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III

General Report.

Generalreferat.

Rapport Général.

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We have before us a problem of great and immediate importance, namely the application of welding to structural steelwork and bridge engineering. At the Congress of 1932 in Paris this question was still viewed with scepticism and such applications of welding were made the subject of many warnings, fears being expressed as to the magnitude of the shrinkage stresses, the cast metal structure of the weld seams, and the difficulties associated with the execution of welded work. The papers now presented show, however, that since 1932 welding has been more and more widely adopted in building and in bridge engineering and that its progress has never been interrupted. All objections to the use of welding in structures to carry stationary (or mainly stationary) loads must be regarded as completely overcome, whether in building or in road bridges. For this purpose solid webbed designs have been the type most used in welded work, but examples of welded frame structures are not lacking.

In the construction of railway bridges there is still, in many countries, some hesitation and backwardness in the adoption of welding; in others — especially Germany — great progress has been attained in this direction, though up to the present only solid webbed railway bridges have been welded. Since 1932 exhaustive and extensive experiments have been carried out, especially in Switzerland and in Germany, with a view to studying the fatigue resistance of welded connections and of all-welded plate web girders, and these have shown that certain forms of welded connections — particularly butt welds — possess excellent fatigue resistance so long as the parent material has good welding characteristics, the mechanical properties of the electrodes are suited to those of the parent material, the roots of butt seams are scraped out and rewelded, and the transition from the seam to the parent material is not too abrupt at the surface and is free from notches (milling being here of great value).

The experiments have also shown that the ends of flange plates which are to be added to plate web girders should be tapered longitudinally and should be connected by transverse fillet welds merging smoothly into the plate below, and that longitudinal fillet welds at the ends of such plates must be adapted to the diminishing thickness of the plate in question and be suitably worked over.

Experiments and experience have shown that apprehension as to the magnitude of shrinkage stresses is groundless: in the seams connecting the web to the flange plates such stresses may, indeed, be very high (2000 kg/cm^2 or more) but in the girders themselves they do not reach this value and are, in fact, no greater than the rolling stresses present in rolled joists, especially in broad flange beams. Such members carry almost as heavy loads as if they were free from rolling stresses, and the same argument obviously applies to welded girders. Even the high shrinkage stresses in the "neck" welds connecting the web to the flange are attended by no danger; this has been proved by exhaustive experiments in reference to the fatigue bending resistance of welded plate web girders which, despite the heaviness of the shrinkage stresses, are found to possess greater fatigue bending resistance than riveted girders, and the explanation lies in the fact that the heavily stressed seams are surrounded by less heavily stressed portions which relieve the high stresses in the part adjacent to them as soon as the latter exceed the yield point.

In other fields of engineering important constructions subject to heavy dynamic stresses are successfully being welded, such as pressure plant for use in shipbuilding, dredger buckets, railway rolling stock, locomotives, etc. In Germany, as in other countries, small and large ships are being built in St. 37 and St. 32 entirely by welding, and the performance obtained with such ships is excellent, despite the fact that in a heavy sea very powerful alternating stresses of high frequency arise, especially in small ships.

Reference may now be made to certain notable welded bridges in different countries.

In *Hungary* the Raba Bridge at Györ was built by welding (Fig. 1) this being a road bridge of 63 m span, in which the main girders are trapezoidal trusses.

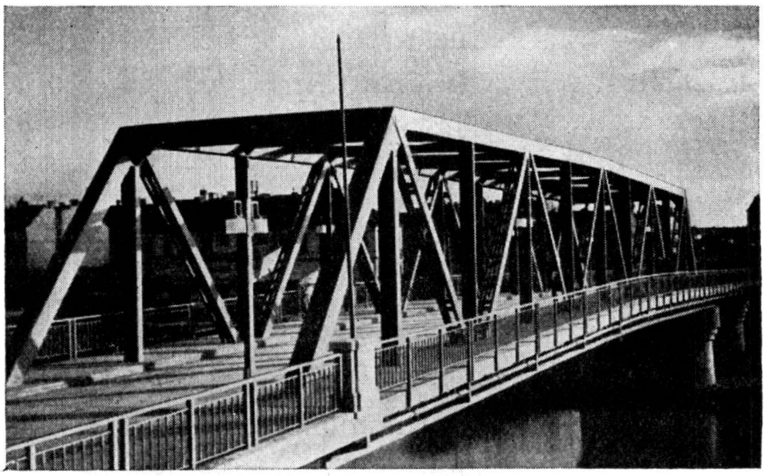

Fig. 1.

In *Poland* there is the well known road bridge near Lowicz (Fig. 2) constructed as early as 1928, for which we are indebted to Prof. *Bryla* of the Technical University of Warsaw. Here the main girders are trusses of 27 m span.

In *Belgium,* in addition to a number of plate-webbed girders, special use has been made of welding in the construction of Vierendeel girders. Fig. 3 shows a road bridge of this type covering 61 m span in the main opening, with plate web girders over the side openings.

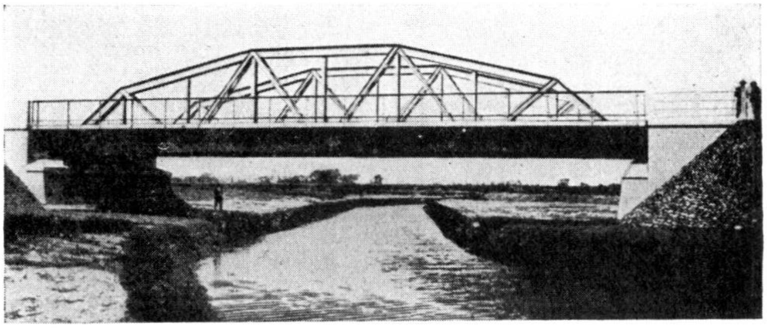

Fig. 2.

In *France* a notable all-welded plate web girder railway bridge near Saint-Denis deserves special mention (Fig. 4). This bold piece of work has been carried out in high tensile steel St. 54, by Messrs. *Cambournac.* The main girders are continuous over three supports and the depth of the web plates is 2.30 m. One of

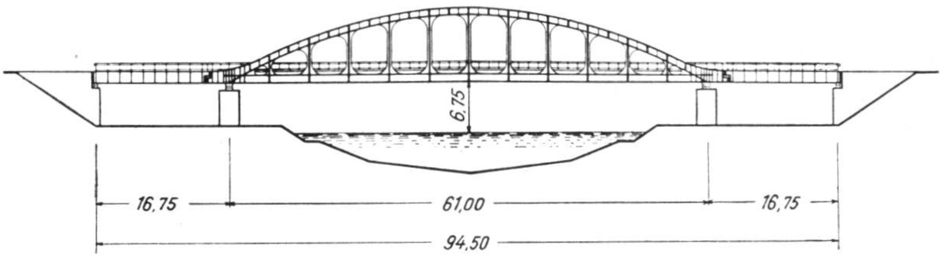

Fig. 3.

the two main girders covers spans of 26.9 and 35.2 m, the other 28.9 and 32.3 m.

In *Yugoslavia* the railway bridge at Zagreb (Fig. 5), which is a plate-webbed frame bridge over three spans, is entirely of welded construction.

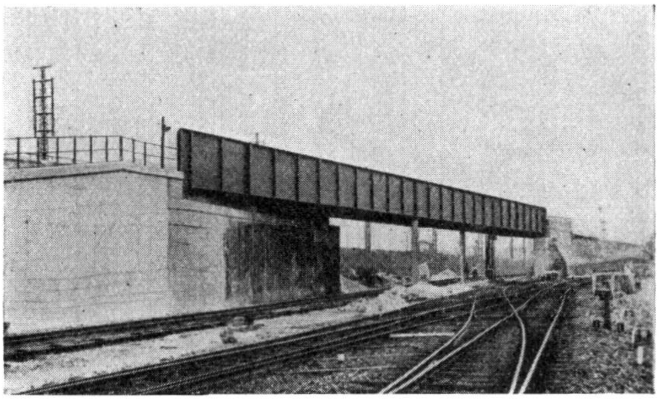

Fig. 4.

In *Roumania* there is a road bridge with trussed girders covering 30 m span (Fig. 6).

In *Sweden* there is the well known Mälarsee bridge near Stockholm (Fig. 7) in which welding has been used for the whole of the roadway, the upper wind bracing, and the supporting columns on which the roadway is carried, amounting to a total weight of 2000 tonnes.

The Traneberg Bridge (Fig. 8), which is otherwise of reinforced concrete construction, has welded roadway girders and upper bracing, the weight of the

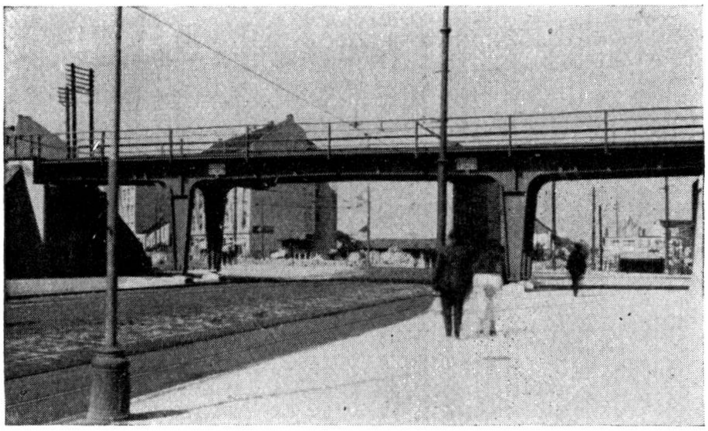

Fig. 5.

welded portions being 1300 tonnes. Another Swedish bridge which is entirely of welded construction is that at Palsund near Stockholm (Fig. 9), which spans over the water by an arch girder of 56 m span and over the approaches by beam bridges of 12 m span carried on steel columns. The overall length of this bridge is 276 m and the total weight 1100 tonnes; the cross girders are made of St. 52 and all the remaining portions of St. 44. Fig. 10 is a view of the completed bridge.

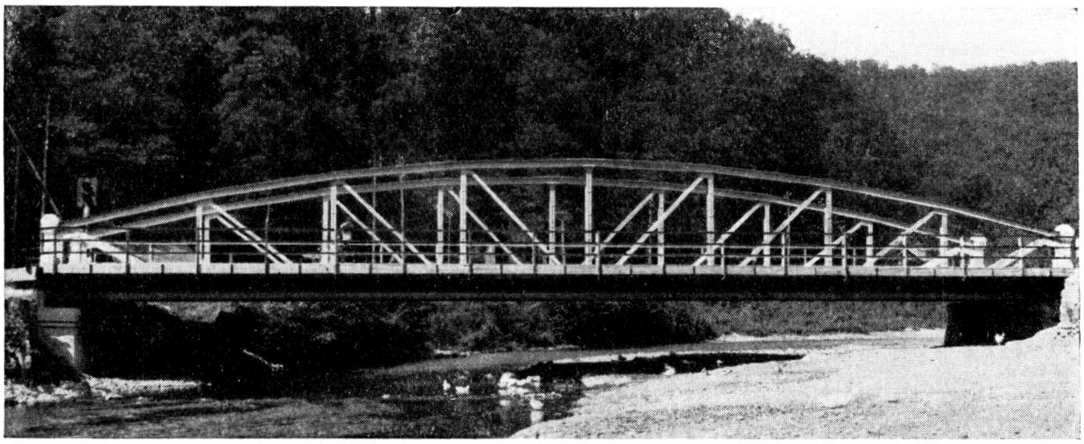

Fig. 6.

In *Switzerland* mention should be made of the road bridge over the Tessin (Fig. 11), a completely welded structure in which the main girders are arches with solid webbed stiffening girders of 70 m span.

Among the hundreds of welded railway and road bridges in *Germany* the following may be named.

1) The bridge over the Ziegelgraben (Fig. 12), forming part of the Rügendam crossing between Stralsund and Dänholm. It is a single track railway bridge

having two fixed spans of 52 m each and one lifting span of 29 m. The material used was St. 37.

2) The single track railway bridge over the Strelasund (Fig. 13), likewise forming part of the crossing of the Rügendam between Dänholm and the island of Rügen, comprises ten openings which are crossed by five continuous plate webbed girders of 54 m span. Here also the material is St. 37.

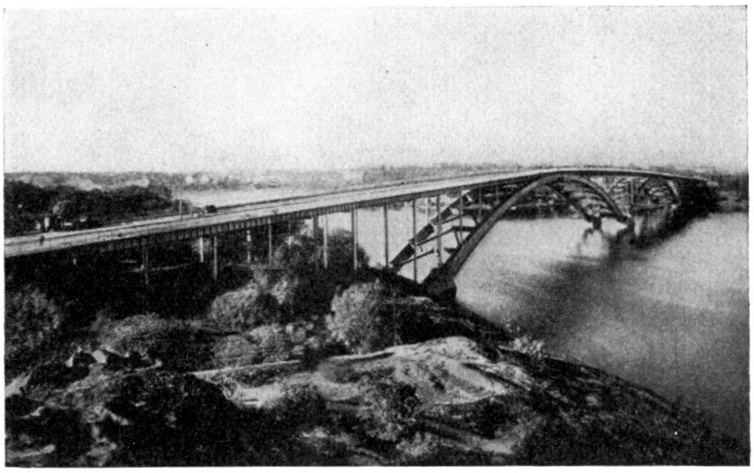

Fig. 7.

3) The bridge for the Reichsautobahn at Kaiserberg near Duisburg (Fig. 14): here the main girders are stiffened arches with plate webbed stiffening girders of 103 m span, and the material is St. 52.

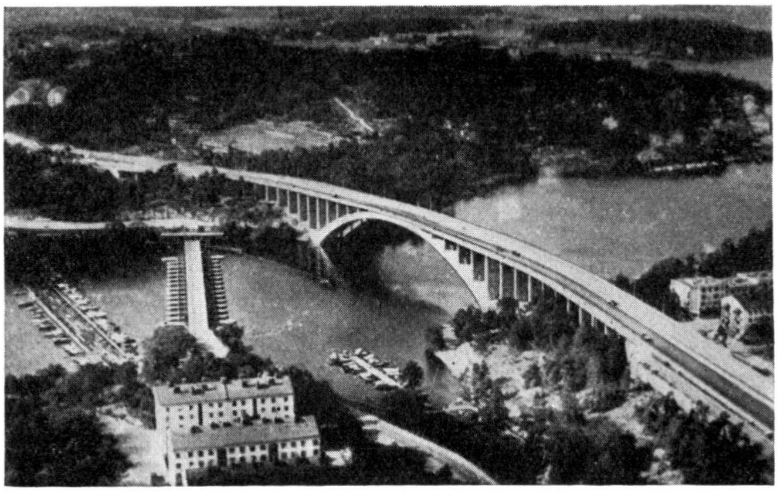

Fig. 8.

4) The Reichsautobahn bridge at Kalkberge (Fig. 15) in the neighbourhood of Berlin. The main girders here are plate-webbed continuous girders of 53.3, 66.7, 66.7 and 63.3 m span respectively, and their depth is 3.0 m, the material being St. 52.

Experience with welded road bridges has been generally favourable, and careful examination of the many welded railway bridges now under traffic in Germany has indicated that their performance in service is excellent, no defects being recorded except insignificant cracks in the web stiffeners.

The main principles to be observed in the welding of bridges are the following:

1) Only those kinds of steel should be welded which are not sensitive to the effects of welding — namely St. 37 and St. 52 which are peculiar as regards chemical composition.

Fig. 9.

2) The mechanical properties of the electrodes must be suitably adapted to the material to be welded.

3) The seams must be limited in number and thickness to the minimum necessary, so as to minimise the production of heat and, therefore, the magnitude of the shrinkage stresses.

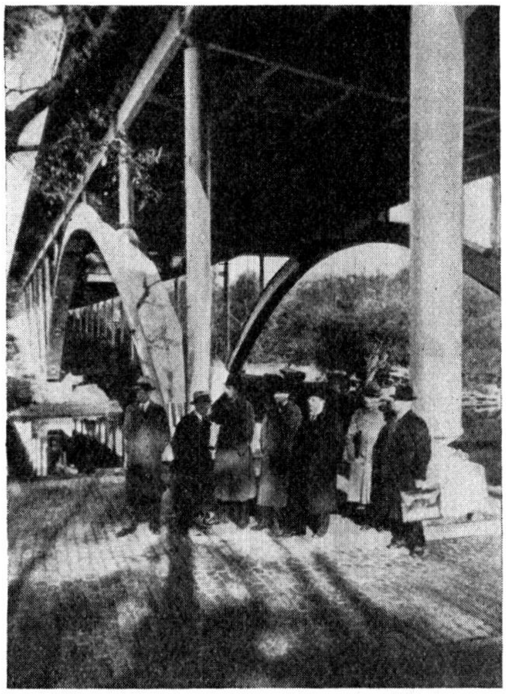

Fig. 10.

4) Web plate joints should take the form of plain butt welds.

5) The necessity for flange joints should be avoided as far as possible by the adoption of long flange plates.

6) Where flange plates have to be connected, the joint should take the form of a plain butt weld or should be made with the aid of cover straps.

7) Butt welds should be placed where the stresses are light (as at points of inflection).

8) The roots of butt welds should be scraped out and carefully re-welded.

9) Butt welds must be X-rayed, and in the case of thick seams this should be done immediately after the first runs of

weld metal have been deposited as experience shows it is in these first layers that cracks occur. For this purpose all fabricating shops which carry out welding work need to be equipped with X-ray apparatus.

10) Seams connecting the web to the flange should also, if possible, be X-rayed by taking samples.

11) Joints should never be made by a combination of welding and riveting. It would be wrong, for instance, to weld the web plate joints and rivet the flange joints, because the slip of the flange joint rivets would have the effect of overloading the web joints.

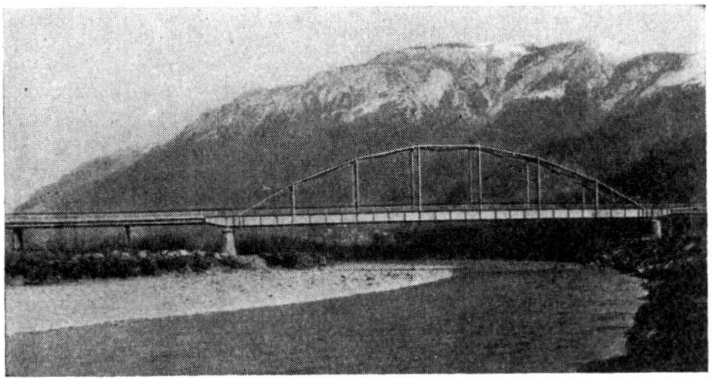

Fig. 11.

12) In tension members the use of transverse seams at heavily stressed points should be avoided. In lightly stressed parts they may be allowed, but must be so arranged as to ensure uniform transition to the parent material.

13) In welding the roadway girders into place care must be taken that no heavy shrinkage stresses arise at the connections. With this object the procedure may be followed, for instance, of first welding the middle cross girder to the

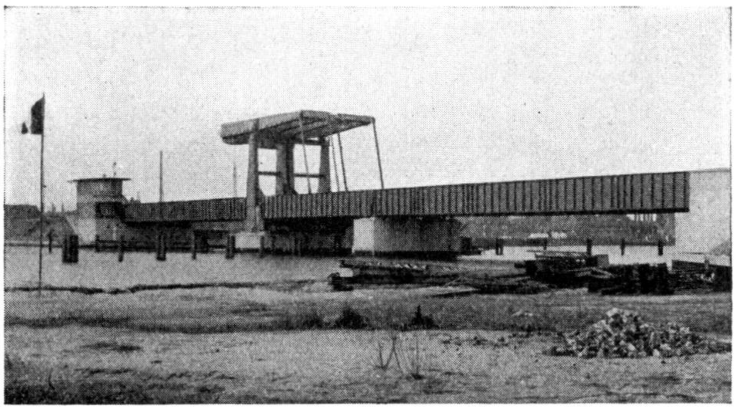

Fig. 12.

main girders, then the adjacent longitudinal girders, next the cross girders on either side of these — hitherto unattached — and finally the last mentioned cross girders to the main girders; and so on.

14) When seams are deposited in several runs, each layer of weld metal must be freed from slag before the next is welded.

15) All welding work, both in the shop and on the site, must be continuously and carefully supervised by competent welding engineers.

16) Welding jobs must be carried out only by tested and reliable welders.

17) The best and simplest welding being done in a horizontal position it is desirable that all important members should be held in suitable rotating supports and so brought into a horizontal position while being welded. Fig. 6 of the following contribution to the discussion IIIb *Dörnen* shows such an arrangement on the site, with a girder in position for welding.

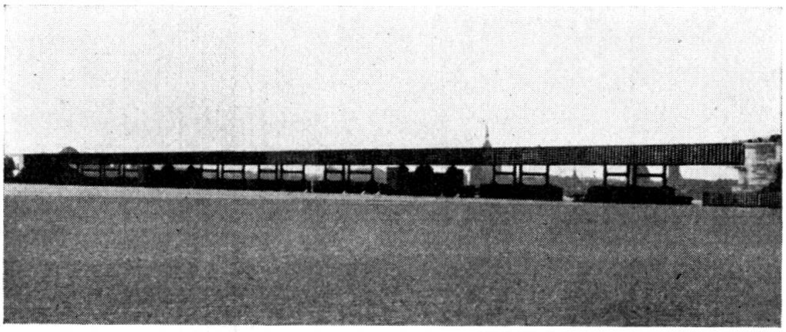

Fig. 13.

Following upon these rules, two kinds of site joint which have been adopted in the construction of plate web girders will be explained:

1) Site joints in the Reichsautobahn bridge at Kalkberge near Berlin already illustrated (Fig. 16). The material is St. 52. The web plate is 3 m high and 20 mm thick, and the flange plates are *Dörnen* reinforced sections 660×44. The joints in the web plate and the flanges are placed at approximately the same positions, corresponding to the points of inflection, and are plain butt joints

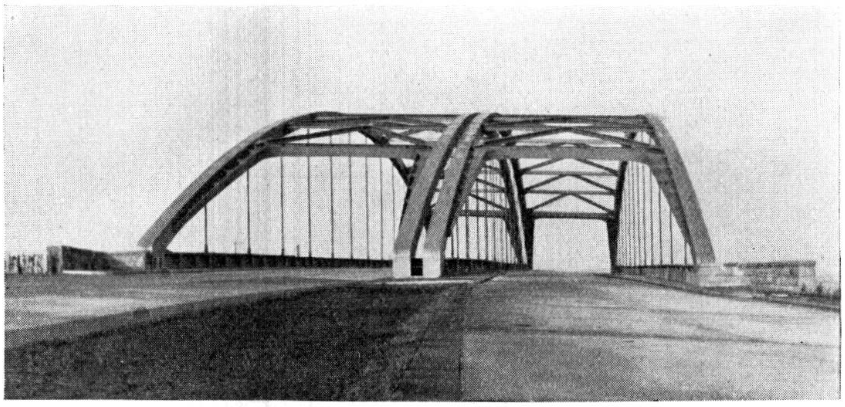

Fig. 14.

taking the form of "tulip" seams in the flanges and of an X-seam in the web plates. The flange joints are placed at 45^0. Five runs were welded in both of the flange joints at the same time, followed by intermittent welding of one side of the X-seam in the web plate from the bottom upwards, simultaneously with the continuation of both seams of the flanges. When one side of the X-seam in the web plate had been completed, the other side was welded. The sequence of welding was so timed that all three seams were completed together.

2) Site joints in the railway bridge over the Strelasund (Fig. 17) which has already been illustrated. Here thicker portions of web plates 40 mm thick are

Fig. 15.

incorporated at the joints with a view to reducing the stresses in the flange plates (*Dörnen* reinforced sections 540 × 55). The web joints thus formed are plain butt welded X-seams and the flange joints were formed immediately between them in the following way:

The flange plates are connected by X-seams at 45°, in addition to which the outside of the flange plates is furnished with small vertical cover straps 150 × 40 mm and horizontal straps 200 × 40 mm above the upper flange and below the lower flange, welded on. The sequence of welding was as follows:

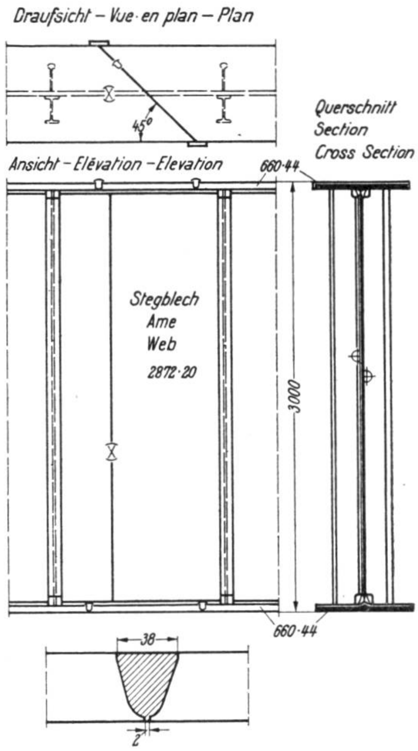

Fig. 16.

The upper halves of the X-seams in the top and bottom flanges were welded at the same time, up to the middle of the height, and were followed by the lower halves of the same seams, welded overhead in the same way. The thickened portion of the web had already been connected to the thinner web plate on one side of it by an X-seam in the workshop, and the remaining butt weld in the web plate was completed after the flange joint already mentioned. Then the butt welds in the flanges were completed, and the neck welds connecting the flange to the web which had previously been omitted opposite the joints were closed. Next the vertical edge covers were attached, and finally the horizontal joint cover plates were welded on.

It is frequently asked why welding is used at all in building work and in bridge construction: why is the well tried method of riveting being given up? Is the idea simply to replace the old by the new?

Undoubtedly every progressive engineer who is not bound by the past feels the urge to create something new, and certainly this is one of the reasons why welding has been introduced into building and bridge construction. The more positive reasons are, however, the following:

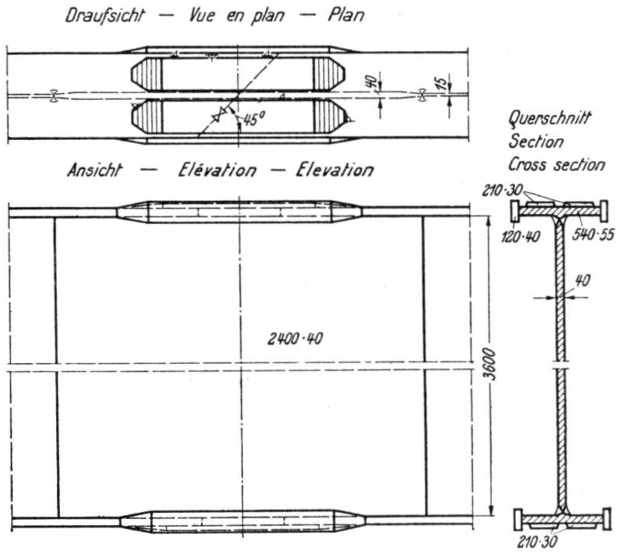

Fig. 17.

1) In general welded girders are more economical than riveted.
2) The appearance of welded structures is better than that of riveted.
3) In the case of plate web girders subject to heavy dynamic stresses a third reason is to be found in the results of the recent tests which show that welded girders possess greater fatigue resistance than riveted.

So far as the economy of welded girders is concerned, it should be observed that in the experience of well equipped steelwork fabricating shops welding is not, in itself, more expensive than riveting. Welded girders are, moreover, usually

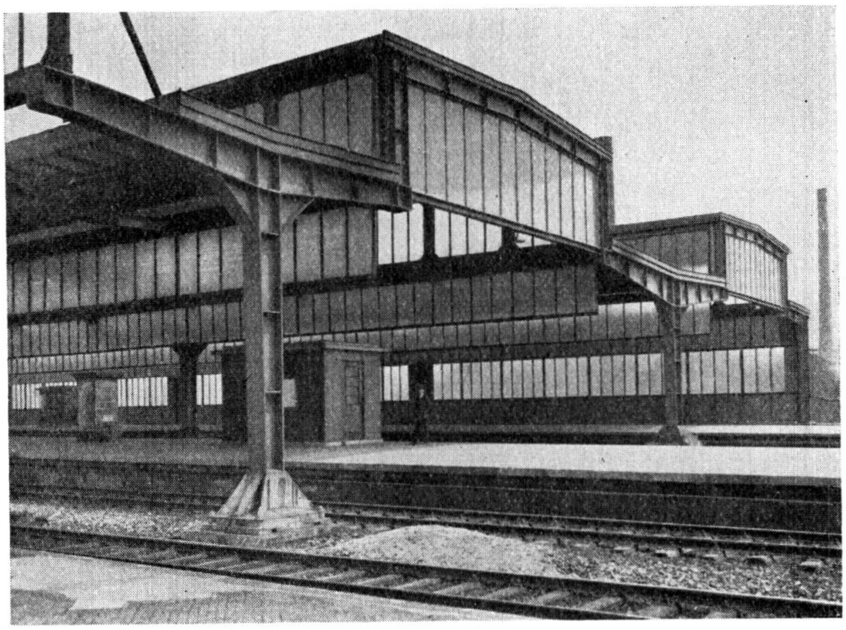

Fig. 18.

16 % lighter than riveted, and there are further incidental savings of even greater importance.

On page 1343 in the "Preliminary Publication" is shown, a two-hinged frame of riveted and of welded construction alternatively, the span and purpose of either design being identical. The riveted frame weighs 19.4 tonnes and the welded frame 14.2 tonnes, so that here there is a saving in weight of 26.3 %.

The following may serve as examples of the extraordinarily good appearance obtained. Fig. 18 shows a welded roof girder for the new railway station at

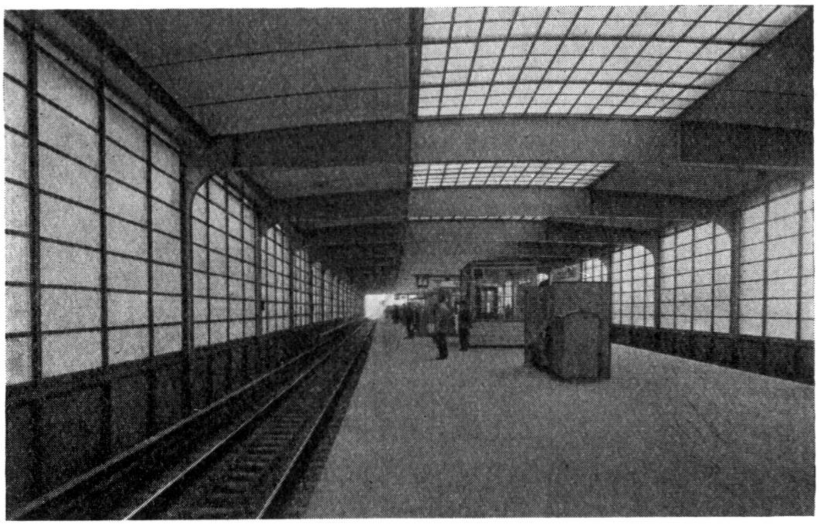

Fig. 19.

Düsseldorf; the pleasing, simple shapes of the kind that appear in this girder and in other portions of the same building cannot be obtained by riveting. Fig. 19 shows the new all-welded tramway station attached to the Zoological Garden railway station in Berlin, and the exceptionally fine appearance presented by

Fig. 20.

welded bridge girders may be appreciated in the railway bridge represented in Fig. 20.

The reasons put forward for the adoption of welding are indeed so convincing that a progressive engineer has every inducement to promote its use in building and bridge work, on the following grounds:

Welding in these applications rests on a scientific foundation underlaid by extensive and careful experiments and research. Good performance has been recorded from welded structures in service. It has been learned how to weld correctly in the proper sequence. It has been ascertained which electrodes and which materials are suitable for welding. Regulations are available for welding in building and bridge work. In the present author's opinion all objections to welding in such work have been overcome and we possess in the X-ray test a simple and dependable means of confirming the qualities of welded seams.

Admitting that many points of detail which need to be clarified by research, are still outstanding it can now be asserted that the use of welding deserves to be promoted as a means of creating structures which are safe in operation, economical and beautiful.