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Experiments on Welded Frame Intersections, with Special Reference to Vierendeel Girders Subject to Heavy Dynamic Stresses.

Versuche mit geschweißten Rahmenecken, insonderheit für dynamisch hoch beanspruchte Vierendeelträger.

Essais sur noeuds rigides soudés, spécialement de poutres Vierendeel soumises à de fortes sollicitations dynamiques.

Dr. Ing. A. Dörnen,
Dortmund-Derne.

The two comparisons between riveted and welded designs of the same steel frame components, which are represented respectively in Fig. 1 (corresponding to Fig. 3 of the paper by *Schaper* in the Preliminary Publication, p. 1370) and in Fig. 2, go to indicate the superiority of welding both from an aesthetic and a technical point of view. The frame shown in Fig. 2 can, indeed, scarcely be made at all by riveting without objectionable features: a number of the rivets have to be excessively long; many of them cannot be hammered effectively if at all; a still larger number are incapable of replacement. It is clear, in fact, that we are here at the limit of what is feasible with riveting.

In both comparisons the welded design is also definitely the more economical, as the cost of construction is approximately 17 % greater in the riveted design for both Fig. 1 and Fig. 2. So far as the example shown in Fig. 1 is concerned this difference has been confirmed in the construction of 27 riveted and 25 welded frames. In the case of full webbed frames the conditions which favour welding are indeed particularly marked, and it was only to be expected that, as Professor *Campus* shows in his paper, the Vierendeel girder which consists of practically nothing but frame corners would lend itself especially well to welded construction.

In view of this circumstance *Dr. Schaper,* Director of the Reichsbahn, called for fatigue tests on welded frame corners of Vierendeel girders in 1932, and such experiments were carried out by *Dr. Krabbe* and the author in the works of the latter from 1933 to 1936 with the object of constructing welded Vierendeel corners for use in railway bridges subject to heavy dynamic stresses, the criterion to be satisfied being that such corners made in St. 37 should be able to withstand two million changes of load under an altenating stress of ± 1400 kg/cm^2 without damage. In order that useful results might be obtained it was necessary that the specimens should not be too small, and they were made roughly one third of the full size used in railway bridges of class "N" of 50 m span. Fig. 3 and 4 below show the testing machine and its method of working, the frequency of alternation being approximately 25 per minute. Altogether 27 specimens were tested.

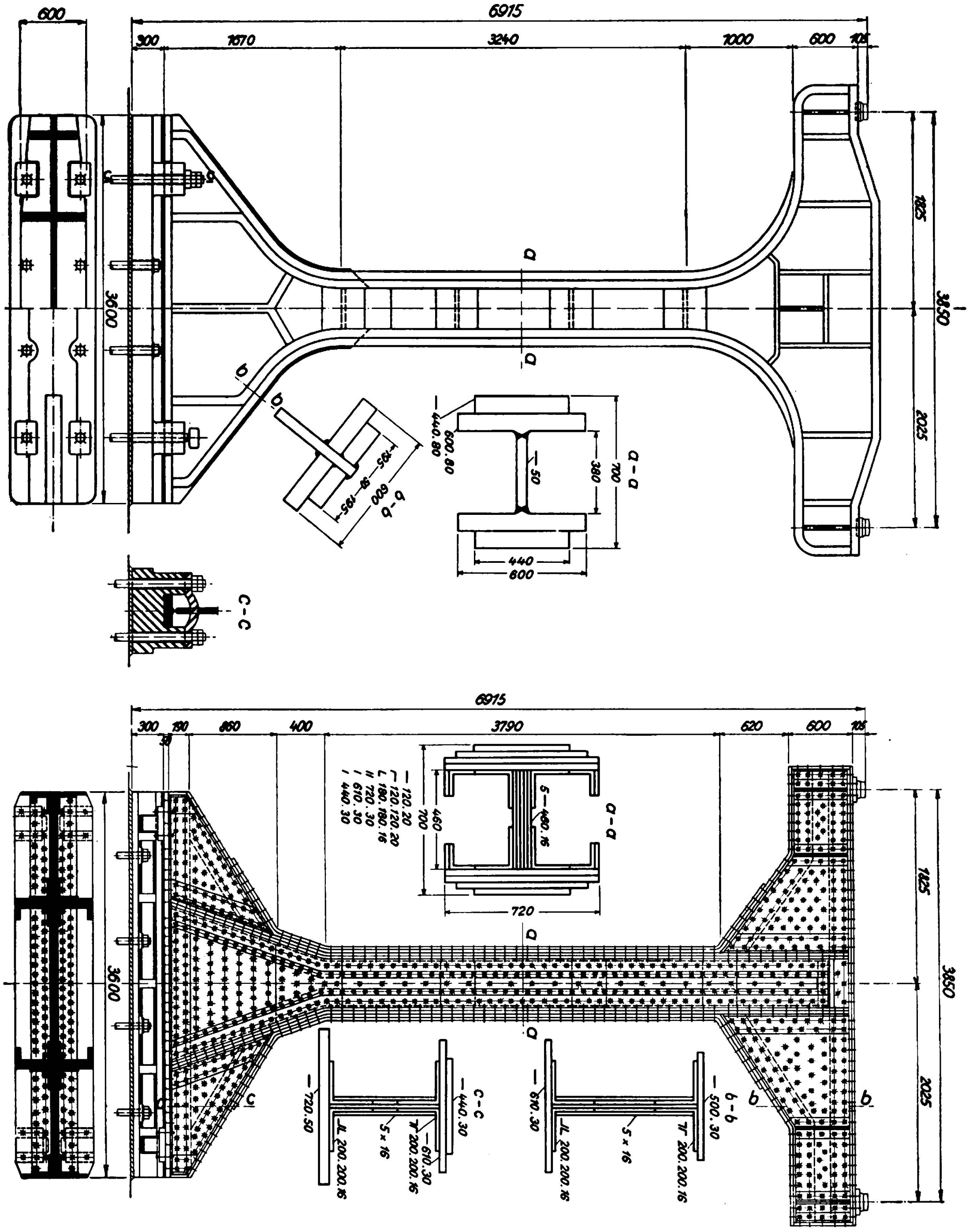

Fig. 2.

Welded Vierendeel girders had already been used in Germany for statically stressed structures. Thus Fig. 5 shows a portion of the main girder for a signal gantry at Stendal,[1] in the design of which endeavours have been made to ensure

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[1] Dr.-Ing. *Schröder:* Zustandsänderungen und Spannungen während der Schweißung des Stahlbaues für das Reiterstellwerk in Stendal. Der Bauingenieur, 1932, No. 19/20.

a properly graduated transmission of stress by thickening the web plate at the corners and welding ribs onto it. Here, as in the next example, no special welding considerations arise as the structures were subject mainly to statical stresses. As a further example, Fig. 6 shows one of the completed girders of 25 m span for the main station at Düsseldorf, and Fig. 7 the detail of the intersections. This construction proved to be exceptionally economical and very easy to carry out, despite the very liberal use of rolled steel sections.

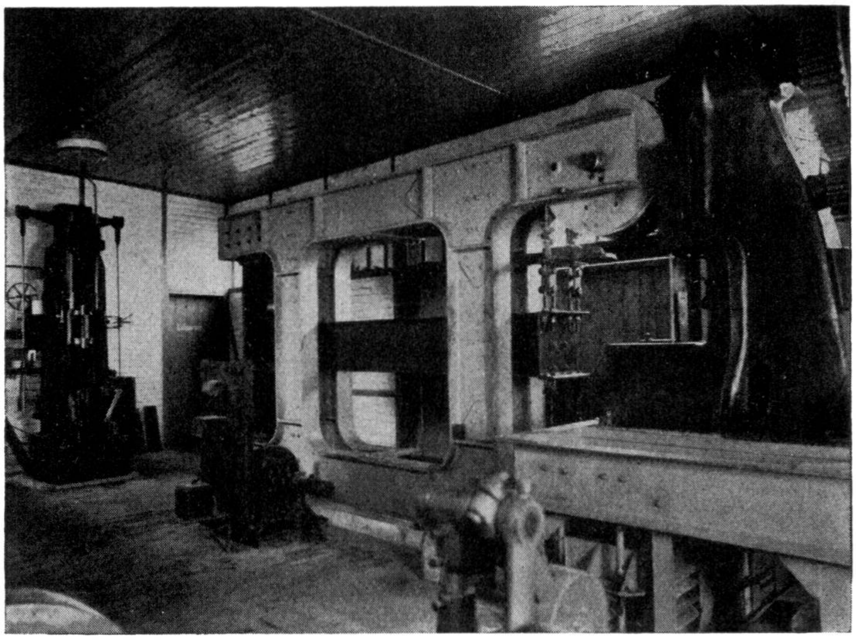

Fig. 3.

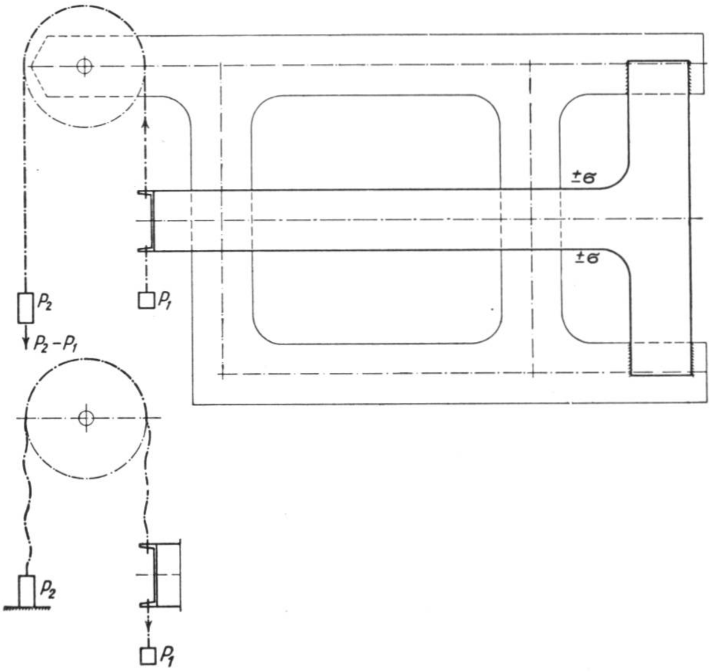

Fig. 4.

The fatigue tests undertaken had reference, however, to corner pieces subject to dynamic stress. The various designs of corners tried are indicated in Figs. 8 and 9, and fall into three groups:

In the first group the flanges of the vertical members are made continuous with the flanges of the booms and no special structural elements are provided to transmit the forces between them (Figs. 8a, 8b, 9e).

In the second group the flanges are stiffened against deformation by welding plates onto or below them (Figs. 8c and 8d).

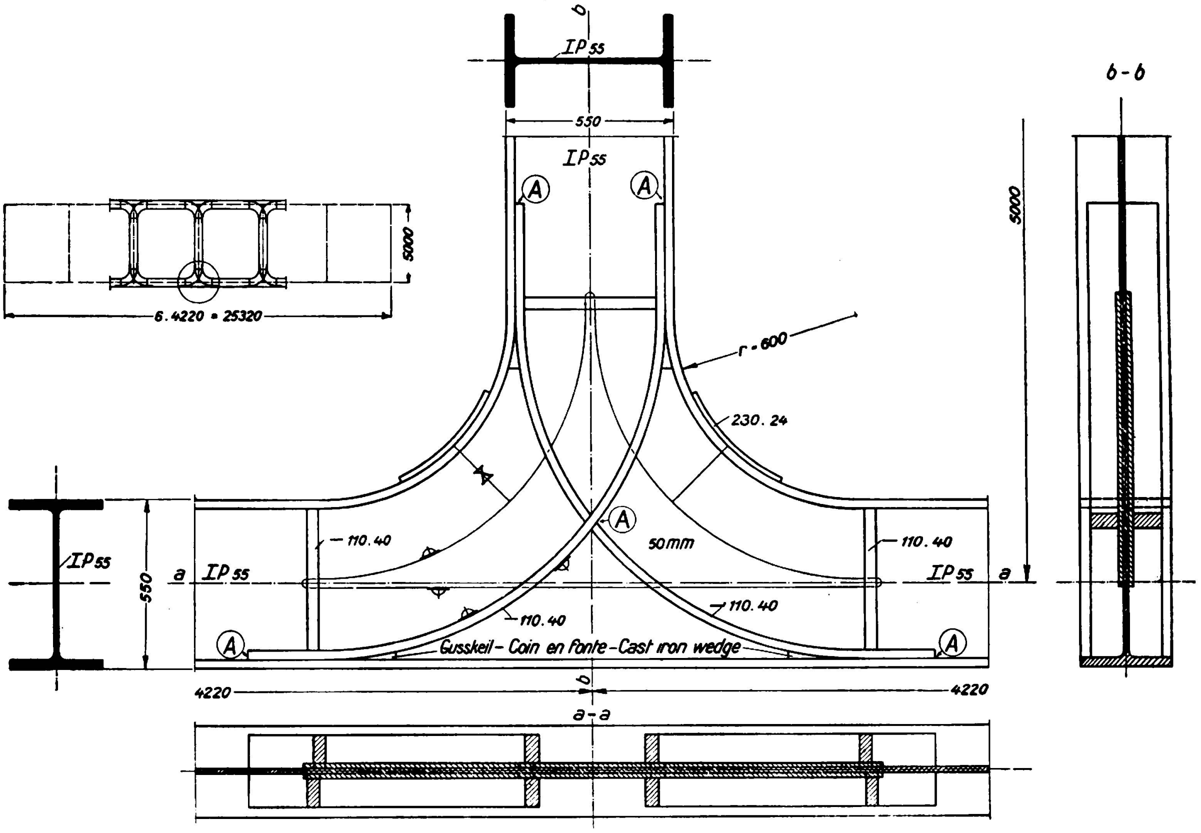

Fig. 5.

In the third group special structural elements are introduced in order to facilitate the passage of forces from the verticals into the flanges, or vice versa. This has been attempted either as in Fig. 8e, by welding cast steel grids onto either side of the web plates, or, as in Fig. 9a, by the provision of a steel casting to connect with the web plates of the flange and of the vertical member respectively. In Figs. 9d and 9e the same purpose is attained by making the flanges of the verticals and of the booms intersect one another.

The corner piece designed as in Fig. 10 was the first to satisfy requirements by withstanding two million alternations of load ± 1400 kg/cm² and subsequently 1.5 million alternations at ± 1800 kg/cm² without manifesting any defects. It is extremely simple and differs from that shown in Fig. 9e only in the substitution of rolled T sections for the flat flanges. The period that the corner shown in Fig. 9e, with flat flanges, withstood the test was considerably shorter — presumably because in Fig. 9e the "neck seams" are directly on the flange whereas in Fig. 10 they are 30 mm away.

While the tests were in progress a special requirement arose, namely the construction of a girder for a rail-car travelling at about 200 km per hour, to resist very heavy dynamic stresses and to be in the form of a Vierendeel girder up to 24.2 m long. Fig. 11 shows the cross section based on the experiments,

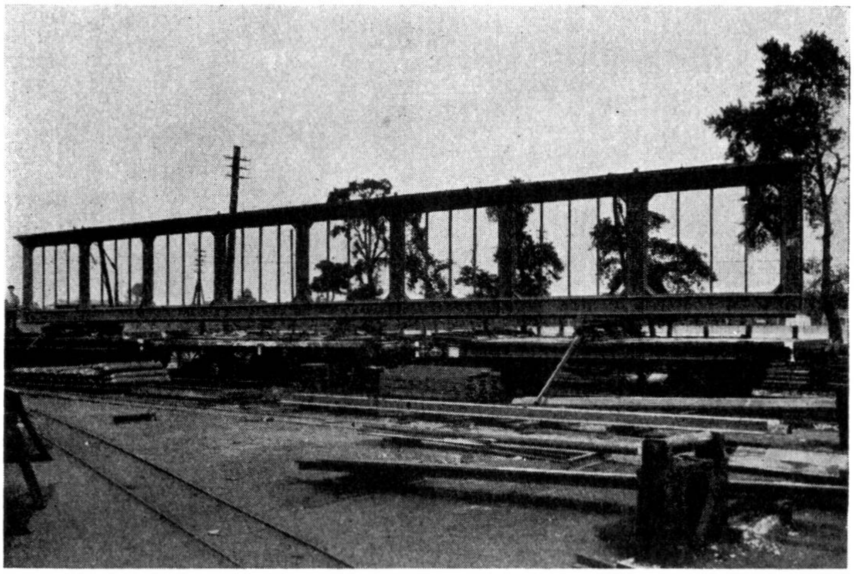

Fig. 6.

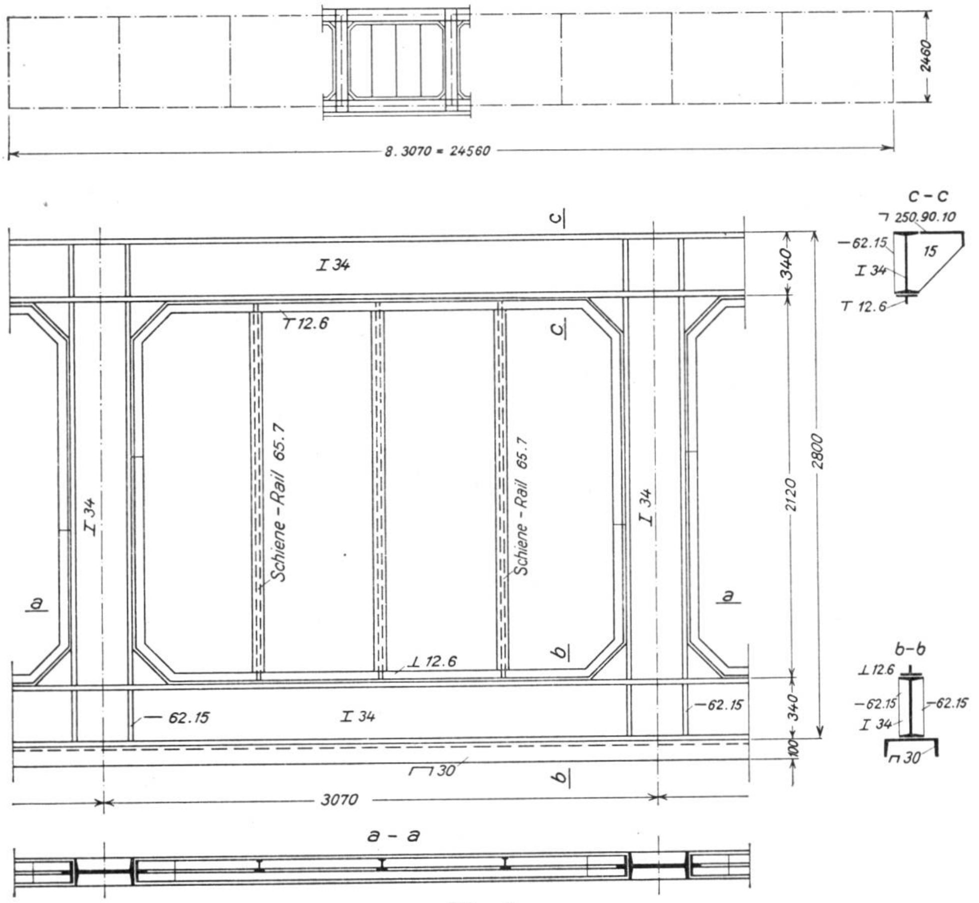

Fig. 7.

and the design of the girder. If the web plate is assembled by welding in advance of the flanges such a girder can be kept practically free from welding stresses

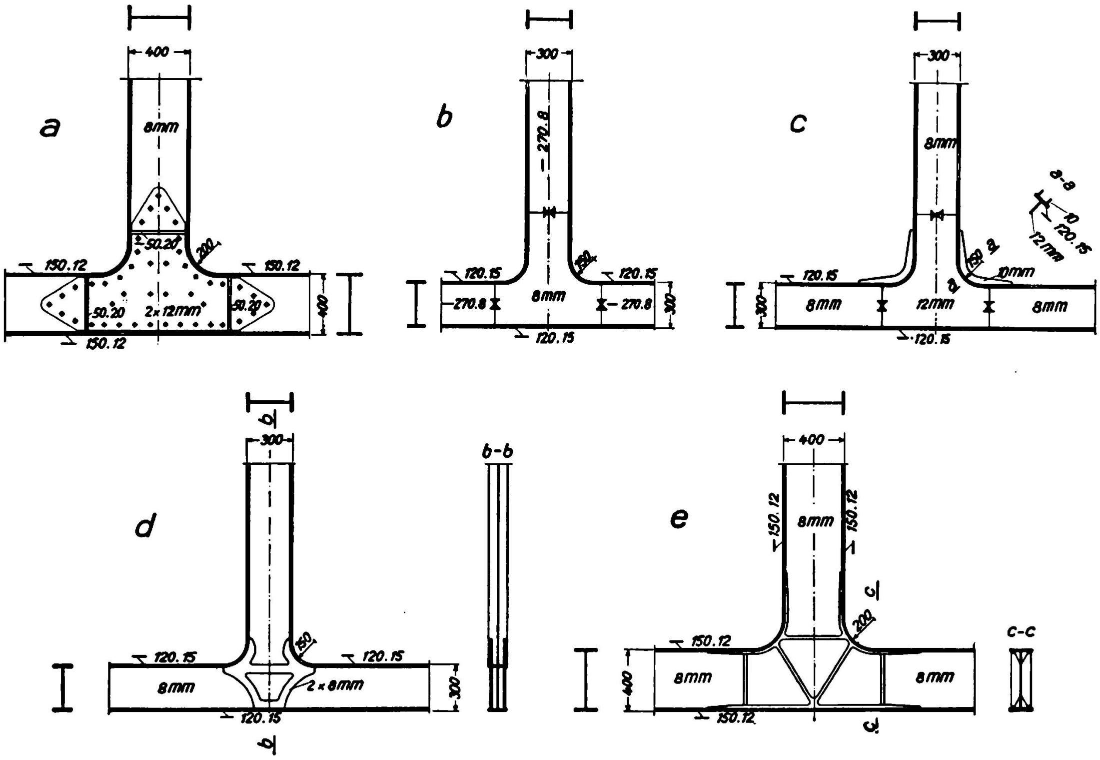

Fig. 8.

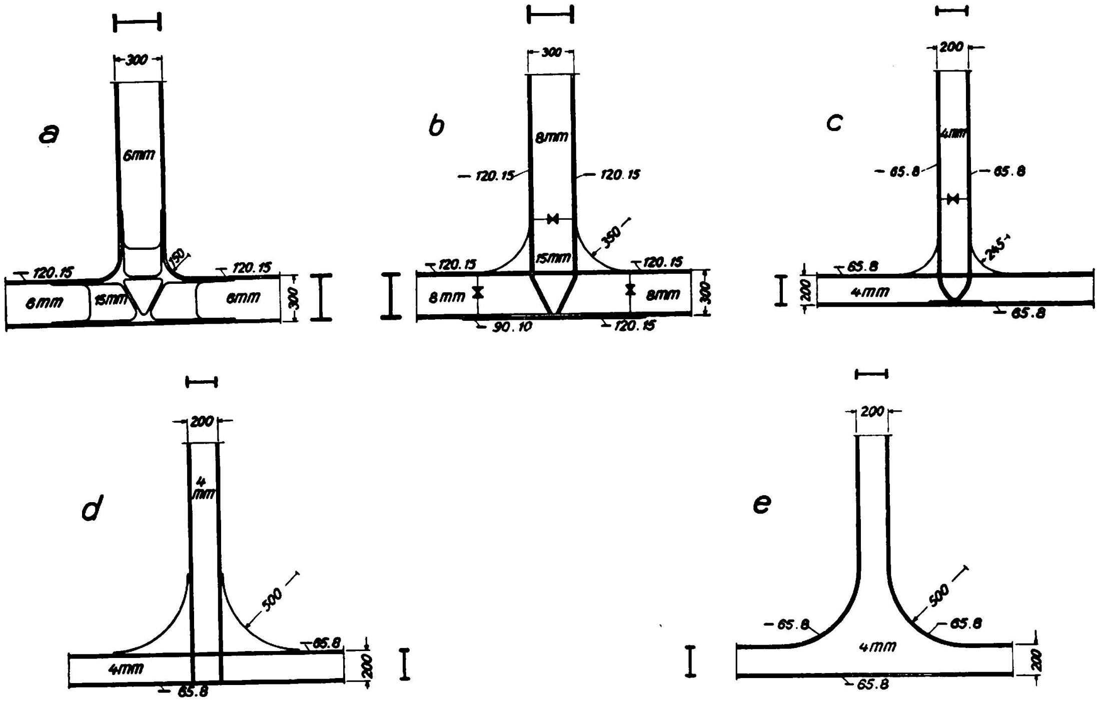

Fig. 9.

due to external effects. Fig. 12 is an isometric view of part of the car frame. The connection between the flange and the web is made jointless by the use of specially rolled section on the *Dörnen* system, and the cross girders are riveted on. The welded construction for the train 61 m in length weighs only about 17 tonnes.

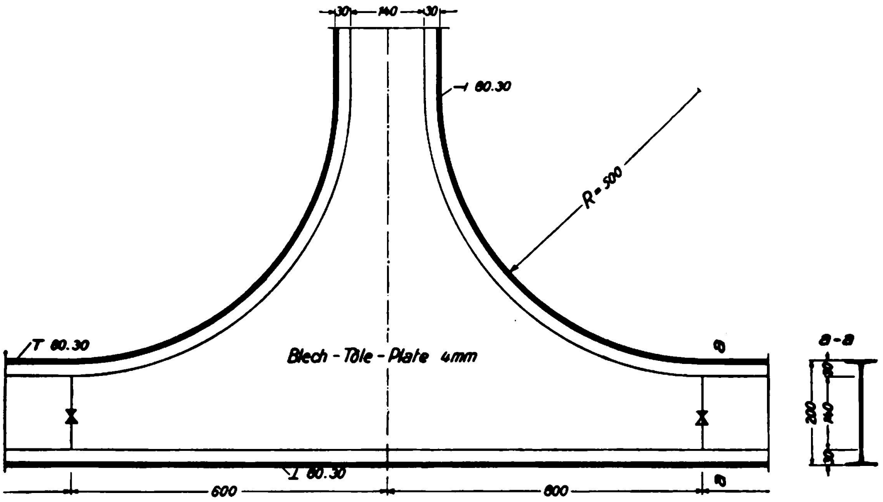

Fig. 10.

As is well known, welded structures behave quite differently from riveted structures as regards dynamic stresses, and the author desires specially to emphasise this before comparing the results of his fatigue tests with those mentioned by Professor *Campus* who used statical tests when measuring his stresses.

1) Under dynamic stresses the most desirable type of corner design is that in which the flanges of the booms are continuous with those of the verticals. In this respect any discontinuity is to be avoided as far as possible.

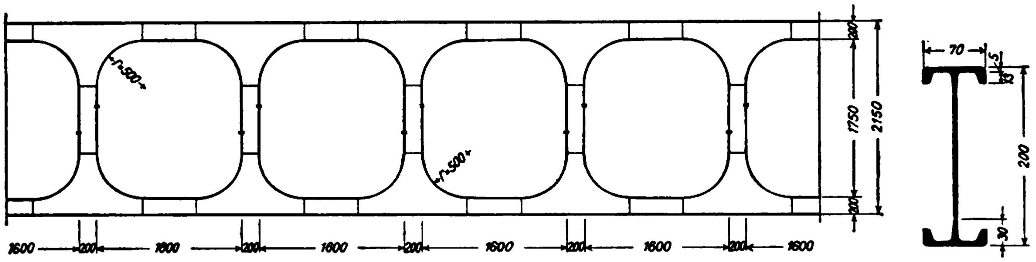

Fig. 11.

2) With a view to avoiding excessive radial forces in the seams connecting the web to the flanges the radius of the inside of the corner must not be made too small. The author is in agreement with Professor *Campus* that an elliptical or hyperbolic shape with a very gradual transition to the straight line, is the best form.

3) The smaller the radius of curvature the greater will be the difference in stress in the curved portion between the edge and the middle of the flange, because the greater is the extent that the edges of the flanges relieve themselves of their stresses, by buckling if they are in compression or by stretching across the curve if they are in tension. Under the low frequency of 25 alternations per minute this effect could be observed and the working of the specimens (which gave the impression of live organisms) could be followed with the naked eye.

4) Under present conditions of welding the presence of transverse seams and ends of fillet seams, and crowding together of seams, is particularly to be avoided

at the points of transition between the curves and the straight lines. In this matter the experiments entirely confirm the results of the investigation which served as the basis for the welding regulations for bridges on the German Reichsbahn. The unfavourable behaviour of these seams is particularly marked at the corners of frames, because there the notch effect is augmented by the change in cross section. On this account the writer feels less inclined than *Campus* to approve the welded intersections used in the road bridge at Lanaye.

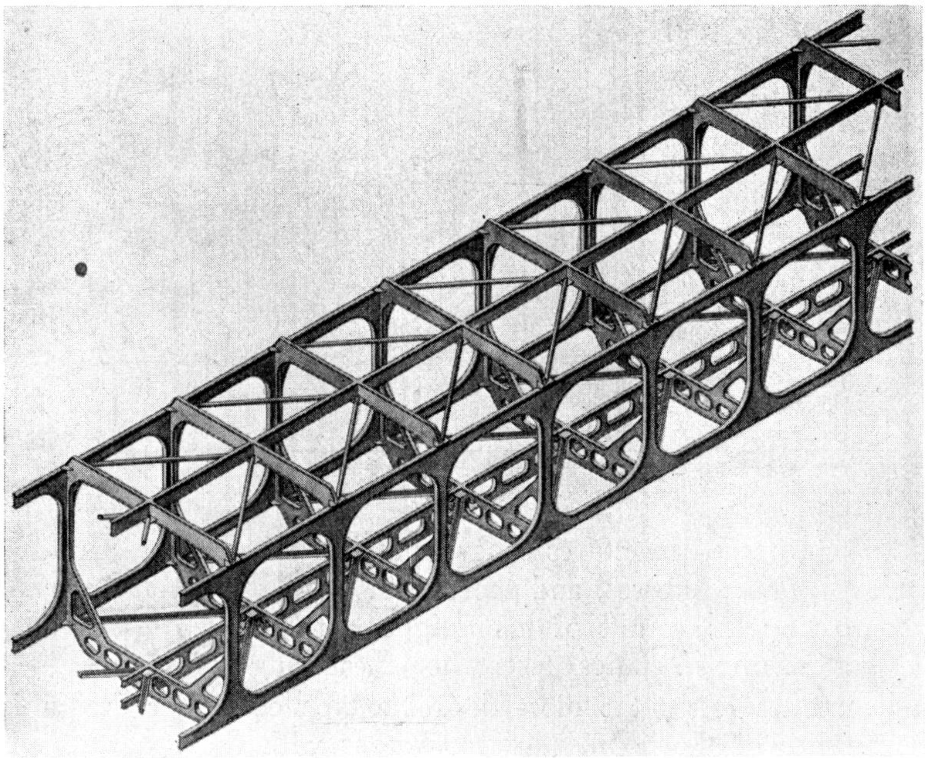

Fig. 12.

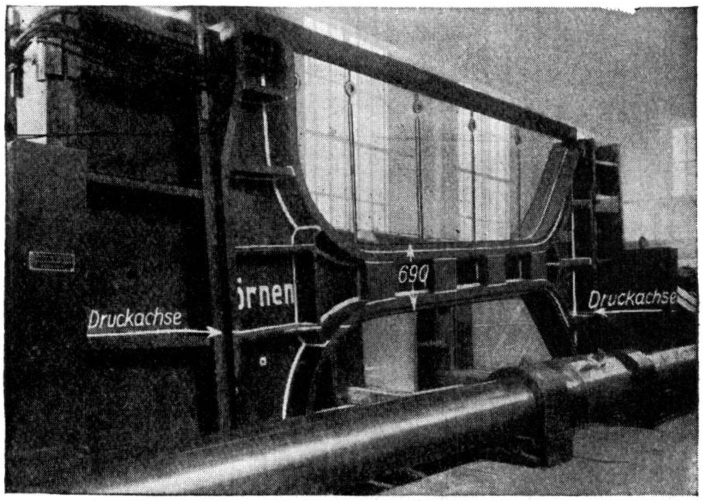

Fig. 13.

5) The web plate should be suitably strengthened at the intersection, which is best accomplished by using a thicker plate. The connection between this plate and the plate of normal thickness must be arranged outside the curved portion and the X-seams forming it must be kept free from internal or external stress. The author would further recommend that important seams be made thicker than the cross section to be connected and that the weld and its neighbouring portions be brought up to a red heat and the weld metal hammered out to the thickness of the plate, and ground smooth.

6) Corners with special structural elements to ensure the transmission of the flange forces were adopted as early as 1930 by *Dr. Schröder* in the signal gantry at Stendal, and as shown in the paper by *Campus*, have not confirmed expectations. It is wrong, however, to conclude from this that the idea underlying the design was faulty, the reason being that an unfavourable effect was exerted by the transverse seams which it was impossible to avoid.

7) Having regard to the complicated conditions of stress which arise at the corners of the frame, cross girders, bracing members and the like are best attached by means of riveting.

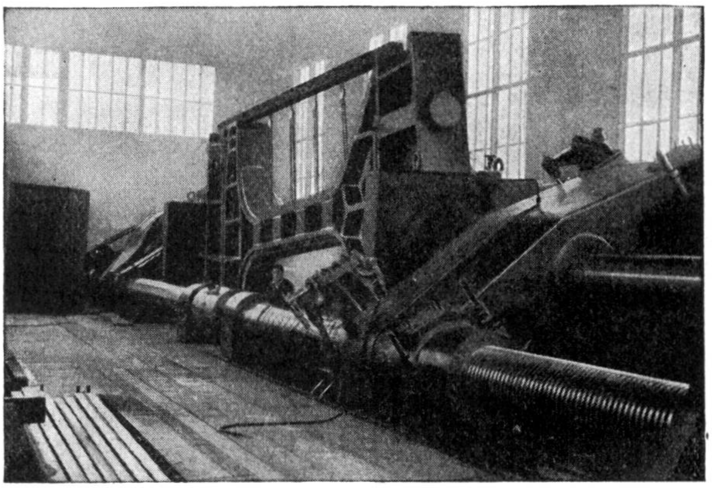

Fig. 14.

The possibility of so constructing full webbed framed designs that the carrying capacity suffers no diminution through welding stresses is indicated by an experiment on the full sized welded columns represented in Fig. 2 which was carried out for the German Reichsbahn in the Staatliches Materialprüfungsamt at Berlin-Dahlem using the 3000-tonne testing machine of the Deutsche Stahlbau-Verband, Berlin. Figs. 13 and 14 show the column loaded eccentrically to correspond with the conditions arising in service. Fig. 15 shows the column greatly deformed after receiving an eccentric load of 1300 tonnes. In regular service it will carry approximately 330 tonnes. Large deformations first occurred under a pressure of 1300 tonnes, without any cracks being observed in the main seams or in the parent material itself, and only a few of the caulking seams connecting the stiffeners of the web plates with the flanges being loose. No defects which might have impaired the carrying capacity of the column had occurred. This experiment should go far to refute any apprehensions that may be felt as regards welding stresses in such structures.

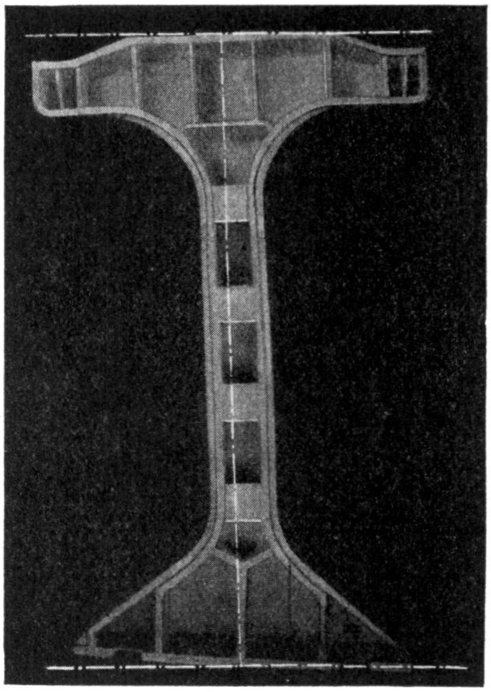

Fig. 15.

(Figs. 13 to 15 have kindly been placed at the author's disposal by the publishers of the journal "Elektroschweissung", No. 7, 1937).