

Corrections to Melan's equation

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IIIb3

Corrections à l'équation de Melan

Korrekturen zu der Gleichung von Melan

Corrections to Melan's equation

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Orebro

I should like to say a few words on the corrections to Melan's equation in suspension bridge analysis.

Until this morning my opinion was that the deflection theory analysis of a suspension bridge is best carried through by using influence lines on the basis of Melan's fundamental equation and assuming inextensible cables. Melan's equation is founded upon several assumptions that do not quite agree with actual conditions. The corrections for these assumptions are generally small. It seems to me that they should not be treated all together but one by one, and be finally added.

That will make the whole procedure clearer. Corrections for different disturbances may be compared from case to case and often they may be estimated without much or any computations or they may be neglected.

Influence lines based on Melan's equation and inextensible cables will be the simplest and they have the great advantage of being applicable to all bridges with different cables.

In using such influence lines the first correction will be for the cable yield (by elastic extension, temperature and anchorage displacements). These corrections are generally small and their rational application has been clearly demonstrated in recent literature.

Similarly the span interaction terms in multiple span bridges can be carried to the same cable yield correction.

That makes possible a very rational treatment of multiple-span bridges by the immediate use of the influence lines of the one-span bridge.

The influence of and correction for stiff towers has been carefully investigated by a great many authors. They have found rather small corrections, in practical cases on the order of one per cent.

In the calculation of the horizontal pull Melan's theory assumes equal suspender forces. That introduces an error, as pointed out by Krivoshein. For a special bridge it has been calculated by myself not to exceed two per cent for the deflections and a fraction of one per cent for the moments.

The effect of the suspender elongation and of the tower shortening under live load is generally neglected.

Moissief (Johnson, Bryan, and Turneure) finds a negligible gain in accuracy by considering this effect. Steinman estimates the correction to be a small decimal of one per cent. Mabillean arrives at the conclusion that the elasticity of the suspenders and towers is of negligible influence upon the stresses. Klöppel and Lie in a particular case find a correction to moments of 0.15 %. However, in his paper in the *Preliminary Publication* Crosthwaite in a particular case finds that the shear increases by 4 % near the towers, which is notable. It may very well be so, and it will be interesting to verify this figure.

When a suspension bridge is loaded the inclination of its suspenders will change, which changes the horizontal force. Klöppel and Lie and Stüssi and Amstutz have investigated this disturbance both theoretically and numerically. It is generally small but depends greatly upon the length of the shortest hangers.

Of all other corrections to be applied I only want to mention the correction to Melan's equation due to the angular deviation of the cable elements. It can be separately evaluated as has been demonstrated in the *Preliminary Publication*.

To-day Professor Stüssi has laid forth a very interesting funicular polygon method for the suspension bridge analysis. When using his method it may be more expedient not to segregate each correction and I think one should not insist upon that because of the obvious advantage of his method of solving a statical problem by means of statical instead of by more mathematical methods.

Professor Stüssi's method deserves full consideration and application, but it would be regrettable if interest is lost in the development of the classical differential equation method which still may be or may become the most serviceable in many instances. It seems desirable not to cut off any line of development but to proceed on both.

Résumé

L'équation de Melan est basée sur des hypothèses qui constituent des approximations. Les termes correctifs sont en général faibles. On peut toutefois les évaluer un à un et les ajouter aux résultats obtenus par l'équation de Melan.

Zusammenfassung

Die Gleichung von Melan ist auf Annäherungen gegründet. Die Korrektionsfaktoren sind im allgemeinen sehr gering und können separat abgeschätzt werden um mit den ersten Ergebnissen der Gleichung von Melan zusammengerechnet werden zu können.

Summary

Melan's equation is founded upon several assumptions that do not quite agree with actual conditions. The corrections for these assumptions are generally small. It seems that they could be treated one by one, and be finally added.

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**Le montage de la travée centrale
du pont sur le Mississippi près de Dubuque (Iowa)**

**Die Montage der Mittelöffnung
der Mississippi-River-Bridge bei Dubuque (Iowa)**

**Erection of the main span
of the Mississippi river bridge at Dubuque (Iowa)**

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The Julien Dubuque highway traffic bridge across the Mississippi River from Dubuque, Iowa to east Dubuque, Illinois, has a total length of 7 082 ft. It provides for two lanes of vehicular traffic on a roadway 24 ft wide between curbs. It has one 6 ft over-all sidewalk and on the opposite side of the roadway a curb 2 ft wide, making a total of 32 ft between handrails. The structure is made up of steel girder spans and all-riveted truss spans supported on concrete piers. Roadway and sidewalk floor slabs are of reinforced concrete.

The principal feature of this bridge is a three-span continuous through truss structure having a total length of 1 539 ft, with a central tied arch span of 845 ft and two end spans each 347 ft. Trusses are 35 ft centers. This type of structure, well-known in Europe, is not common in America. This is said to be the longest continuous truss span in the world. The length and positioning of this span was fixed by navigation requirements, here unusually severe because of the docks immediately at the bridge site. It is the longest channel span of any bridge across the Mississippi River except only the Natchez and Baton Rouge bridges.

This type of span was selected after studies of various possible structures, because of its comparable economy, its pleasing appearance, and its inherent advantages for erection. The design provided for such erection by a program which needed a minimum amount of additional metal incorporated in the members of the structure to provide for erection stresses. The total steel in this 1 539 ft span is 4 225 tons (2 000 lbs). This total includes only 200 tons above the minimum required for the final service of the span.

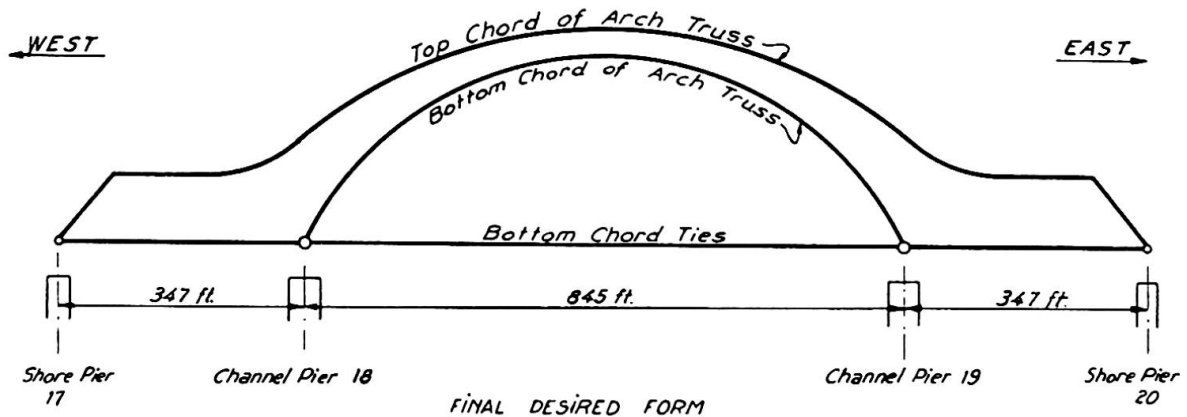


Diagram I. General form and various elements of the structure.

This was accomplished by carrying out the erection in several stages : (1) By cantilevering each half of the total span length as two 2-span structures, but omitting all vertical hangers of the central span and all metal suspended from them; (2) By connecting these two halves of the span to constitute a three-span structure, set in a way to have adequate capacity to support the omitted hangers and bottom chord ties and floorbeams; (3) By a shortening of the distance between shoes of the central span from the position chosen for operation (2) to provide for splicing its bottom chord ties and adjusting the span into its functioning as a tied arch : thereafter adding stringers and other floor metal.

To make compensation for the deflection or sag of the overhanging portions of the arch trusses in their cantilevered position of Stage 1, and to afford controlled positioning of the trusses for other erection stages, the details were arranged so that each entire half span could be rocked on its channel pier shoe by lifting or lowering its shore end. Provisions were also made for longitudinal shifting. To make the mid-arch connection after Stage 1, the shore ends of the end spans were lowered 3 ft 6 1/2 in below final normal position for connecting the bottom chords of the arch trusses, and raised to 3 ft 3 in below normal position for connecting the corresponding top chords. During erection Stage 2 these shore ends were set 1 ft 6 in below normal position. Thereafter, lowering to 2 ft 8 1/2 in below normal would bring the bottom chord tie together for splicing. Alternately it was contemplated that this final splicing of the bottom chord ties might be accomplished by applying pulling jacks to them; and the Contractor decided to make the connection in that way. The concluding operation was to jack up these end shoes to final elevation at which the trusses are designed to function permanently, and to add the rest of the floor steel and the concrete floor slabs. In final position the dead load reaction on each of the four end shoes, — which are in fact rocker columns — is 125 tons.

A general consideration of the functioning of the structure will make evident that a very considerable control of stress distribution was possible by raising or lowering the ends of the spans. To have added the hangers and the floor metal with the cantilevering operations under Stage 1 would have required extensive enlargement of many truss members, — solely for the erection condition. In its functioning as a three-span continuous

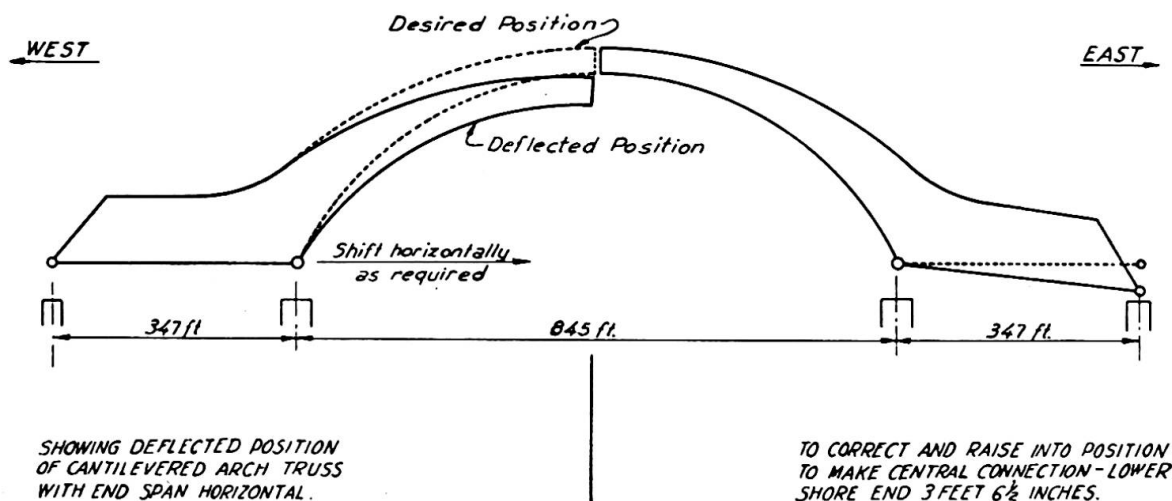


Diagram II. Method of compensating for deflection of cantilevered arch trusses.

truss, under the controlled conditions described for Stage 2, the structure was adequate to support the hangars, bottom chord ties, floorbeams and bracing. Installation of stringers, curbs, handrails and other floor metal was deferred until after the bottom chord ties had been finally spliced and connected so that the central span was functioning as a tied arch. In making these various adjustments of the span by lowering and lifting the ends, the reactions were measured as well as the deformations. The amounts of the reactions for the various deformations closely corresponded to the theoretical amounts as determined in the design calculations.

The general procedure of the erection operation can most readily be followed by the reviewing the accompanying diagrams and photographs. Diagram I illustrates the general form and identifies various elements of the structure herein referred to. Diagram II illustrates the method of compensating for deflection of cantilevered arch trusses so these parts could correctly be brought together to accomplish the riveted connection.

Photograph 1 is a general view showing adjacent parts of the bridge as well as the main span.

Photograph 2 shows the main span completed in final form ready for traffic. The scale of the structure may be noted from the automobile on the central span and of the man standing near the midspan hanger. This view is taken looking downstream. All other pictures are taken looking upstream.

Photograph 3 shows a fairly advanced state of erection. It will be noticed that the west end span, at the left end of the picture, extends in part across the shore. This span was supported during erection on two steel falsework bents, one of which remains in place in this picture. It was set up principally by the derrick standing on the top chord. After reaching the west channel pier erection of the arch truss continued by cantilevering, with the derrick moving forward on the top of the span.

The east one-half of the structure appearing to the right of the picture, to the extent here shown was erected by cantilevering in both directions, balanced upon the east channel pier. Temporary inclined steel struts set on a projection of the pier below water supported the first panel point east

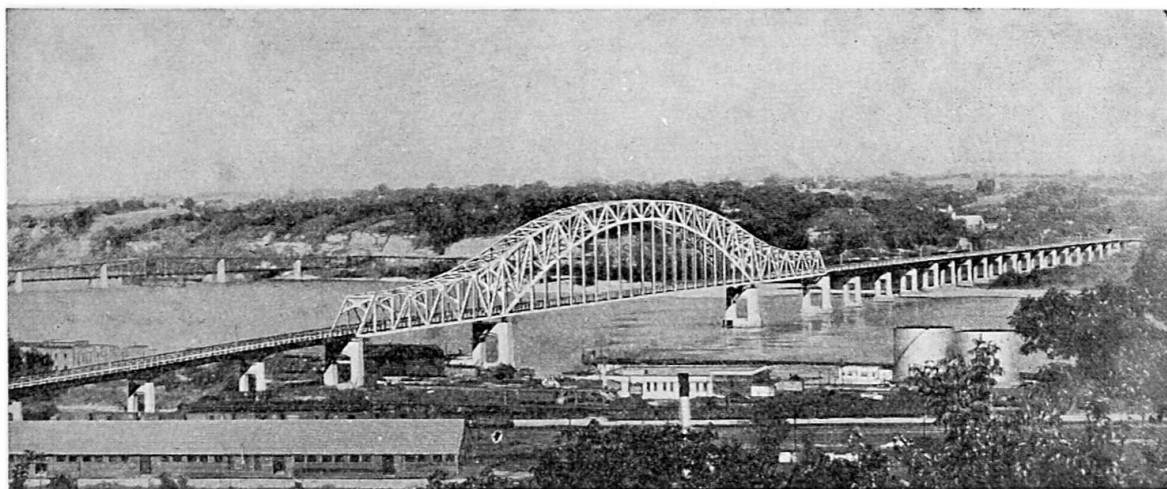


Fig. 1. General view of Mississippi river bridge.

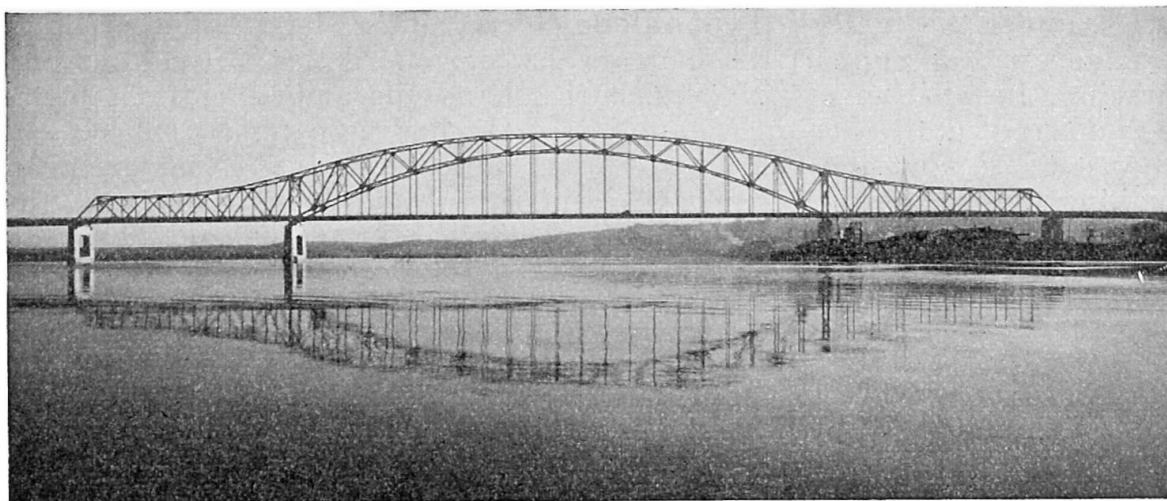


Fig. 2. Main span of Mississippi river bridge.

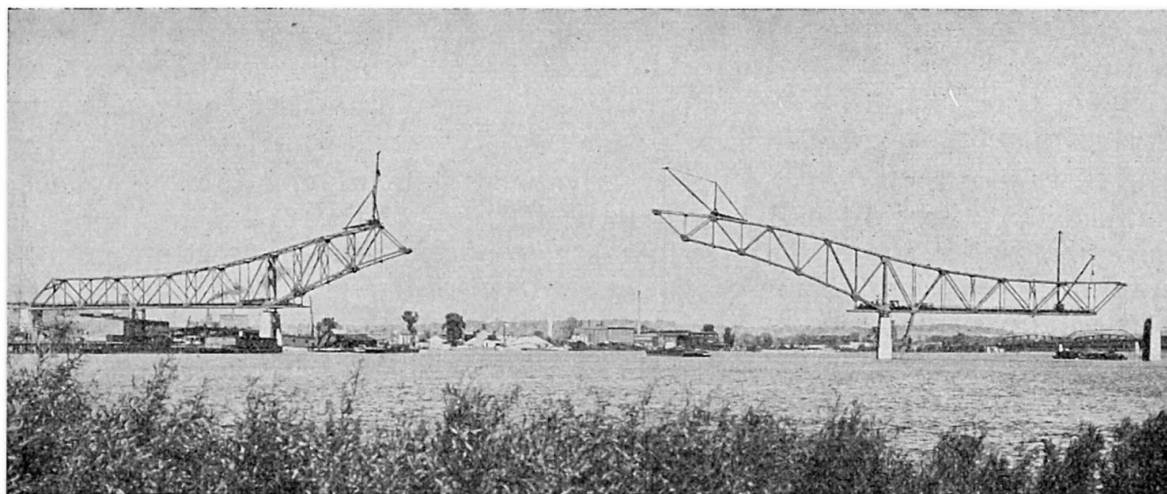
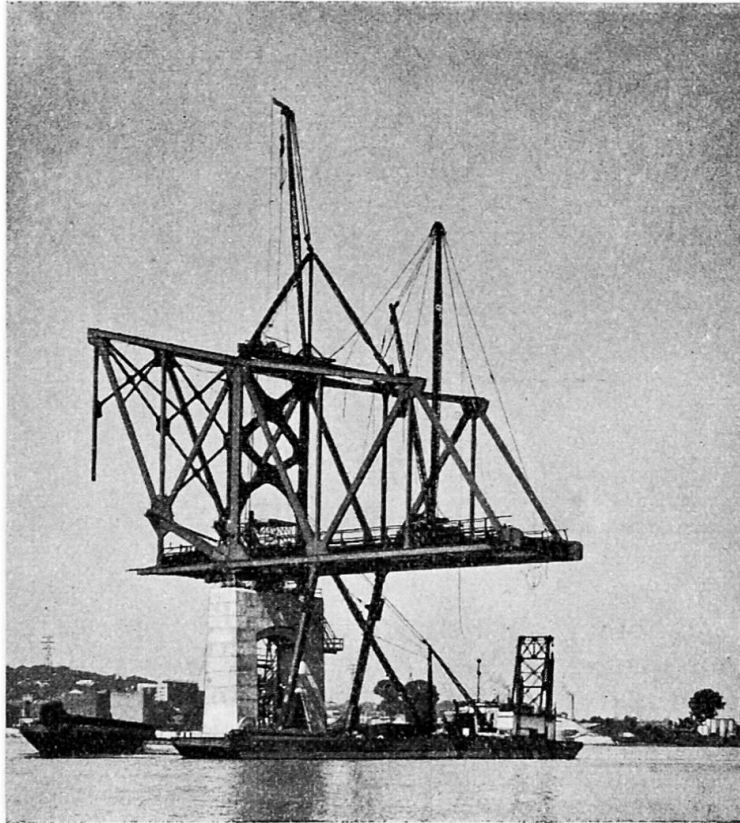


Fig. 3. Fairly advanced state of erection.

Fig. 4. Beginning of the cantilever erection.

of the pier. On this base erection proceeded in both directions from the pier, in suitable order to maintain balanced loads on the pier. This picture was made just before placing the end panel members which landed the span on the east shore pier. The span as shown extends 312 ft from the pier in each direction, making a total length of 624 ft of balanced structure. It may be remarked that this is no time to invite a wind storm.



This view also illustrates the means of steel delivery. As needed the steel members were brought on barges to positions immediately below the erection derricks and so lifted directly from the barges to their places in the structure, for all parts of the structure above water (fig. 4).

Photograph 5 shows a somewhat further advancement of erection. The end panel members are in place and anchored to the east shore pier, terminating some anxiety. The derricks erecting the arch trusses have moved forward, and more panels are added.

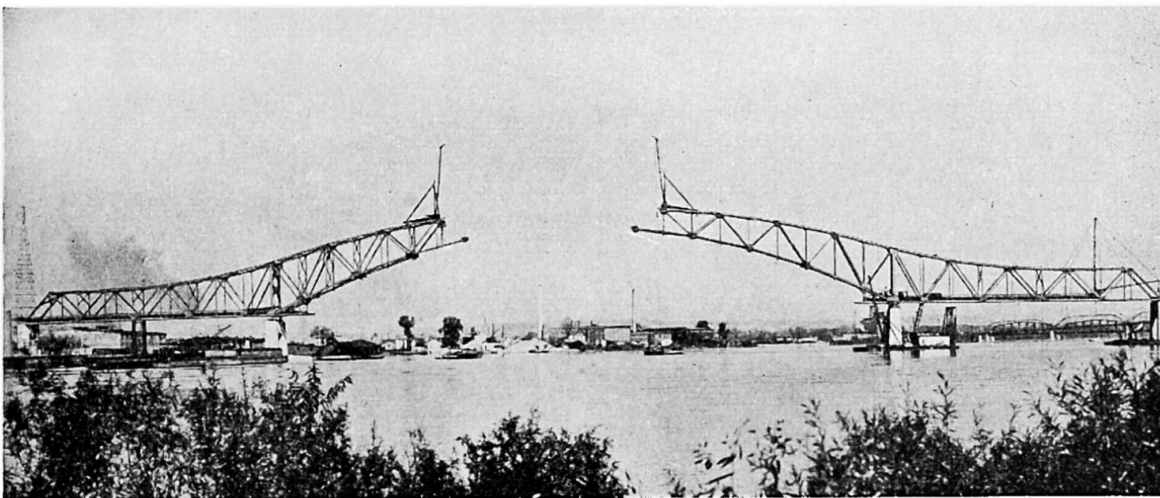


Fig. 5. Further advanced cantilever erection.

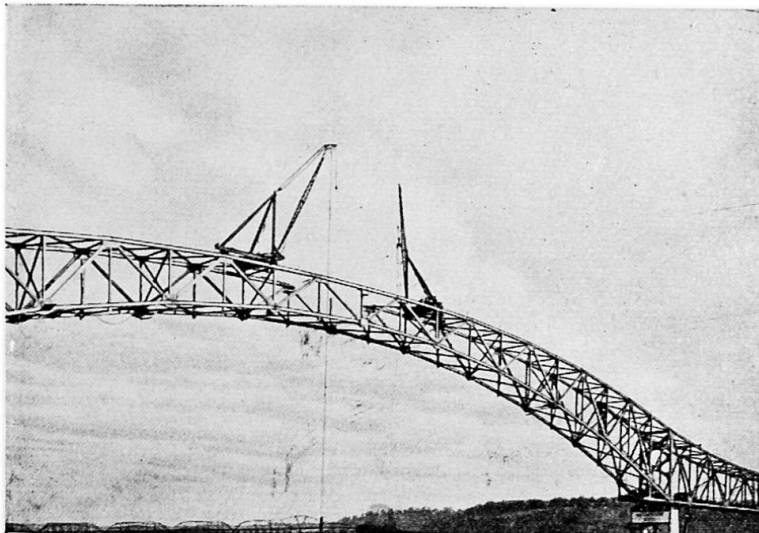


Fig. 6. Connection at the middle of the arch span.

Photograph 6 shows the connection being made at the middle of the arch span. It will be noticed that both bottom chords of the arch trusses are in place. The final portion of top chord of the near truss has been set in place and there remains only to place the final top chord of the far truss. Only minor final vertical and horizontal adjustments of the ends of the span were necessary to bring these parts together to make perfect joinings of the riveted connections, with rivet holes as provided in the fabrication. No reaming of holes or drilling of any special holes was necessary to make these connections.

Photograph 7 shows the structure after the arch trusses had been fully riveted and the span adjusted for erection Stage 2. The two derricks on top of the center span have begun to move back, putting in the hangers as they retreat to the channel piers. The floorbeams between each pair of hangers, and the sections of the bottom chord ties were also placed as the derricks moved back but none of these parts were in place when this picture was made.

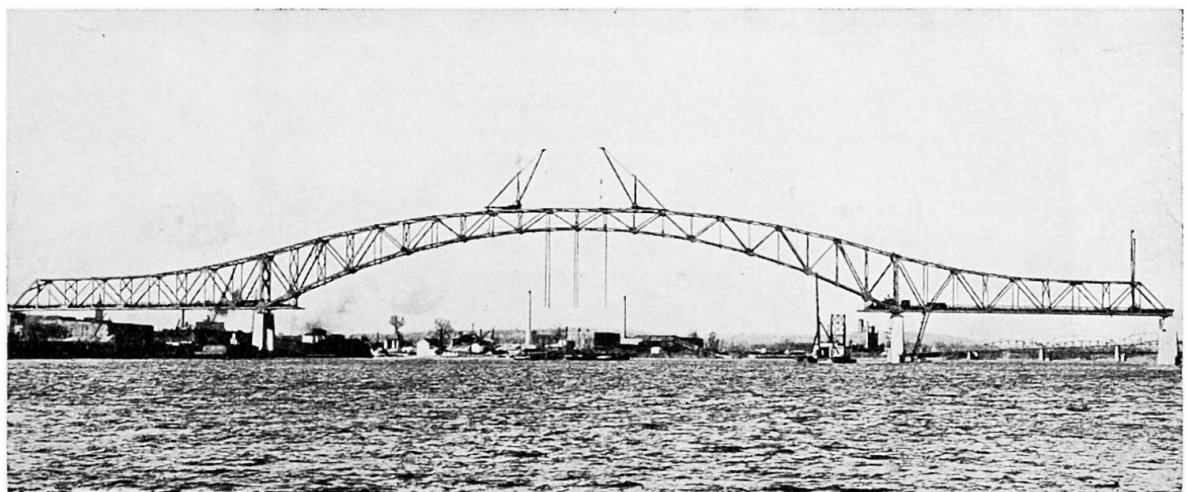


Fig. 7. Arch span fully connected.

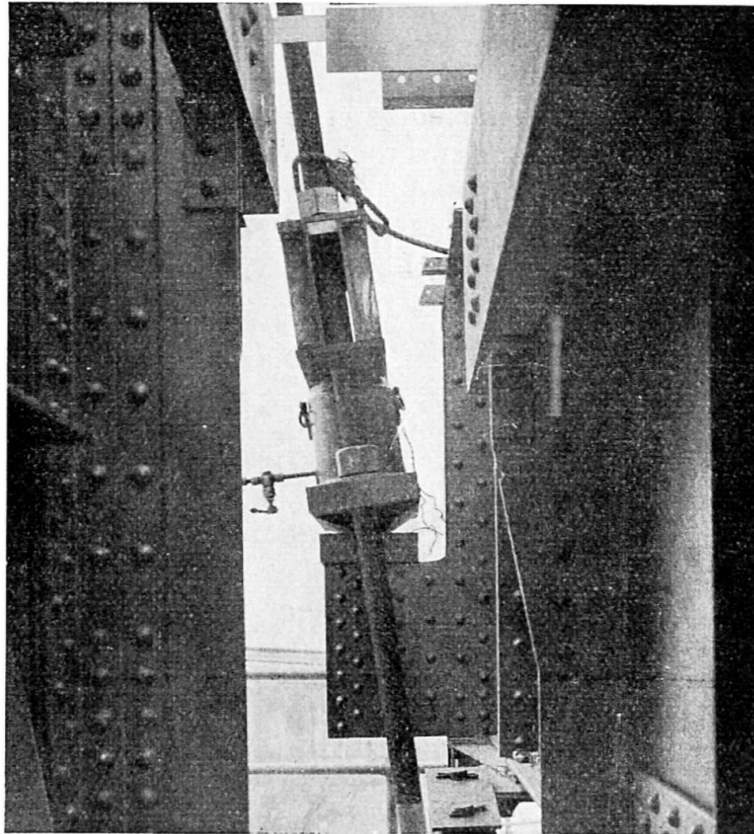


Fig. 8. Details provided for lowering and raising the ends of the spans (jack and tie-down bolts).

Photograph 8 shows the jack, the tie-down bolts and other details provided for lowering and raising the ends of the spans. It may be noted that these details will permit longitudinal shifting if and as necessary.

In conclusion it may be of interest to note that the main shoes are built with "knife edge" rocker supports rather than with usual rocker pins. Also all eight shoes are of roller or rocker types. A vertical pin set in one of the channel pier engages the span and provides longitudinal anchorage. This detail substantially eliminates torque in the piers.

A full description of the bridge including a complete discussion of the methods of design and summaries of design calculations has appeared in Proceedings and will be published in the next volume of Transactions of the American Society of Civil Engineers.

The bridge was planned, designed, and construction supervised by Howard, Needles, Tammen & Bergendoff, Consulting Engineers, the writer's firm. Contractor for Substructure was Robers Construction Co & La Crosse Dredging Corp. : for Superstructure, Bethlehem Steel Company. In September 1948 this bridge was awarded first prize by the American Institute of Steel Construction as the most beautiful of its year in its class of long span structures.

Résumé

La travée centrale du pont de Dubuque sur le Mississippi, le plus grand pont en treillis du monde, a une longueur de 1 539 pieds. Elle se compose d'un arc sous-tendu de 845 pieds et de deux travées d'extrémité de 347 pieds.

C'est une construction entièrement rivée. Le montage le plus économique put être réalisé sans échafaudage en construisant chaque moitié de la travée avec montage en cantilever. Les dispositifs prévus pour la levée et la descente des extrémités extérieures et le ripage latéral furent utilisés pour le raccordement des deux demi-arcs. Les autres éléments métalliques furent assemblés suivant un plan prédéterminé : le pont passa du type à poutres continues sur deux ouvertures à celui de poutres continues sur trois ouvertures, le tirant étant placé en dernier lieu.

Zusammenfassung

Die Mittelöffnung der Dubuquebrücke über den Mississippi, der längsten durchlaufenden Fachwerkbrücke der Welt, ist 1539 Fuss lang. Sie besteht aus einem Bogen mit Zugband von 845 Fuss Länge und zwei Endfeldern von je 347 Fuss Länge. Die ganze Konstruktion ist genietet. Die diesem Bauwerk eigenen Merkmale ergaben, dass die Montage ohne Gerüste wirtschaftlicher und vorteilhafter war. Jede Hälfte des Hauptfeldes wurde zuerst als durchlaufender Zweifeldträger im Freivorbau montiert. Die für das Heben und Senken der landseitigen Enden der Endfelder und für das horizontale Verschieben vorgesehenen Vorrichtungen erwiesen sich als zweckmässige Massnahmen, um den Bogen in seiner Mitte zu verbinden. Die restliche Stahlkonstruktion wurde montiert, wenn sich die Träger in vorausbestimmten, verschiedenen Bauzuständen befanden : indem sie zuerst als dreifeldriges durchlaufendes Fachwerk und später mit dem Mittelfeld als Bogen mit Zugband wirkten.

Summary

The main span of the Dubuque Bridge across the Mississippi River, said to be the longest continuous truss span in the world, is 1 539 ft long with a central tied arch span of 845 ft and two end spans each 347 ft, of all riveted construction. Its inherent characteristics made erection without falsework economical and advantageous. Each one-half of the total span was first erected as a two-span continuous truss by cantilevering methods. Adjustments provided for raising and lowering the shore ends of the end spans and providing longitudinal shifting afforded ready means for joining the arch at its center. The remaining steelwork was erected with the span in pre-determined different positions, functioning as a three-span continuous truss, and later with the central span functioning as a tied arch.