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The fabrication and erection of large welded girders

Construction et montage des grandes poutres soudées pour appareils de levage et de manutention

Die Herstellung und Aufstellung grosser geschweisster Kran-Träger

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INTRODUCTION

The building of new steel plants in Great Britain has given structural engineers an excellent opportunity of applying modern theories of design and modern forms of construction to buildings of exceptional magnitude.

It was inevitable that welding should be used extensively in these modern structures. Such vast projects fully justified the preparation of jigs and manipulators on a scale that could not be contemplated on normal constructional projects.

The crane girders provided unusual problems of manufacture, transport and erection and form an interesting subject of welded construction.

INFLUENCE OF PLATE MILL CAPACITIES ON THE DESIGN

The maximum size, thickness and area of plates that can be produced by the plate mills should be carefully considered before the design of any large girder is attempted. Full information should also be obtained with regard to the extra charges that may be claimed by the mills for producing plates of abnormal width, thickness or area. It should be borne in mind that extra transport charges from the mills to the fabrication shop may also be involved.

This information will influence the position of the joints and is extremely important if a design economical in material costs and welding is to be produced.

COLD STRAIGHTENING OF MATERIAL

All material produced by the rolling mills requires straightening and levelling after having been allowed to cool. The cold straightening of sectional material is invariably carried out at the rolling mills, but the cold levelling of plates and flats can be carried out either at the rolling mills or in the fabrication shops according to individual requirements. Most fabrication shops are equipped with roller levelling machines for cold levelling flats and plates. Unfortunately these machines were with few exceptions installed to deal with riveted construction, where girder flanges of large thickness can be built up from a series of comparatively thin plates; hence the capacities of the machines are limited and only in exceptional cases can plates over 1½ in. thick be levelled.

The roller levelling machines in use in the plate mills and fabricating shops are usually of the seven roller type with the rolls arranged as shown in fig. 1. It will be noted that the two front rolls are located in the same vertical plane and are capable of exerting a considerable squeezing pressure. By means of the front rolls, plates and flats which have a bend in the direction of their widths can be straightened. This operation is performed by inserting small pieces of thin steel-sheet (known as shims) between the roller and the material, causing an additional local pressure which elongates the edge of the plate where the added pressure is applied. The position in which the shims are placed calls for experience and skill on the part of the operator.

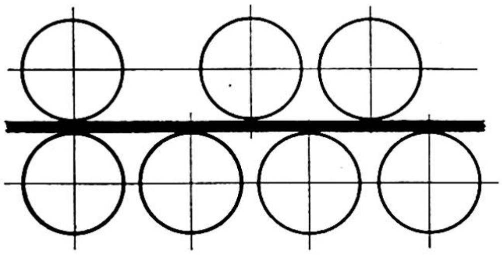

Fig. 1. Arrangement of rolls. Roller levelling machine

It will be appreciated that this process requires considerable pressure, and whilst a given machine is capable of levelling the surfaces of plates say 1½ in. thick, only plates considerably thinner can be side straightened. Plates for large welded girders usually exceed the limits of the capacities of the roller levelling machines in use in the constructional shops, in which case these processes can, within limits, be carried out by the rolling mills. As an example, one rolling mill in this country can surface level plates by the roller process up to 3 in. thick.

For large welded girders it is preferable to order the plates sufficiently wide so that the correct width and straightness can be obtained by planing.

The degree of surface level is very important for welded crane girders and particular care must be taken with the flange plates, which have to transmit heavy wheel loads to the web plate, and form a level seating for the crane rails. It is recommended that the degree of level for the flange plates of heavy girders should not exceed $\frac{1}{32}$ in. in a 3 ft. 0 in. length. The level of web plates and similar plates, not directly load bearing, can be increased to $\frac{1}{16}$ in. in a 3 ft. 0 in. length.

Handling of finished material

After the material has been cold levelled, the greatest care must be exercised in lifting, loading into wagons and the subsequent unloading, otherwise the level of the plate can be completely ruined. The use of a stiff lifting-beam with a number of hooks for gripping the material is recommended for loading the material and transporting by the mill or fabrication-shop cranes. It is also important that the wagons or the vehicles used for transporting the material are provided with a generous number of level supports.

Fig. 2 shows a form of lifting beam in common use.

Preparation of material

When the material has been levelled, the plates forming the various parts of the girder are placed on the marking benches, and carefully marked out to the required sizes before being passed to the edge planing machines. Before the marking out of

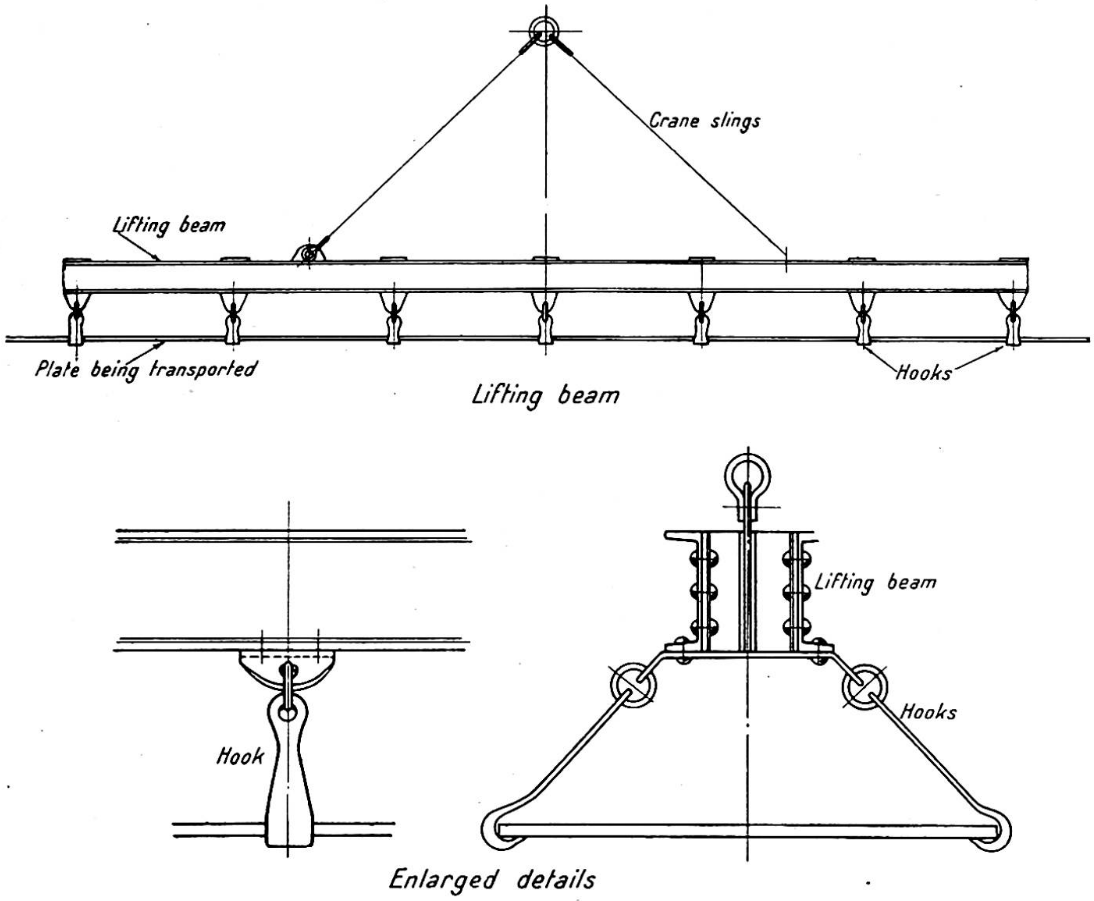

Fig. 2. Typical plate lifting beam

the material is commenced it is necessary to assess the amount of shrinkage that is expected to take place during the welding process. The amount that a girder will shrink in length and depth is influenced by the number of butt joints in the web and flanges, the number of web stiffeners and the amount of welding, but by experience it is possible to assess the shrinkage with a fair degree of accuracy. If a number of girders are to be made, measurements can be taken of the first girder manufactured and the subsequent material adjusted accordingly. The amount of expected shrinkage must be added to the finished sizes of the plates during the marking-out process.

Testing specimen joints

When the design of a large girder has been completed, and the form of welded joints, the types of electrodes to be used and the welding procedure decided upon, full-scale physical tests of the important joints can be carried out at a moderate expense. The test specimens should be prepared in the fabrication shop, under the normal working conditions, to reproduce as closely as possible the conditions of the production welding. The specimen should be planed to a given width, and the section through the weld polished, etched and sulphur printed. This information, together with the data of the type of electrodes used, welding procedure and the results of the destruction tests, should be recorded for future reference. After the tests have been completed, it is occasionally found that a small amendment to the bevel of a preparation or a throat thickness will give increased results, which justifies the decision to carry out the destruction tests.

For a very large welded project it may be considered advisable to prepare a scale-model girder, which can be loaded in a testing machine in a manner comparable to the loading of the girder. Fig. 3 shows a model girder, prepared to represent crane girders of 110 ft. 0 in. span, 12 ft. 5 in. deep and weighing 90 tons. The flanges of the

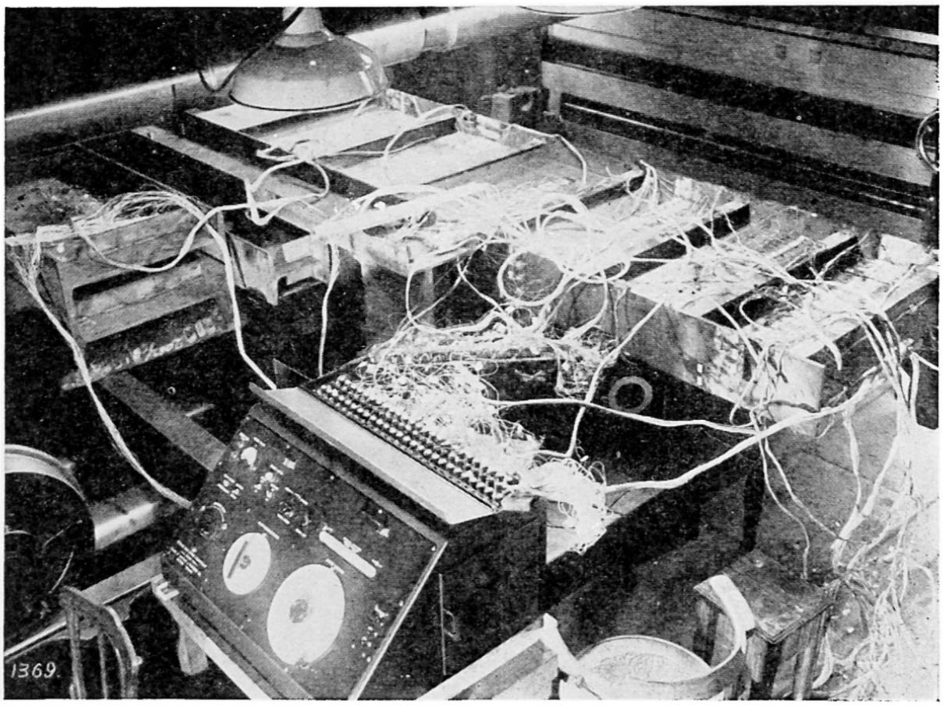

Fig. 3. Testing of scale model girder. Load applied horizontally

girders were 36 in. wide and $2\frac{1}{2}$ in. thick and it was important to determine the distribution of flange stress, and if possible the intensity of stress at the junction of the flange plate to the web plate. The opportunity was taken to obtain information with regard to web stresses and the stresses in the stiffeners. The results were recorded by the electrical strain-gauge method and the equipment used for the experiment can be seen in fig. 3. Fig. 4 shows a typical data-sheet tabulating the results.

Quality of material

All material used for the girders described below was manufactured in accordance with British Standard No. 15. This steel has an ultimate tensile strength of 28 to 33 tons/in^2 with a yield point of 16 tons/in^2.

Examples of welded crane girders

Fig. 5 shows details of a welded crane girder, one of a number fabricated for the melting-shop building of a steel plant. These girders were 110 ft. 0 in. long, 12 ft. 5 in. deep over the flanges and each weighed approximately 90 tons. The flanges were 36 in. wide and $2\frac{1}{2}$ in. thick, the web plate 106 in. wide and 1 in. thick, the flitch plates 19 in. deep and $2\frac{1}{2}$ in. thick.

The maximum width of plates that can be produced by the rolling mill from which the material was obtained is 108 in. and the maximum thickness of material that could be cold-roller-levelled was 3 in. These limits determined the depth of web plate and 106 in. was within the maximum width after allowing the necessary margin for edge planing.

It was decided, in view of the accuracy of level required, to keep the thickness of the flange plates well within the levelling limit of 3 in.; and to achieve this without using an excessively wide flange plate, whilst providing the amount of inertia required, it was decided to use thick plates between the web plate and the flange plate. These

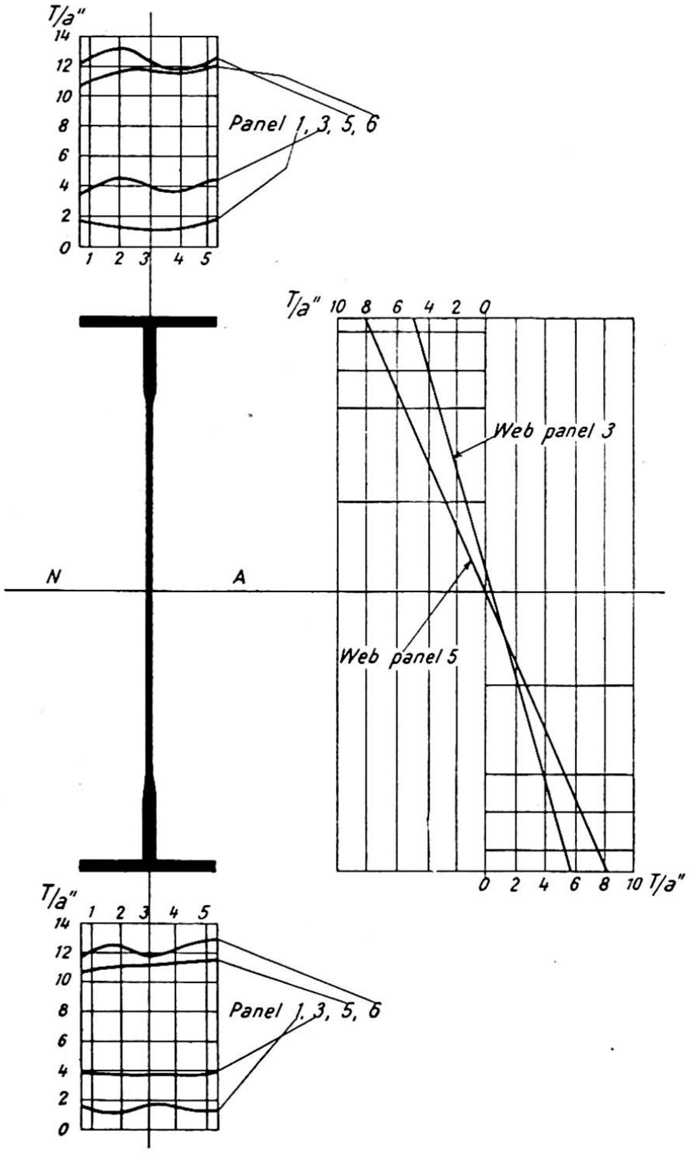

Fig 4. Tests on model girder bending stresses in flanges and web load 75 tons
Note: For T/a'' read tons/in.²

plates are referred to as flitch plates and are analogous to flitch plates often used between the flange angles and web plates of riveted girders when it is necessary to increase the moment of inertia of the girder without using an excessively thick flange plate.

It will be noted that the flange plates were reduced in thickness at the points of reduced bending moments, the reduction being made on the inside of the flanges, to maintain a level top flange under the crane rail and, as will be seen later, to facilitate the removal of the girder from the manipulator. To ensure flange straightness the flange plates were ordered from the mills 37 in. wide and planed to 36 in. wide. The flitch plates were planed to width and reduced from $2\frac{1}{2}$ in. to 1 in. thick, with a 1 in 5

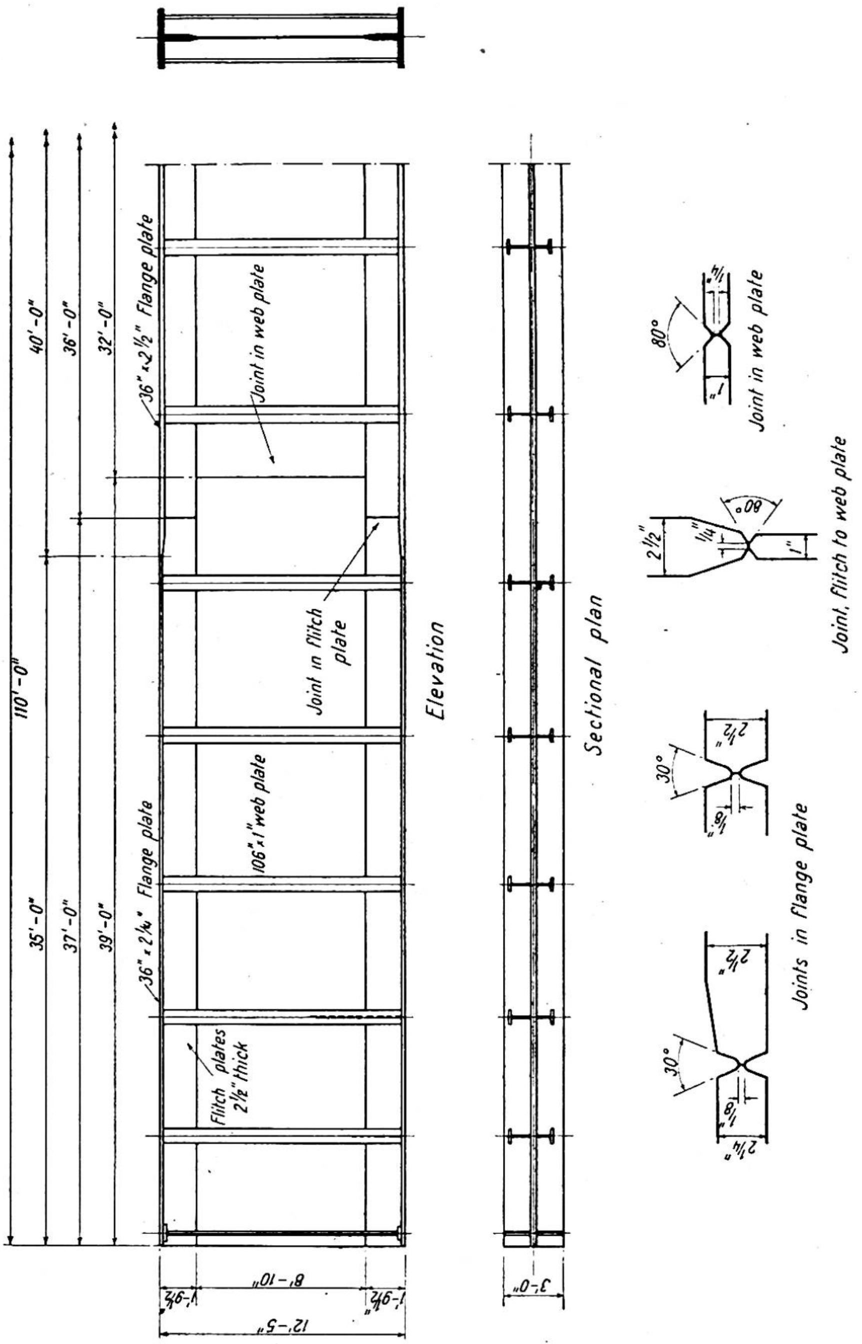

Fig. 5. Welded crane girder 110 ft. 0 in. span. Approximate weight 90 tons

bevel for butting to the 1 in. thick web plate. The web plates were edge planed to size and bevelled for welding.

It will be noted that the butts in the flange and flitch plates were arranged with double Ų preparation with butting root faces $\frac{1}{8}$ in. wide. As will be seen later, this preparation was for vertical welding. The butts in the web plate and the web plate to the flitch plate had double V preparations with root faces $\frac{1}{4}$ in. wide arranged for down-hand welding. All joints had tight butting surfaces, no gaps being allowed for welding. The practice of providing gaps was considered unnecessary, as this leads to considerable difficulties with jigging, adds to the shrinkage and increases the possibility of distortion.

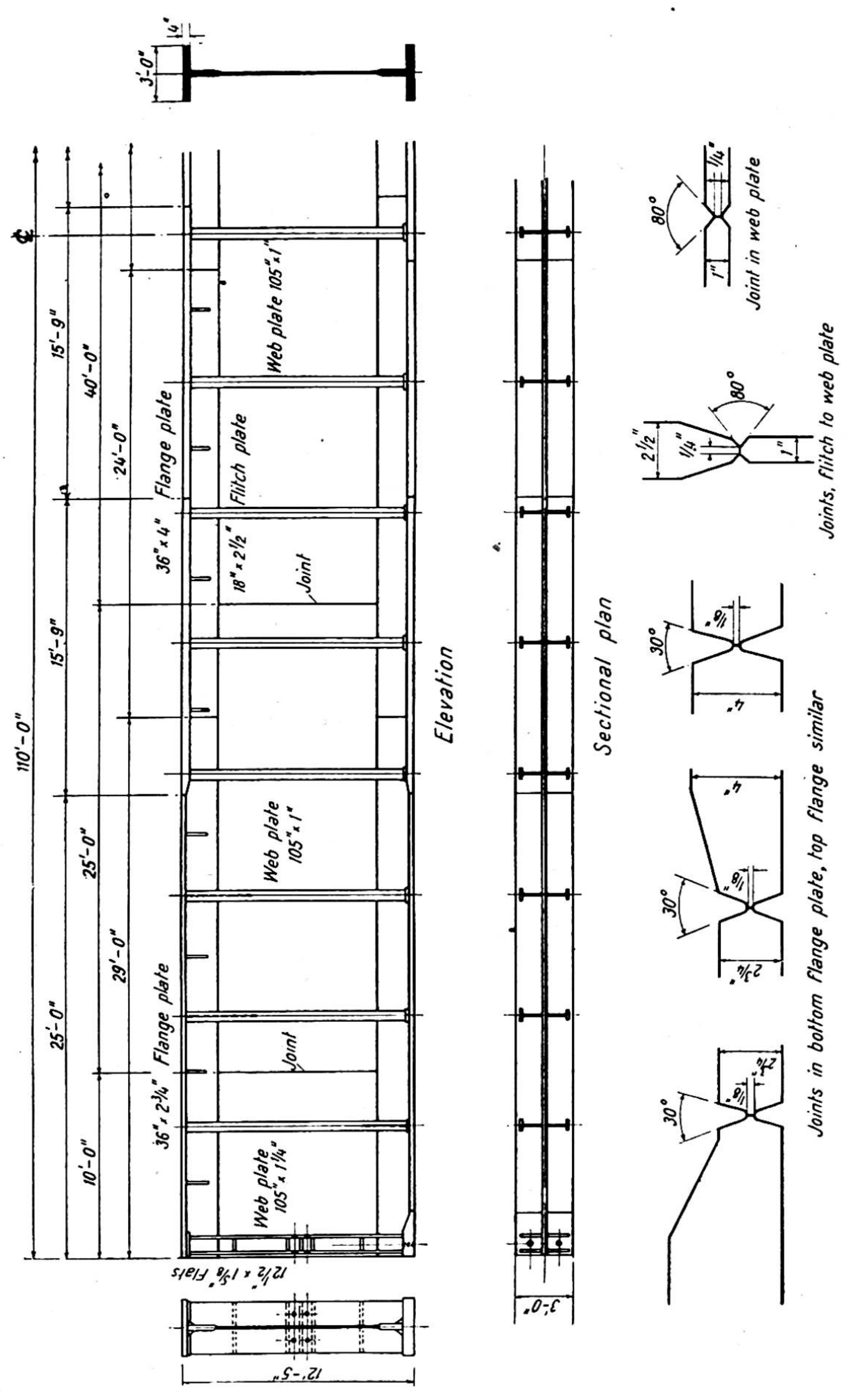

Fig. 6. Welded crane girder 110 ft. 0 in. span. Approximate weight 100 tons

Fig. 6 shows a further girder, one of several constructed for another steel plant building. These girders are 110 ft. 0 in. long, 12 ft. 5 in. deep over flange plates, and each weighs approximately 100 tons. It was impossible with these girders to keep the thickness of the flanges within the 3 in. cold levelling limit, and flanges 36 in. wide and 4 in. thick were used. These plates were ordered from the rolling mills 4½ in. thick and were surface planed to 4 in. thick, in order to provide the level surfaces required.

Welding details

The welding preparation for the girders is given in figs. 5 and 6. The butts in the flange plates and flitch plates were welded vertically, two welders working simultaneously, one on either side of the plate. This method minimises angular distortion of the plates, lessens the possibilities of weld cracking and avoids the necessity of turning the work over during welding. No. 8 gauge electrodes were used for the first run, and the weld was completed by subsequent runs of No. 6 gauge electrodes.

For the butts in the web plates and the butt of the web plate to flitch plate $\frac{1}{4}$ in. diameter deep-penetrating electrodes were used for the first run, followed by a further run of No. 4 gauge normal-penetrating electrodes. For the $\frac{5}{8}$ in. fillet welds, attaching the flitch plates to the flange plates, one run of No. 4 gauge electrode was used, followed by one run using a $\frac{3}{8}$ in. diameter electrode. Deep-penetrating electrodes were not used for any down-hand fillet welds. The stiffeners were welded to the web plates, with continuous fillet welds, carried out in a horizontal-vertical position.

Welding procedure

It cannot be too strongly stressed that the sequence in which the various welding operations are carried out is of the utmost importance. If the welding sequence is carefully considered most of the difficulties of weld cracking and distortion can be avoided. The object is to allow the material to shrink freely and not to restrain shrinkage by welding in an ill-considered manner.

The sequence adopted for welding the girders previously described was as follows:

(1) The butts in the flange plates welded.
(2) The butts in the web plates welded.
(3) The butts in the flitch plates welded.
(4) The stiffeners welded to the webs.
(5) The web welded to the flitch plates.
(6) The flitch plates welded to the flanges.
(7) The feet of the stiffeners welded to the flanges and flitch plates.

The operations 1, 2 and 3, allow the material to shrink freely in its length before being restrained by any longitudinal welding. The welding of the stiffeners in operation 4 causes a further shrinkage in a longitudinal direction. It is not until this shrinkage has taken place that the longitudinal welds in operations 5 and 6 can be carried out.

Design of manipulators

When fabricating girders of normal size, it is common practice to assemble the prepared material in jigs, tack weld all parts in place, remove from the jigs and place in a manipulator for final welding. The manipulators are so designed that the work can be rotated and placed in a position to ensure the most efficient and rapid welding. With exceptionally heavy girders this practice cannot be adopted and the manipulators must be designed so that the individual parts forming the girder can be put in place by the fabricating-shop cranes and clamped in position for welding.

Fig. 7 shows a diagrammatic cross-section through the manipulator, which consists essentially of four welded rings 18 ft. 0 in. outside diameter, connected together by a triangulated system of plate girders. The girders resist the torsion during the turning operations and carry the loads from the screws clamping the parts in place, in addition to the imposed dead loads.

The manipulator was mounted on plain rollers, four driving and four idle, and a series of horizontal rollers guide the rings during rotation. Experience has shown that flanged rollers are a source of trouble and add considerably to the power required for rotating. The manipulator was rotated by a 45 h.p. motor, geared to a turning rate of one revolution in 4 minutes. To eliminate unequal torsion in the driving shafts,

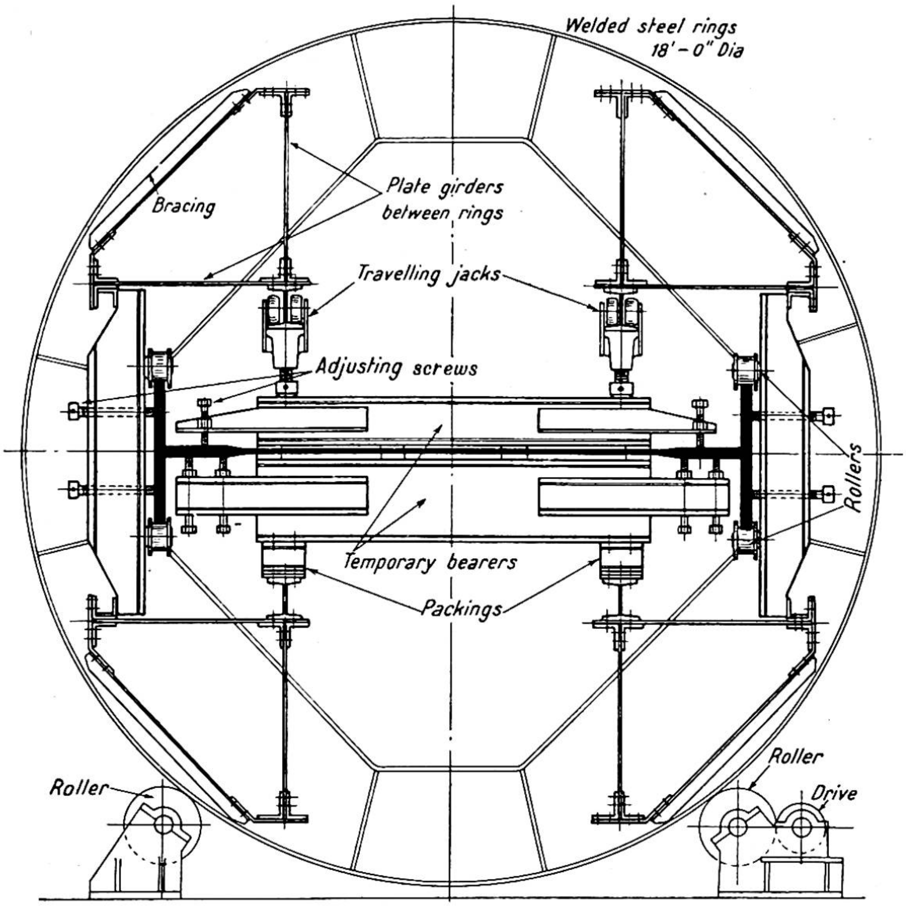

Fig. 7. Cross section through manipulator

with a consequent time lag in the driving rollers, a system of articulation was used. A series of girders span the manipulator and form a level bed on which the web plates and flitch plates are laid and adjusted. The manipulator was so designed that ample working space and accessibility was provided for the assemblers and welders.

Jigging and manipulation

The jigging operation adopted for the girders was as follows. The manipulator is rotated until the bearers for the web plates are in a horizontal position. The bearers are carefully levelled and adjusted by means of screws and packings. The web plates are then fed into the manipulator by means of the overhead shop-crane. The flange plates are fed into the receiving end of the manipulator and are carried and guided by the rollers shown in fig. 7. At this stage the flange plates are close-butted, clamped in position, and welded vertically by welders operating from either side of the butt simultaneously. The upper surfaces of the butts in the web plates can also be welded at this stage. The flitch plates are placed in the manipulator on top of the web plates and skidded into position. The web plate and flitch plates are set in position and adjusted by means of screws attached to the bearers. The flange plates can be lifted or lowered by means of opposing jack screws.

When these operations have been completed, specially prepared beams are placed on top of the web in a position immediately over the cross bearers; these are firmly clamped by means of the travelling jack screws. The web stiffeners which have been prefabricated and machined to the exact length are placed in position, adjusted and clamped down by the remainder of the travelling jacks, two jacks being used for each stiffener.

At this stage of the jigging operation, all parts are securely clamped and the manipulator is rotated through 180°. The underside of the girder is now uppermost and the remainder of the stiffeners are fitted and clamped as before. After clamping the girder is checked for size, alignment, freedom from twist, etc., and an examination made to ensure that no gaps occur between the butting surfaces.

Welding

Following the sequence already stated, the butts in the web plates are welded first, the flange plates having been welded immediately after they were adjusted in the manipulator. Two welders are employed on each butt in the web plates, both commencing at the centre of the web and working outwards to the flanges in opposite directions. The manipulator is rotated and the butts are completed on the reverse side of the web. The butts in the flitch plates are welded with the girder in a vertical position, both sides of the butt being welded simultaneously.

The stiffeners are welded to the web plate with the girder in a horizontal position, two welders being employed on each stiffener, commencing at the centre of the girder and working outwards. The welding of the longitudinal butt between the web plates and the flitch plates is carried out with the girder in a horizontal position. Two welders are employed, each working outwards from the centre of the butt length, using a $\frac{1}{4}$ in. diameter deep-penetrating electrode, followed as quickly as space will allow by two further welders to complete the joint with an additional run of No. 4 gauge normal-penetrating electrodes. After completing one-third of the length of the joint in the centre of the girder, the manipulator is reversed and a similar amount of welding completed on the reverse side. The outer thirds of the joints are welded in a similar manner.

The $\frac{5}{8}$ in. fillet weld between the flange plate and flitch plate is welded with the girder inclined at an angle of 45°.

Removing girder from the manipulator

For removing the finished girder from the manipulator, a number of rollers were designed which can be attached to the manipulator. When a girder is completed, the manipulator is rotated until the bottom flange is uppermost with the girder in a vertical position. The roller gear, which in this position can be handled by the overhead shop-crane, is bolted to the manipulator with the rollers in close contact with the flange of the girder. After the rollers have been secured, the manipulator is rotated until the top flange is uppermost; this rotation brings the roller gear to the shop-floor level. Packings are inserted to bed the rollers firmly on concrete foundations provided in the shop floor.

At this stage all clamping screws securing the girder are loosened and the full weight of the girder rests on the roller gear. It will be noted that the rollers used for inserting the flange plates into the manipulator now operate as guides for the removal of the girders. The girders are drawn out of the manipulator by winches.

Fig. 8 shows this operation being carried out.

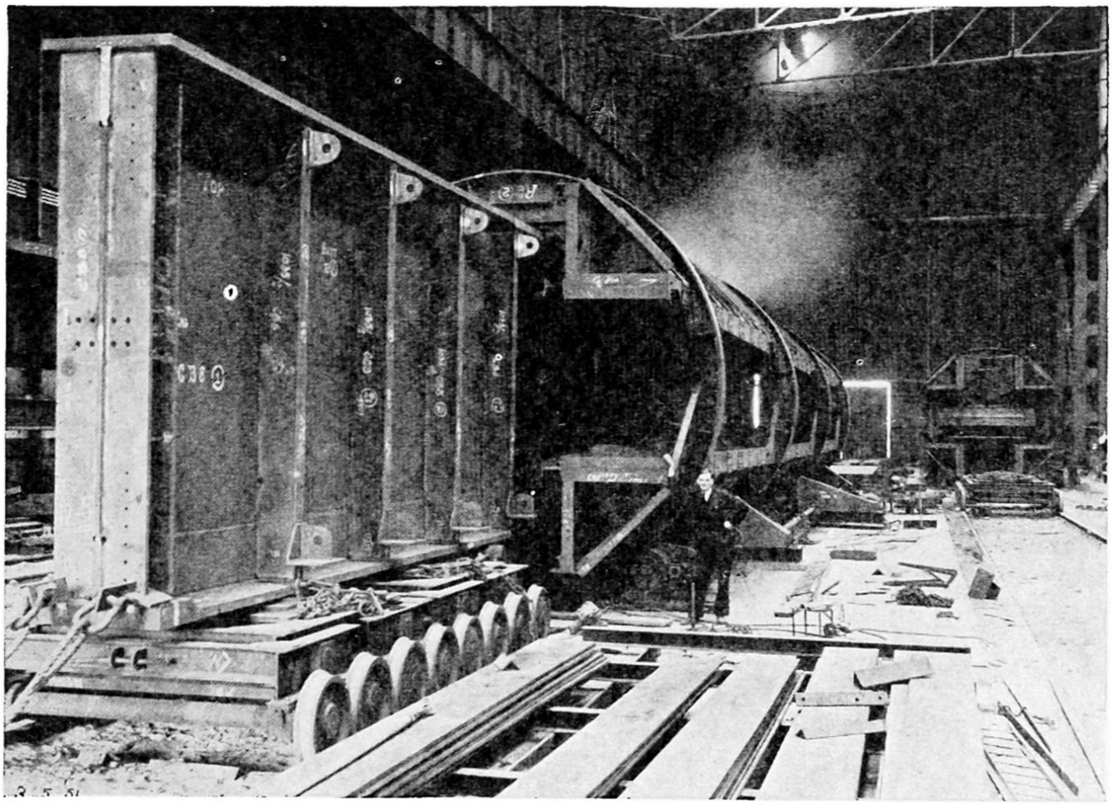

Fig. 8. Welded girder leaving manipulator. Second manipulator in the background

TRANSPORT TO SITE

Girders of the size and weight described cannot be transported by rail or road, and it is essential that the assembly and welding is carried out close to the site of erection.

On large projects it is usually possible to convert a convenient ancillary building of the plant into a temporary fabricating shop, in which the manipulators can be installed. The material can be fully prepared and transported to the site by normal means. Special tracks can be laid from the temporary fabricating-shop to the site of erection capable of carrying the weight of a completed girder and of such a width as to provide ample stability to the bogies used. It will be appreciated that if the girders are transported vertically, bogies on a 4 ft. $8\frac{1}{2}$ in. track will not provide sufficient stability.

ERECTION OF GIRDERS

Erection of any unit is considerably simplified if the point of lift is applied at the centre of gravity of the unit. This enables the unit to be guided into position with a minimum of effort on the part of the fixers and a minimum amount of skill on the part of the crane driver. Cranes capable of lifting 100 tons are not often available, and to fabricate a crane for one specific contract is rarely an economical proposition.

The crane shown in fig. 9, usually known as a Goliath crane, is probably the most efficient type of crane for erecting buildings requiring exceptionally heavy lifts. The crane can be arranged to span the building and if the cross bridge and the vertical legs are of unit construction the Goliath crane can be adapted for use with buildings of various heights and spans. This type of crane has the advantage that the legs are clear of foundations and flues within the building, and that it is stable without the use of kentledge or guys.

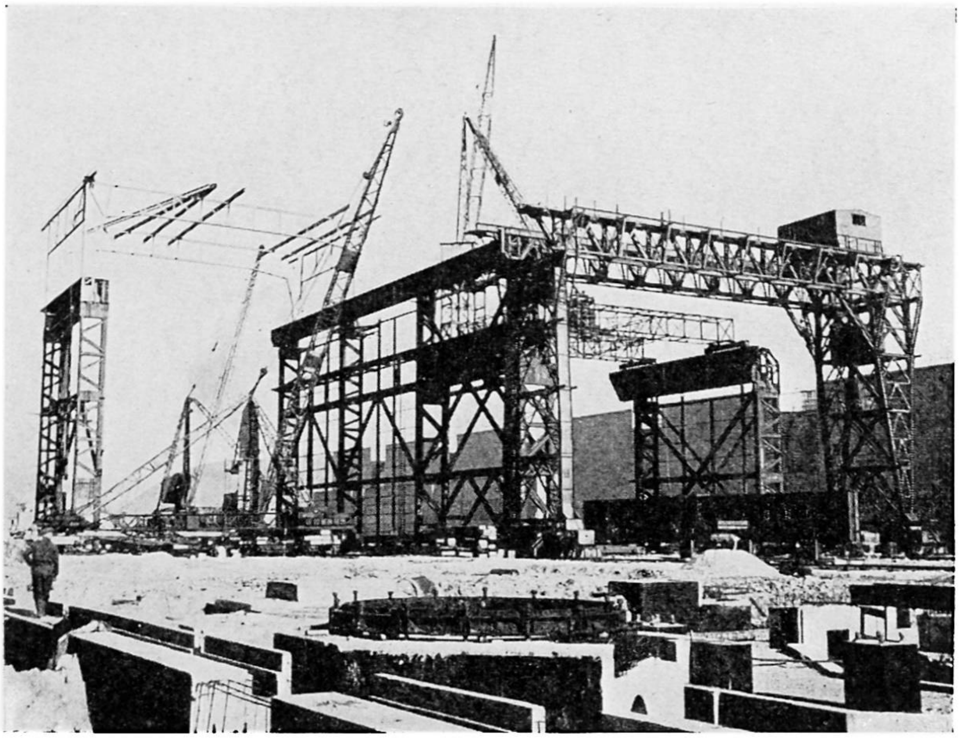

Fig. 9. Goliath erection crane with a 90-ton girder in position for lifting

Fig. 10. 100-ton welded girder being lifted by a derrick crane and a derrick mast

Fig. 10 shows a 100-ton girder being lifted at two points by a Scotch-derrick crane, and a derrick mast with winch. The lifting capacity of the crane shown is 65 tons, and the position of the lift can be so arranged that the crane can be used to capacity without any possibility of overloading.

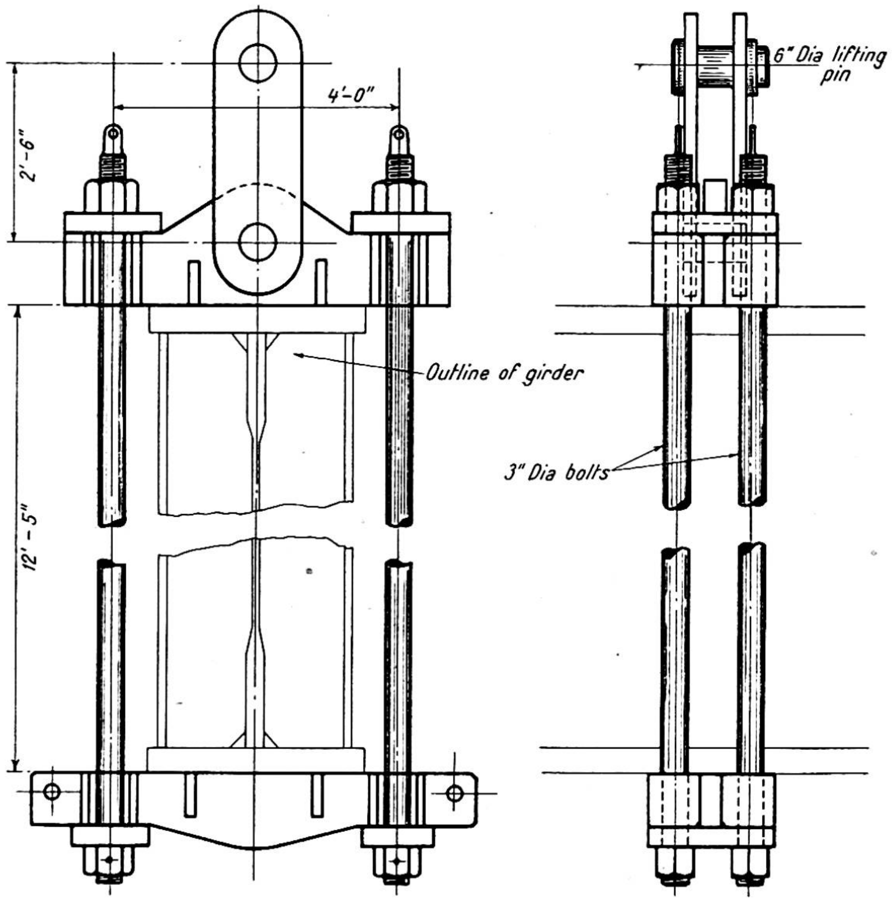

Fig. 11. Lifting cradle for 100-ton girder

Fig. 11 shows a lifting cradle designed for lifting a 100-ton girder from one central point.

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Summary

The paper suggests collaboration between the rolling mills and the structural designer if full advantage is to be taken of the maximum mill limits.

The importance of accurate cold levelling of the plate material and the subsequent care that should be taken when handling material is described.

Examples of large welded girders produced for steel plant buildings are given, together with details of welds, welding procedure and a description of the manipulators used.

A brief description is given of methods employed in transporting and erecting very large girders.

Résumé

L'auteur suggère une coopération entre les laminoirs et les ingénieurs d'études, si l'on veut pouvoir tirer intégralement parti des possibilités maxima des laminoirs. Il attire l'attention sur l'importance d'un dressage à froid précis des matériaux et sur les précautions qu'il y a lieu de prendre pour la manutention ultérieure de ces éléments.

Il cite des exemples de poutres soudées de grandes et de très grandes dimensions qui ont été construites pour des aciéries et donne des indications de détail sur le soudage et sur les dispositifs prévus pour la manutention de ces poutres, ainsi que pour leur transport et leur montage.

Zusammenfassung

Der Aufsatz weist hin auf die Zusammenarbeit zwischen Walzwerk und Konstrukteur, die nötig, ist, um die grössten Walzen voll ausnützen zu können.

Die Wichtigkeit des genauen Kaltrichtens der Bleche und die nachherige Sorgfalt bei der Bearbeitung des Materials wird beschrieben.

Als Beispiele dienen grosse geschweisste Träger für ein Stahlwerk, einschliesslich der Einzelheiten der Schweissnähte, des Schweissvorgangs und einer Beschreibung der verwendeten Vorrichtungen.

Zum Schluss werden die Methoden für den Transport und die Aufstellung sehr grosser Träger kurz beschrieben.