortion has to be correctly estimated and the

initial lengths of members predetermined. The assumptions made cannot be proved by pre-assembly in the shop, as they can in the case of a riveted truss; but unless they are correct the truss will not be true to line and level after welding.

(3) Carrying out prestressing, if desired, during erection.

These difficulties do not apply to plate girders in which splices can be satisfactorily welded at site.

A compromise sometimes adopted is to make all-welded members with the end connections reinforced and drilled for site bolting and riveting. This method has been adopted in New South Wales and found to be economic; it does not, however, overcome the difficulties but avoids them. Moreover some economy of the all-welded design is lost and the shop-work is complicated by both welding and drilling having to be performed.

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Summary

It is essential in order to get the best results and the greatest economy that the method of erection of any bridge should be considered when the design is prepared and that the design should be modified as may be necessary in order to conform to it. The historical background shows that difficulties in erection have in fact been one of the outstanding factors controlling the development of bridges.

In the paper, the various methods of erection and their effect on the design of bridges are considered. These methods include the use of falsework, floating out, service girders, cantilevering, rolling out and suspension. Numerous examples are quoted and reference made to suitability for prestressing and other requirements. Some alternatives are quoted to the more or less standard types of details used in

American suspension bridges, and reference made to their effect on economy in erection and design.

The various kinds of erection cranes are then dealt with, including creeper cranes on the bridge; cranes travelling on service girders or staging and floating cranes; and blondin cableways. The necessary capacity of the erection crane is considered and the desirability of keeping it as low as possible, by means of the provision of site splices in the heaviest members to reduce the maximum weight of lift. Examples are given of this and of the reinforcement that may be required in a bridge to enable it to carry the weight of the crane. The conditions under which floating cranes or blondins are necessary are considered and examples of the use of both are given.

In conclusion reference is made to the erection problems which have yet to be satisfactorily solved in the development of all-welded truss bridges of substantial size; and the compromise sometimes adopted of shop-welded members with end connections designed for riveting or bolting.

Résumé

Si l'on veut obtenir les meilleurs résultats et réaliser le maximum d'économie dans la construction d'un pont métallique, il est nécessaire de tenir compte de la méthode d'érection lorsque l'on étudie la conception même de l'ouvrage, cette conception devant être adaptée aux conditions d'érection. L'expérience montre que les difficultés de montage ont constitué l'un des plus importants facteurs qui conditionnent le développement des ponts métalliques.

L'auteur passe en revue les différentes méthodes d'érection et étudie leur influence sur la conception des ponts. Ces méthodes comportent l'emploi d'ouvrages provisoires, de supports flottants, de poutres de service, de montages en porte-à-faux, du roulage et de la suspension. De nombreux exemples sont cités et mention est faite de l'opportunité de la précontrainte et autres conditions. Différentes dispositions de détail plus ou moins normalisées sont signalées à propos de la technique américaine de construction des ponts suspendus, avec indication de leur influence du point de vue économique.

L'auteur présente les différents types d'appareils de manutention employés, y compris les grues se déplaçant sur le pont lui-même, ou sur des poutres de service, les grues échafaudées et les grues flottantes, ainsi que les blondins. Il indique la capacité à prévoir pour la grue de montage, ainsi que l'opportunité de la maintenir aussi basse que possible, en prévoyant tous dispositifs d'assemblage permettant de réduire le poids maximum à lever. Il cite des exemples, portant également sur le renforcement qu'il peut être nécessaire de prévoir sur un pont pour lui permettre de porter le pouds de la grue. Il expose les conditions qui nécessitent l'emploi de grues flottantes ou de blondins.

En conclusion, l'auteur signale les problèmes de montage qu'il importe de résoudre d'une manière satisfaisante en vue du développement des grands ponts en treillis entièrement soudés, ainsi que le compromis parfois adopté, consistant à prévoir des éléments soudés en atelier, avec assemblage par rivetage ou boulonnage.

Zusammenfassung

Zur Ermittlung der besten und wirtschaftlichsten Lösung muss die Montage-Methode schon bei den Entwurfsarbeiten für eine Brücke in Betracht gezogen werden und der Entwurf muss dem Montagevorgang nötigenfalls angepasst werden. Ein Blick in die Vergangenheit zeigt uns, dass Montage-Schwierigkeiten in grossem Masse die Entwicklung des Brückenbaus hemmten.

Der Verfasser betrachtet die verschiedenen Montage-Methoden und ihren Einfluss auf den Entwurf einer Brücke. Bei diesen Verfahren handelt es sich um die Verwendung von Lehrgerüsten, das Einschwimmen, den Bau von Hilfsträgern, den Freivorbau, das Einschieben und das Einhängen. Zahlreiche Beispiele werden aufgeführt und die Möglichkeiten der Vorspannung und anderen Massnahmen werden erwähnt. Einige Varianten für die mehr oder weniger vereinheitlichten Lösungen des amerikanischen Hängebrückenbaus werden angegeben und hinsichtlich ihres Einflusses auf die Zweckmässigkeit der Montage und des ganzen Entwurfs untersucht.

Anschliessend werden die verschiedenen Typen von Montagekranen beschrieben unter Einschluss von Laufkranen auf die Brücke selbst, Kranen, die auf Hilfsbrücken montiert sind, Derricks, Schwimmkranen und Blondin-Seilkranen. Das notwendige Tragvermögen eines Montagekrans wird untersucht und auch die Forderung, dieses so niedrig wie möglich zu halten, indem zur Abminderung des grössten zu hebenden Gewichts die schwersten Bauteile mit Montagestössen versehen werden. Dieses Problem und die Frage der Verstärkung einer Brücke zwecks Aufnahme der Belastung durch einen Kran werden an Hand von Beispielen dargelegt. Die Bedingungen, unter welchen Schwimmkrane oder Blondins zweckmässig sind, werden untersucht und durch Anwendungsbeispiele belegt.

Zum Schluss wird auf das Montage-Problem hingewiesen, das sich im Zusammenhang mit der Entwicklung von vollständig geschweissten Fachwerkbrücken beträchtlicher Spannweite stellt. Dieses Problem konnte noch nicht befriedigend gelöst werden. Auch der nicht selten gewählte Kompromiss mit in der Werkstätte geschweissten Stäben und verschraubten oder genieteten Knotenpunkten wird erwähnt.