All-welded dragline boom of 150 ft length

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Mât de pelle mécanique entièrement soudé de $45^{m}7$ de portée

(avec remarques concernant la conception des nœuds)

Vollständig geschweisster Ausleger eines Eimerseilbaggers von $45^{m}7$ Länge

(mit einigen grundlegenden Bemerkungen über die Ausbildung der Knotenpunkte)

All-welded dragline boom of 150 ft length

(with some basic remarks about the design of welded nodes)

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While a great number of plate girders for road bridges as well as for railway bridges have been successfully welded during the last two decades, designers are still reluctant to use the same technique for lattice girders when these are subjected to predominantly dynamic loading (stress reversals, impact).

The basic difference between a plate girder and a lattice girder lies in the fact that in the former the vertical shear forces are being changed gradually all along the length of the span into couples of horizontal forces (representing the bending moments), while in a lattice girder this change-over takes place abruptly at discreet points only, i.e. at the nodes : the force in the flange of a plate girder is a continuous function of the distance from the support, the force in the chord members of a lattice girder is constant between the nodes. Consequently, a failure at the nodes of a lattice girder will be inherently more dangerous than one in the welds between web and flange of a plate girder; the former may be immediately fatal, the latter will lead to a redistribution of stresses but will normally allow time for repairs before anything really drastic happens. The engineer, conscious of his responsibility towards the public using the bridge, is naturally and quite rightly reluctant to incur any grave risk, and the farthest he will go, at present, is to weld the individual members of a lattice girder for a bridge while the connections at the nodes are riveted in the traditional manner.

The author does not share the view that no economic advantage is ever likely to result from an all-welded lattice girder bridge. A comparison of welded and riveted nodes only — without reference to the structure

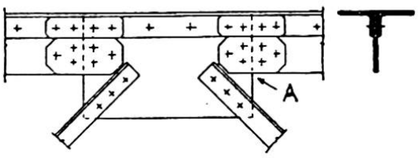


Fig. 1. Riveted design.

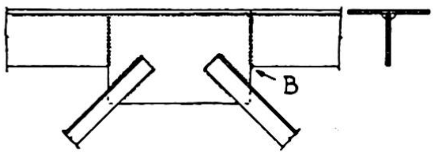


Fig. 2. Welded design.

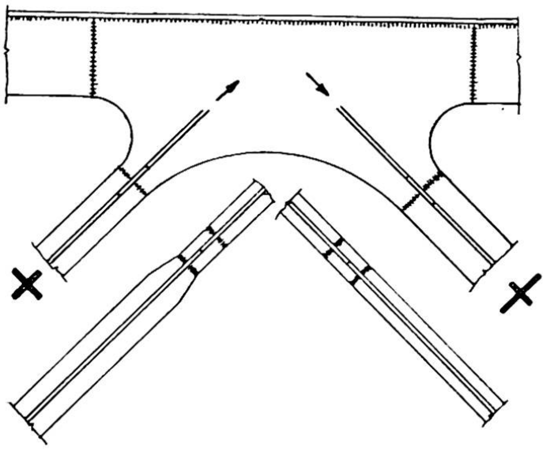
as a whole — is misleading, because the main advantage of an all-welded structure will undoubtedly be found in the fact that welding makes possible the use of more economical sections for the compression members (e. g. tubes), and does away with the reduction in cross-sectional area of tension bars.

The possibility of developing and using wholly welded lattice girders for bridges thus hinges to a great extent on the design and the execution of the connections at the nodes. The author is here concerned solely with design considerations; it is the task of the metallurgist, the electrical engineer, the physicist and the chemist to put the proper tools into the hands of the designer, which will eventually enable him to rely implicitly on the soundness of all welds under all conditions of stress. Even when this has become an undoubted fact the design of the nodes will still require considerable foresight, so as to use the perfect tool in a perfect connection.

A welded connection is distinguished from a riveted one by the simple fact that welds can, by their nature, occur only at the *edges* of a piece of metal (apart from plug welds which, for a variety of reasons, are undesirable), while rivets are more or less evenly spread over the face of a member, and the edges are the only places where they do *not* occur.

An important rule can be derived from this observation : welds should *not* be placed at points where sudden changes of section occur and where from this reason alone stress concentrations are likely to arise at the edges; conversely, where welds *must* be placed at such points, the change of section should be as smooth as possible. A riveted design such as shown in figure 1 is, as experience has shown, perfectly sound, for the simple reason that the sudden change in section is here more apparent than real : there are no appreciable stresses at points A and most certainly no concentrations of stresses. In a similar welded design (fig. 2) the position is totally different; any shrinkage stresses arising from the welding process will be superimposed upon the high stresses that are bound to occur at points B where there is a sharp break in the outline of a now monolithic unit. As the vertical welds in a case such as shown in figure 2 cannot conveniently be placed anywhere else, it becomes imperative to shape the gusset plate itself in accordance with the requirements of a welded design, in other words, the rectangular plate used with rivets should be replaced by the shaped plate shown in figure 3. With modern flame-cutting equipment the cost of cutting such shapes is small, and with a little thought spent on arranging the various shapes to be cut from one sheet, the amount of scrap can be reduced to a very small percentage.

The welds between the vertical flat of the chord member and the gusset plate in figure 3 are butt welds. Butt welds have the advantage over fillet welds that they do not force the stresses to deviate from their straight flow. They are therefore generally more resistant to fatigue stresses and there can be little doubt, on present knowledge, that they will prove the ideal



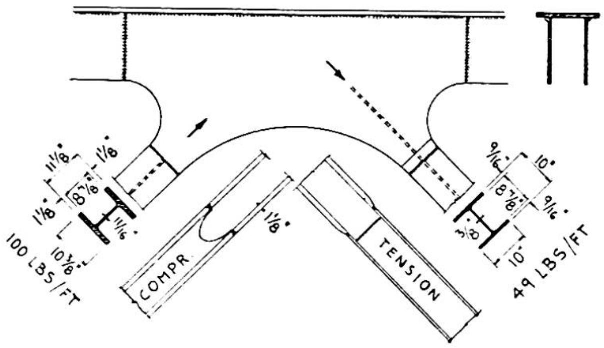


Fig. 3 (left) and **4** (right). Specially shaped gusset plates for welded nodes.

mode of welding for lattice girders subject to dynamic loads. If this view is accepted it applies equally to the *internal* members of a lattice girder and it therefore raises the question of the most suitable shape for these members from a welding point of view. The problem is here more difficult than in the case of the chords, because these internal members end altogether at the nodes, while it will normally be possible to carry at least some part of a chord member through, and splice it, if necessary, some distance away from the node (see horizontal part of T-section in figure 3).

In the case of tension members it would appear that the required result could be attained simply by forming these members from single flats in the plane of the gusset plates. Members with practically no stiffness at all about one of the principal axes are, however, frowned upon in modern bridge design, and a second choice would be a cruciform section, with most of the material in the part butting against the gusset plate. Such sections would also be suitable for compression members, although here the cross-section would have to be more or less symmetrical in order to give the necessary stiffness for both axes. At the ends, the outstanding fins could taper off, so that at the connections again most of the material is in the plane of the gusset plate (fig. 3).

Where the chords have two vertical webs, and where there are, therefore, two gusset plates, parallel-flanged beams would appear to be the best choice for the internal members, as most of their material is concentrated in the flanges, which would butt against the gusset plates. For compression members the flange connection will normally prove sufficient and the webs should be rounded so as to avoid stress concentrations (fig. 4); the webs of tension members could butt against diaphragms between the gusset plates. By making the gusset plates of a suitable thickness it would be possible to connect parallel-flanged beams of different depths to the same node; an example is shown in figure 4, the sizes and dimensions of the joists being standard American rollings.

An opportunity offered itself recently to put at least *some* of these ideas into practice. The structure in question is a boom of uncommonly large size for an excavating machine of the dragline type. From the engineer's point of view this seemed a particularly suitable object for an experimental design, as such machines are certainly subjected to very heavy and partly almost incalculable dynamic stresses — probably much more so than an ordinary bridge which is not called upon to move bodily—

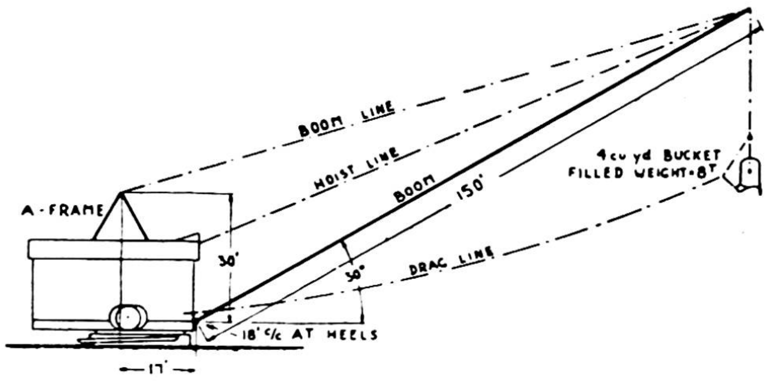


Fig. 5. Diagrammatic sketch of the dragline.

while at the same time any failure was not likely to occasion loss of human life. The *practical* reason for the adoption of an all-welded design was of course the expected saving in weight — an important consideration with these heavy machines where the dead weight is constantly on the move.

The functions of the machine should be clear from the diagrammatic sketch figure 5. It is designed to lift a total weight of 8 tons and to swing it around at an angular velocity of 2 revolutions per minute, which is equivalent to a tangential speed of over 20 miles per hour at the tip of the boom. The sudden lifting of the working load, the angular acceleration at the beginning of each working cycle, and the retardation at its end, impose heavy inertial forces on the structure.

Figure 6 shows the general arrangement of the boom. It is 150 ft long, with a centre portion of 9 ft depth and 12 ft width; at the lower end it widens to 18 ft. In its working position, at about 30 degrees from the horizontal, its tip is suspended from the body of the machine, but

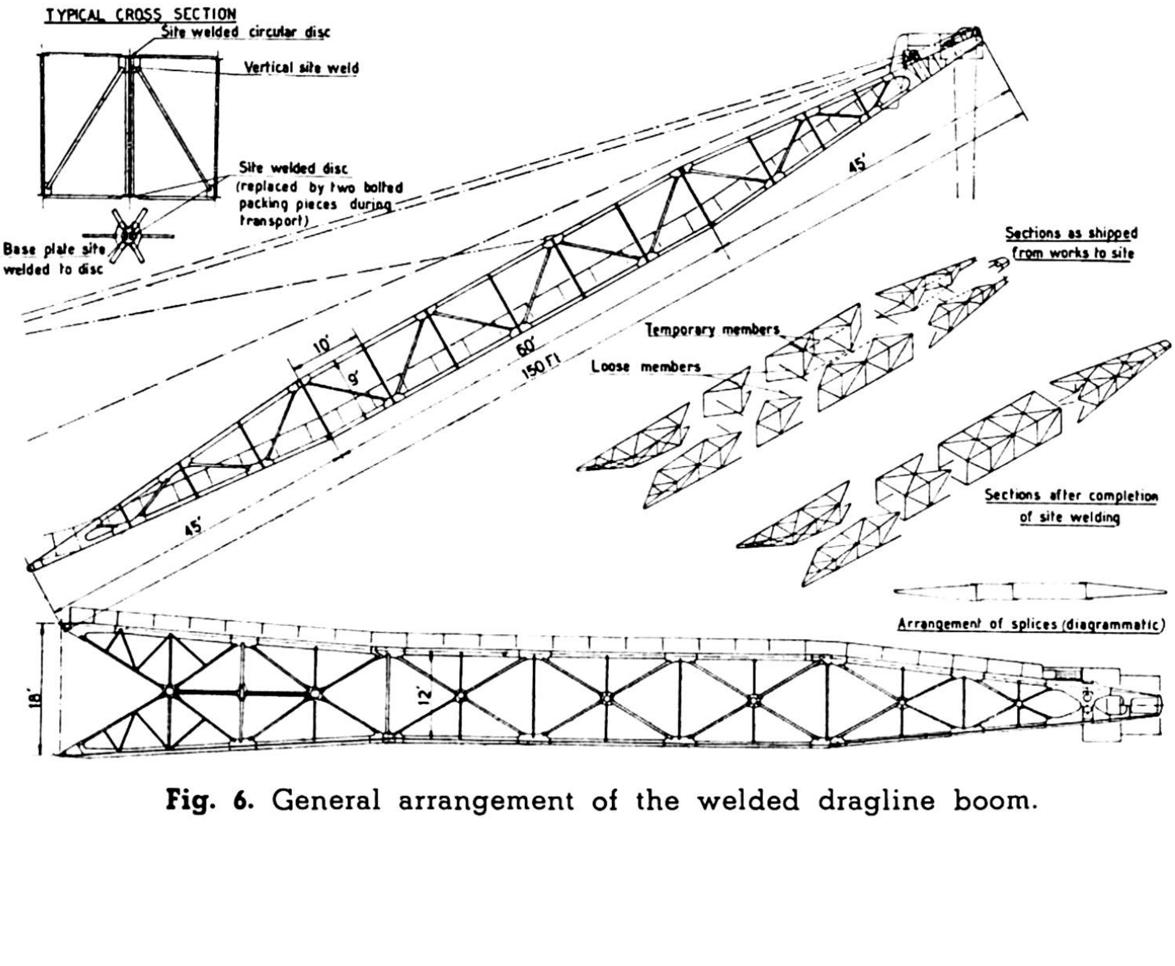


Fig. 6. General arrangement of the welded dragline boom.

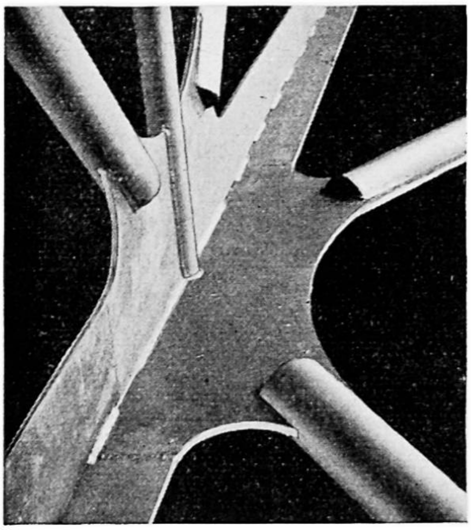


Photo **Alfa.**

Fig. 7. Typical node.

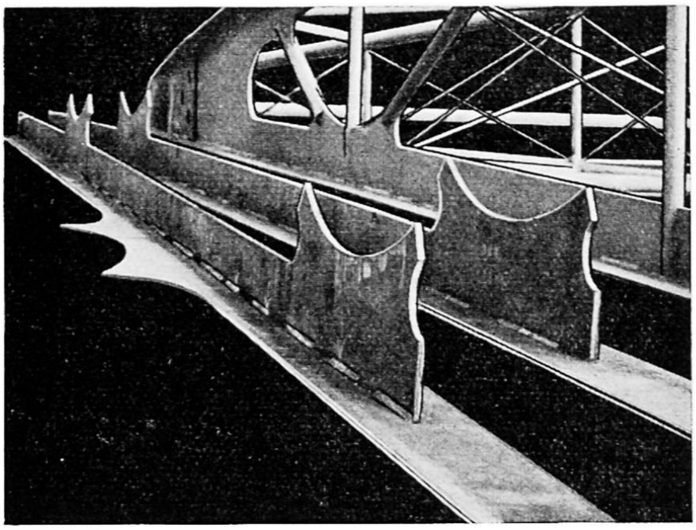


Fig. 8. Chord member. In the background the completed lower portion of the boom.

in order to reduce the influence of the selfweight of the boom, a further subsidiary suspension has been arranged somewhere near the middle of its length.

The main nodes are at about 20 ft centres, and their design is basically as shown in figure 3, with T-sections built up from two flats as chords. Shaped gusset plates have been inserted into the planes of *both* flats of the T-section, but at every node the two gusset plates, one horizontal the other one vertical, are of different lengths so that the butt welds in the two flats of the T-chord do not coincide. Figure 7 is a photograph of a typical node, figure 8 shows some chord members, with the completed lower portion of the boom in the background.

The internal members are not, as suggested above, of cruciform section — such shapes not being rolled at present — but were made of tubes. In a structure of this type practically all forces are reversible so that all diagonals have to be calculated as compression members. The tube is the ideal cross-section in such cases, although the welded connections do not quite conform to the principles laid down above. The connections are made by slotting the tubes and sliding them over the gusset plates, a construction that necessitates the use of side fillet welds instead of butt welds. It should be pointed out here that the use of tubes, with their inherent lightness, would be hardly feasible in a riveted construction.

The principles that governed the design of the gusset plates were also observed at the ends of the boom where the chords draw close to each other. Solid web portions were inserted here, and the transition from the solid to the latticed parts was again effected by well rounded ends to the solid webs (fig. 8 and 9). Especially at the tip these solid parts serve a multiplicity of functions, for instance in connection with the various wheels here required, but all design difficulties were easily and effectively overcome by the combined use of flame cutting and welding, with the result that the structure would not only appear to be structurally sound, but is also pleasing to the eye — a consideration that is bound to carry much weight in the design of actual bridges.

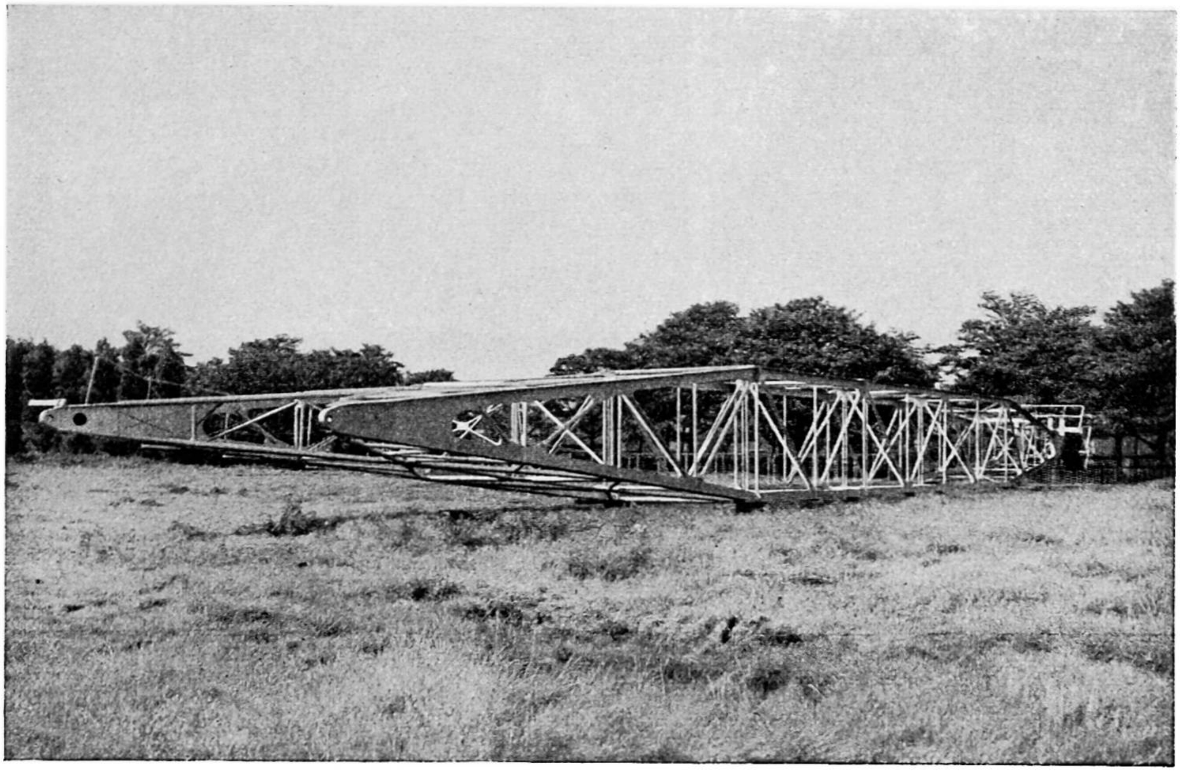


Photo **Turners Ltd.**

Fig. 9. Completed boom prior to its attachment to the machine.

Figure 9 and 10 show the completed boom, prior to its attachment to the machine (1).

Résumé

La réalisation des ponts en treillis entièrement soudés constitue encore un des problèmes à résoudre. L'auteur indique les différences fondamentales entre poutres à âme pleine et celles en treillis, ainsi que celles entre les nœuds rivés et soudés des poutres en treillis. L'auteur donne également quelques suggestions pour un développement des nœuds soudés pour les ouvrages soumis à sollicitations dynamiques. Quelques-unes de ces suggestions ont trouvé une application pratique lors de la construction d'un mât de pelle mécanique dont ce mémoire donne une courte description.

Zusammenfassung

Vollständig geschweisste Fachwerkbrücken gehören noch der Zukunft an. Die grundlegenden Unterschiede zwischen Blechträgern und Fachwerk-

(1) A detailed description of this structure, and an account of the design considerations and of the calculations, has been published in the *Transactions of the Institute of Welding*, December 1946. The paper was awarded the Sir William J. Larke Medal of the Institute for 1946, and the author is indebted to the Institute for permission to use some of this material for the present, more general, paper.

trägern, und zwischen geschweissten und genieteten Knotenpunkten von Fachwerkträgern, werden aufgezeigt, und Vorschläge für die weitere Entwickelung der geschweissten Knotenpunkte dynamisch belasteter Fachwerkträger zur Diskussion gestellt. Einige dieser Vorschläge haben kürzlich bei dem Entwurf des Auslegers eines Baggers Anwendung gefunden, der kurz beschrieben wird.

Summary

Wholly welded lattice girder bridges are still largely a matter of the future. The basic differences between plate girders and lattice girders, as also between riveted and welded nodes of lattice girders, are discussed, and some suggestions put forward for the possible future development of dynamically loaded lattice girders. Some of these suggestions have recently been used in the design of a dragline boom, of which a brief description is given.

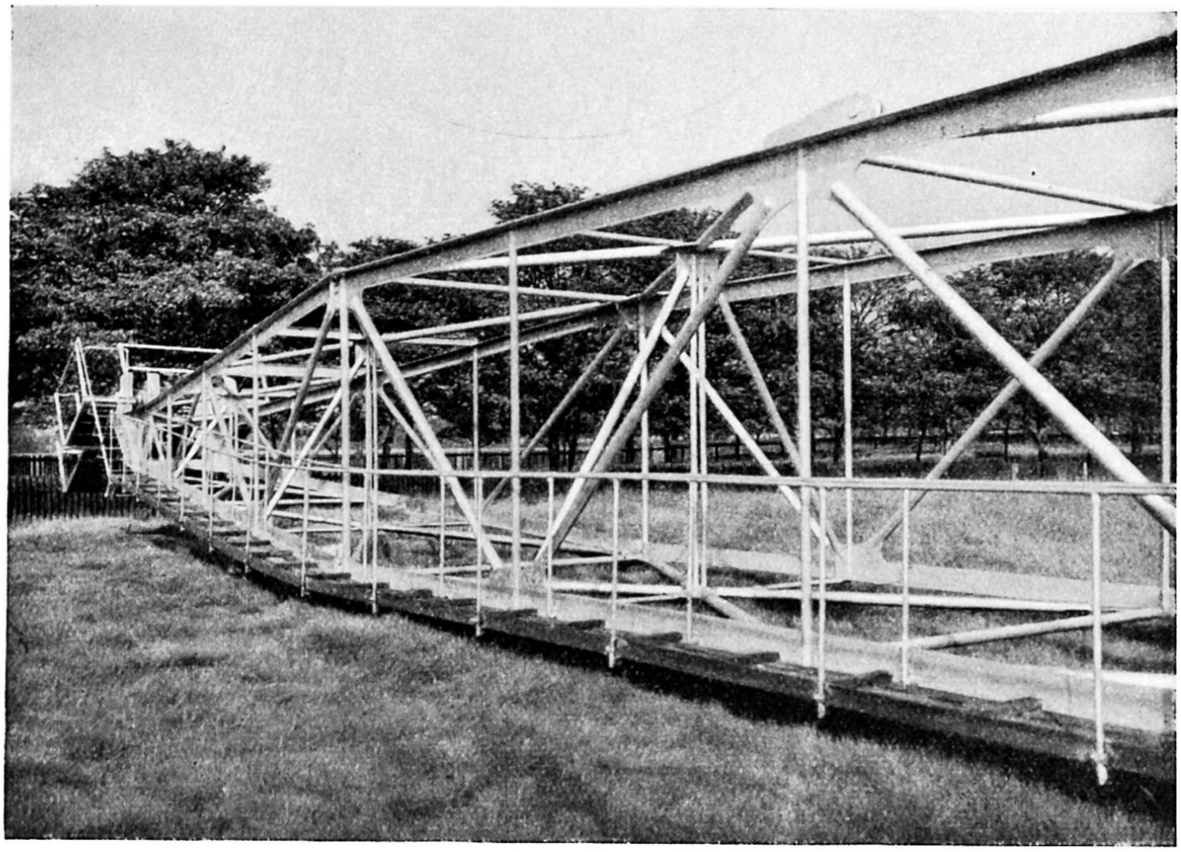


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Fig. 10. Other view of the completed boom.

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