Experience obtained with structures executed in Switzerland

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Experience obtained with Structures Executed in Switzerland.

Erfahrungen bei ausgeführten Bauwerken in der Schweiz.

Observations sur les ouvrages exécutés en Suisse.

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In the structural steelwork industry of Switzerland welding began early to be adopted as a substitute for riveting, so early that its practice swept far ahead of the relevant scientific research and testing technique. It was guided, in its constructional forms, by the experience of other countries, and its first applications were the welded connections of colums and beams in building frames. In parallel with these, welding began to be used to an increasing extent for the making of plate girders, by reason of their evidently simple structural form and the economic advantage of the saving in weight secured through its use. Isolated experiments were made in the construction of welded of lattice structures, and here certain welding engineers soon embarked on the transition from the characteristic riveted, to a new welded type.

The absence of scientific knowledge and test results led to the industry relying largely on tests of a practical nature.

Fig. 1 shows one of the two service bridges over the Rhine built in connection with the spillway for the Albruck-Dogern power station. The total length is approximately 150 m and the spans of about 30 m each were launched endways without the use of falsework. Experimental stress measurements were made, within the elastic limit, with a view to ascertaining the internal shrinkage stresses caused by the heating effects of the welding process; these experiments were then extended beyond the yield point in order to observe the behaviour of the selected form of construction up to the point when breakage occurred.

A rapid increase took place in the building of welded structures, based on knowledge thus acquired in actual working, and on the study of foreign technical literature: but such development was limited almost entirely to solidwebbed construction and to cases where the loading was either static or only lightly dynamic, as in road bridges. The development of welding was governed not so much by economic considerations as by insistence that the new form of construction must be technically satisfactory to the engineer.

This gratifying outcome of the creative urge of the engineer sustained a check, however, from the onset of the economic crisis, and also from the notable increase in the cost of welded work that occurred when the low fatigue resistance of welded connections (and the necessity for designing accordingly) became recognised.

Among the more remarkable products of this period — apart from a number of commercial buildings in various towns and centres of industry — are the

Fig. 1.
Power-Station Albruck-Dogern.
Service bridge during construction of barrage.

exhibition hall for the Fair in Basle[1] and the machine hall for the Federal Institute of Technology in Zürich[2]. Welded construction was frequently employed also in station roofs on the Swiss Federal Railways, and one of the most notable

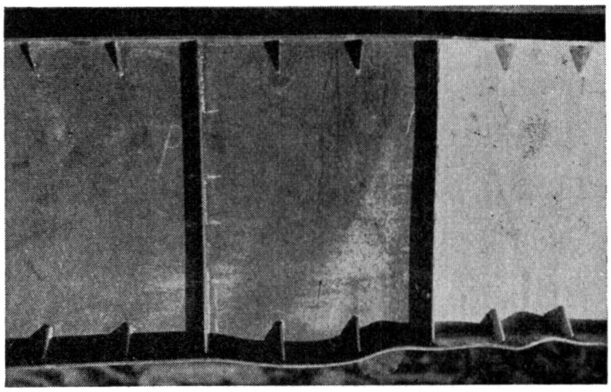

Fig. 2.

Power Station Albruck-Dogern.

Rupture tests on models of service-bridge over Rhine river.

instance of this appears in Fig. 3 showing cantilever roofs of 7 m projection at the Geneva-Cornavin station. A number of welded jobs were carried out in the field of road bridge construction, one of the most remarkable being the bowstring bridge of 70,7 m span over the Tessin on the Giubiasco-Sementina[3] route.

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[1] Schweizerische Bauzeitung, 1934, Nr. 8. Ossature Métallique, 1934, Nos 7/8.
[2] Schweizerische Bauzeitung, 1933, Nr. 21.
[3] Bulletin I. A. B. S. E. No 3.

Among other welded road bridges deserving of mention are those over the Brenno near Acquarossa and over the Rhone near Loèche, each of 40 m span.

When welding was first applied even the erection joints were welded; for reasons of cost, however, the Swiss steelwork industry has reverted to the plan of combining the use of welding in the shops with riveting or bolting on the site. When welding was performed at the site, the increased amount of supervision required and the necessity for electrical plant on the site were found to be too expensive in view of the limited sizes of the structures — and indeed organisation and plant of this order, on the site, is economical only on large jobs such as seldom occur in Switzerland.

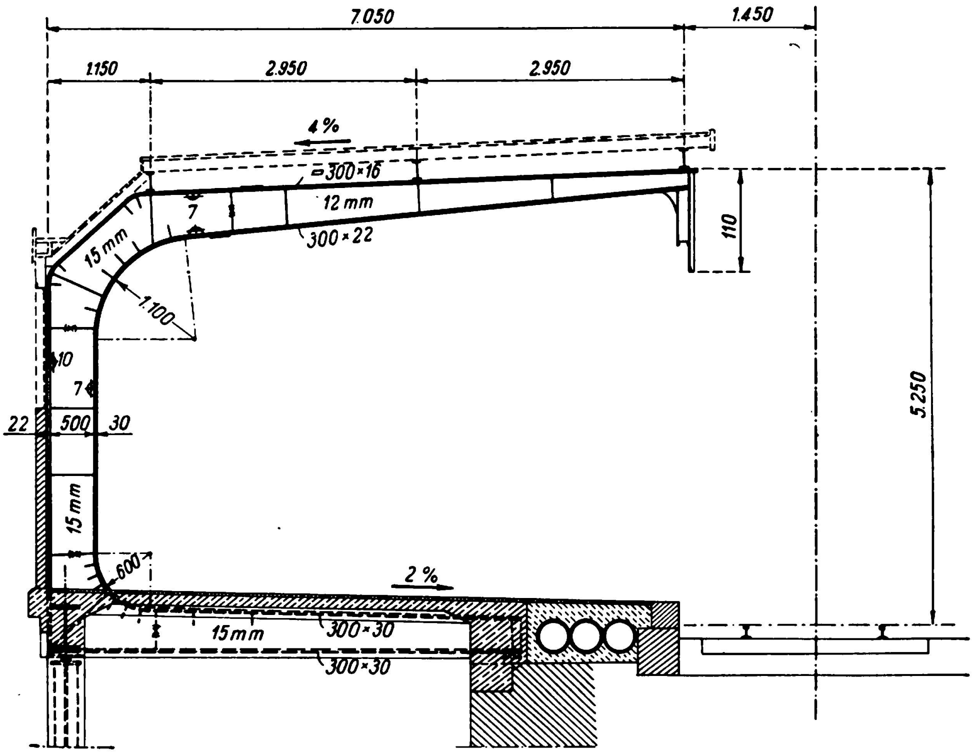


Fig. 3.

Platform roofs, Geneva-Cornavain, Swiss Federal Rlys.

Measurements were continually being made on structures with a view to elucidating the influence of heating effects, and of the associated shrinkage stresses. In parallel with these, and in preparation for the new Federal Regulations for the application of welding, certain experiments were proceeding at the Federal Institute for Testing of Materials in Zürich, having reference to the conditions of stability and permissible stresses in welded connections (See Schweizerisches Archiv für angewandte Wissenschaften und Technik: *Prof. Dr. Roš* and *A. Eichinger*). Also, studies of the constructional form of welded connections were being made by a commission on the application of welding to structural steelwork, deriving from the Swiss Institution of Civil Engineers and Architects and from the technical commission of the Swiss Association of Bridge and Structural Firms. When the lowness of the permissible stresses in the neighbourhood of the fatigue limit of the material became recognised, and when this knowledge came to be associated with that derived from practical measurements of additional internal shrinkage stresses, the application of welding slowed down — for the implied requirements as to structural form made the cost so much greater that riveted construction again came inte favour.

Among certain of the Swiss authorities who regulate building matters, exaggerated views are held regarding the importance and effects of shrinkage stresses and their influence on the safety of structures. It is a fact that rolled beams sometimes receive even greater thermal stresses than welded beams, without harmful results. Experience shows that high internal stresses gradually relieve themselves in the course of time. In welded structures, given proper design and execution, thermal stresses may be neglected. The possibility which exists of discovering faults by means of X-ray examination, and of modifying the working procedure accordingly, often leads to exaggerated conclusions. The mere fact of the results of such examination not showing entire freedom from faults does not necessarily reflect on the mechanical properties of the welded connection.

In the meantime, the new Federal Regulations on the calculation, execution and maintenance of structures in steel, concrete and reinforced concrete appeared, after lengthy preparation, early in 1935, and under these regulations the use of welding is permitted in all forms of structure. In view of the continued development of welding practice the regulations are limited to fundamental matters such as the quality of the weld metal and welded connections; permissible stresses in butt and fillet welds; guiding principles for the execution of welded structures; the testing of welded connections, personnel and plant. Methods of calculation and constructional arrangement are left to the technical competence of the engineer making the design. In this way the standards constitute a control without any hampering effect, and further development is left in the hands of specialist engineers co-operating closely with the works authorities, the welders and the research institute.

Recognition of the fact that the fatigue strength of a welded connection is governed by the degree of variation in the stress, and that in making such a connection it is necessary to avoid any additions of stress due to thermal effects, has led to the enunciation of the following requirements where welding is applied to construction:

The qualities of the weld metal should approximate as closely as possible to those of the parent metal. Thin electrodes, on account of their uniformly better quality, are to be preferred to thick ones. The roots for fillet welds should always be welded with thin electrodes. Butt welds are to be re-welded on the root side after the root of the seam has been chiselled and cleaned. When welds are formed in several layers, no slag inclusions, pores or hollow spaces must occur, for defects of this kind influence the fatigue strength of the welded joint as though they were internal notches. In order to maintain the correct size of gap the constructional parts about to be joined should first be tacked, and welding should then be carried out in thin layers, alternating in sequence on each side so as to minimise warping. If thick electrodes are being used it is particularly important to build up the seams in thin layers so as to avoid overheating the welded parts. Since rapid cooling of the outer fusion zone loads to brittleness texture of the cast metal, covered or dipped electrodes are used, producing a deposit of slag which serves to delay the cooling. Differing views are held as to the value of hammering the weld seams during their deposition. In order to minimise oxidation the welding are should be kept as short as possible. It is desirable to avoid excessive speed in welding as this leads to overheating and consequently to an increase in the termal stresses. Weld seams should have the slag removed from their surface and should be cleaned.

In specially important cases it is recommended that the welded connections should be annealed down to the temperature of the lower transformation point. Fig. 4, showing the welded front member of a truck of 60 tons capacity, is an example in which such after-treatment was necessary. It was shown by exhaustive statical and dynamical tests that the measured stresses approximated closely to those calculated in respect of static loading, while as regards dynamic loading

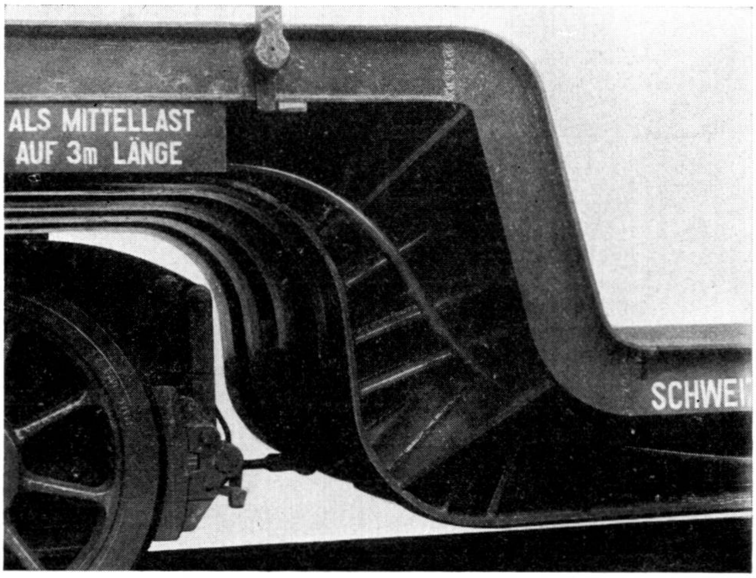


Fig. 4.

Well Wagon 60 t capacity, welded head piece, Swiss Federal Rlys.

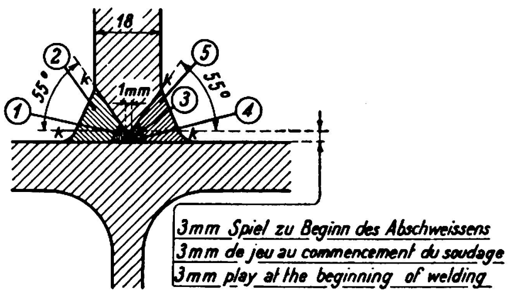
the effective stresses were slightly increased, by an amuont equal to about 1 % of the live load.

In the shaping of weld seams, a slight convexity is usual. Fillet welds are confined to connections of vital importance subject to dynamic loading, as their use entails increased cost. Whether the advantages of an undisturbed flow of stress through the weld formation are in fact realised in the same way as in the parent material of uniform shape is a question which remains outstanding. The beginning and end of a run must merge smoothly into one another. Over-welding is sometimes advocated in the effort to avoid notches, but differing views are held as to the value of this, which need to be cleared up. The grinding of welds in dynamically loaded structures, which is sometimes demanded in addition as a means of securing uniform seams and transitions free from notches, increase the cost. Among constructors the value of this precaution is disputed.

In the case of structures exposed to the weather or other damaging effects, all welds must be executed with special thoroughness.

From the point of view of shrinkage, X-shaped welds are reported on more favourably than U or V-welds. The building authorities often desire K-welds as shown in Fig. 5, but these are difficult and expensive to make under workshop conditions and should be used only where their special advantages are decisive. The difficulty is overcome by the Wulstprofil (plate rolled with a central pointed ridge) commonly used in Germany, but this has found no application in Switzerland on account of its cost and the difficulty of obtaining it. Fillet seams are to be avoided if possible as they lack the advantages of relief of load, like riveted connections. Eccentric connections, even in isolated instances, are to be avoided as dangerous.

It is known that in welded structures any changes of shape that may occur in the individual elements are apt not only to cause difficulties of construction but



K-shaped weld.
1 first pass: electrode No 8 or 10
2 weld completed
3 chiselling root
4 re-welding of root electrode No 8 or 10
5 weld completed
No notches at "K".

Fig. 5.

also to increase the additional thermal stresses, and this has led to systematic study of the question of the sequence in which the welding operations should be carried out, associated with measurements of the shrinkage stresses. At the instance of the Swiss Federal Railways some careful investigations of this matter were carried out by reference to two main girders for a railway bridge on the Seetalbahn. On one of these girders the web was provided with all its stiffeners first and the plates of the lower and upper booms were then added in that order; in the case of the other girder the booms were first welded to the naked web and the outer and inner stiffeners were subsequently added to the latter. In both cases the welding was done in a strictly symmetrical manner working from the centre to the ends of the girder. In making the corner welds connecting the flange plates to the web an attempt was made to compare the relative amounts of deformation as between welding with the parts in direct contact with one another and welding them across a small gap.

The measurements of shrinkage stresses showed that these increased from the centre of the girder towards the ends. The flange plates received a fairly uniform compressive stress in the direction of their length and this reached a maximum at the axis of the web. Within the web plate no uniformity in the flow of stress could be established. No influence attributable to the difference in the welding procedure applied to the two girders could be detected in the shrinkage stresses, and indeed no important difference of any kind appears to result, but the method of stiffening the web plate before attaching the flanges seems to confer greater stiffness on the girder. The intermittent method of welding showed no advantages over continuous welding, and as regards deformation there was no difference between the two. Short, thick tacking beads gave better results than long, thin tacking seams. Temperature measurements taken at the same time that the web was being welded showed maximum values of 170° C at a distance of 60 mm from the seam, but the advance heat in the web was relatively slight, 30—40° C. The welding of the staggered seams attaching the flanges to the web gave rise to somewhat greater deformations but was accompanied by notably less heating.

These experiments do not allow any rigid conclusions to be drawn as to what occurs in the assembly and welding of structures, and pending further research

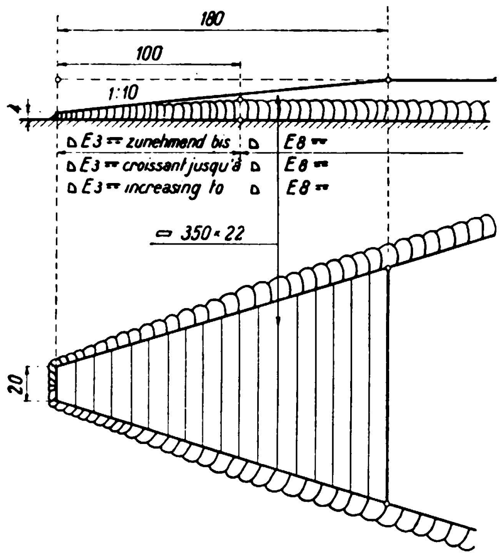


Fig. 6.
Welding ends of flange plates

it must be left mainly to the works to discover what sequence of weld deposition entails the least amount of warping. Site welds, when unavoidable, should be kept very simple in form.

The principles for the formation of welded connections which have been gathered from practical experience in this way, studied together with the experiments of wide scope that have been carried out by German industrial associations and research institutions, have led, in Switzerland, to a development of the details of welded construction similar to that in other countries. Since the superiority of the butt joint, from the point of view of fatigue resistance, has been established, it behoves the designing engineer to cast himself loose from the ideas of riveted construction and seek new forms of bars and intersections such as will allow the general adoption of butt-welded joints.

In cases where rolled sections are to be strengthened by the addition of plates, the ends of the latter are made wedge-shaped and their thickness is planed off after the manner of Fig. 6 so as to avoid sudden changes in stress and consequent reduction in fatigue strength. Where the dimensions of the basic section exceed what is attainable with rolled beams the section is built up from separate web and flange plates: in Switzerland neither Nasenprofile (nosed sections) nor Wulstprofile (bulbed sections) are usual for this purpose. It is a not uncommon practice to utilise the two halves of a broad flange beam with a web plate interposed — particularly since this form of connection facilitates keeping the stress in the transition from web to boom within permissible limits. These "neck seams", though dimensioned only in accordance with the shear, are in fact subjected to stresses arising from the bending moments in the girder. There is need for elucidation of the conditions of stress present in these seams, and of the influence so exerted on the strength of the structure.

For the connection of web plates, butt welds supplemented by cover plates have proved preferable to other forms in view of the inferior fatigue resistance

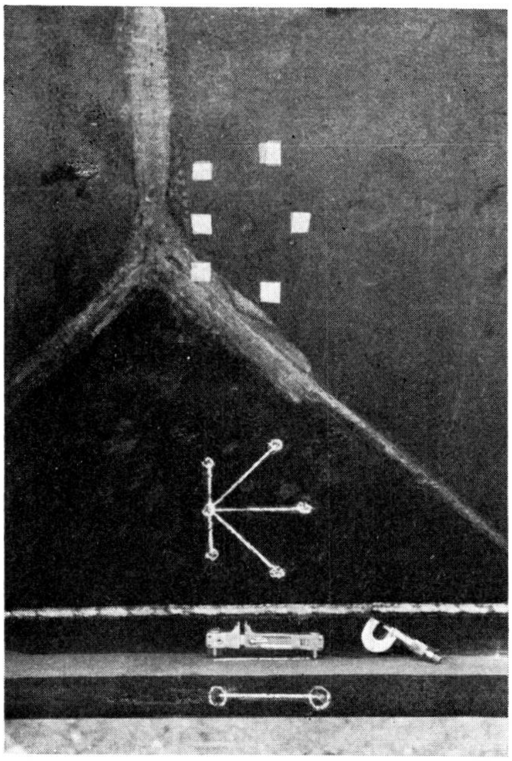


Fig. 7.
Web plate joint, Seetalbahn Swiss Federal Rlys.

offered by fillet welds and of the increased length of butt welding required when internal covers are used. Good results have been obtained with bevelled seams on butt joints as in Fig. 7, which have been used in the main girders of the Seetalbahn railway bridge of the Swiss Federal Railways; also with straight butt seams having small planed cover plates in the tension zone as in Fig. 8, whereby this additional cover serves to compensate for the reduced amount of tensile stress in the seam. The latter arrangement was adopted for the railway bridge in the Zurich-Baden section, in accordance with Fig. 9. The illustration shows this structure, recently constructed with a span of about 26 m at the stage when the new bridge was coupled to the old ready for sliding the former into place and the latter away. Measurements made on joints formed in accordance with Fig. 7 showed that the transverse shrinkage is greatest in the middle section of the directly stressed butt seam, whereas in the triangular seams the shrinkage is smaller. On there grounds the form of point shown in Fig. 10 is recommended.

The simple rectilinear butt weld as adopted in the Rügendamm bridge,[4] so machined as to ensure a gradual transition free from notches, has hitherto not

[4] Bautechnik, 1935.

been applied in Switzerland. As regards stiffening of the web plate the practice is to avoid having welds on the stiffeners immediately opposite one another in the same cross section. Where the stiffener meets the flanges it is cut off to clear the "neck seams" of the latter. Opinion is divided as to whether it is a

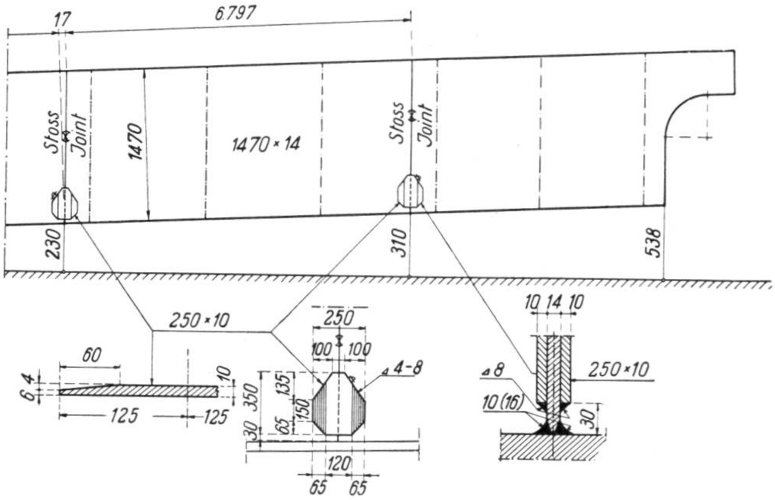


Fig. 8.

Web plate joint of railway bridge Zurich—Baden line Swiss Federal Rlys.

good plan not to connect the stiffener with the tensile boom; and the desirability of gusset stiffeners between the main stiffeners is a further question that calls for elucidation.

In building up flange sections, the use of superimposed plates is giving way to that of thick plates, on account of the cost of the longitudinal seams entailed

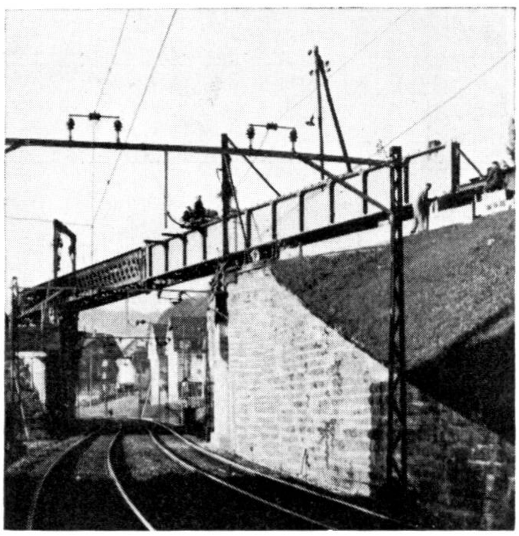


Fig. 9.

Overbridge Zurich—Baden line Swiss Federal Rlys.

by the former. In girders of moderate length the difficulty of forming joints in these thick flanges is avoided by carrying the full cross section over the whole length; this expedient, however, is limited by considerations of transport governing the supply of the material, and also on economic grounds in view of the extra charge made for excess length of the materials. When it is impossible to dispense with joints in the flanges they are formed at points where lower stresses exist in the girder. The type of flange plate joint shown at a in Fig. 11 does not avoid the production of notch effects, even if the reinforcing plates attached by side seams are planed with a view to smooth transition.

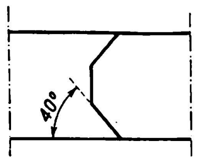


Fig. 10.

Neither have good results been obtained by adopting the solution shown at b, wherein the thick plate is planed down to equal the thin plate and the overlap is connected by fillet welds and a transverse V-weld, further reinforced

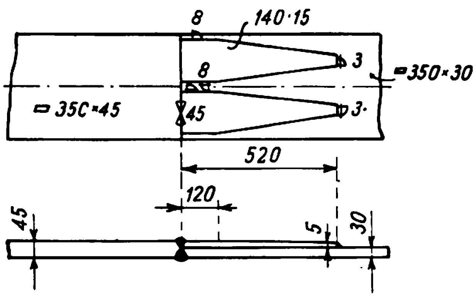


Fig. 11 a.

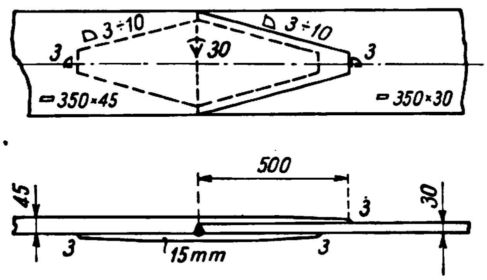


Fig. 11 b.

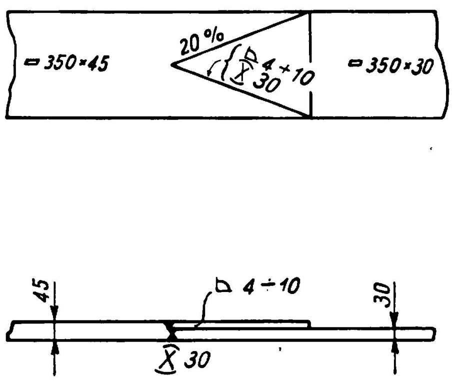


Fig 11 c

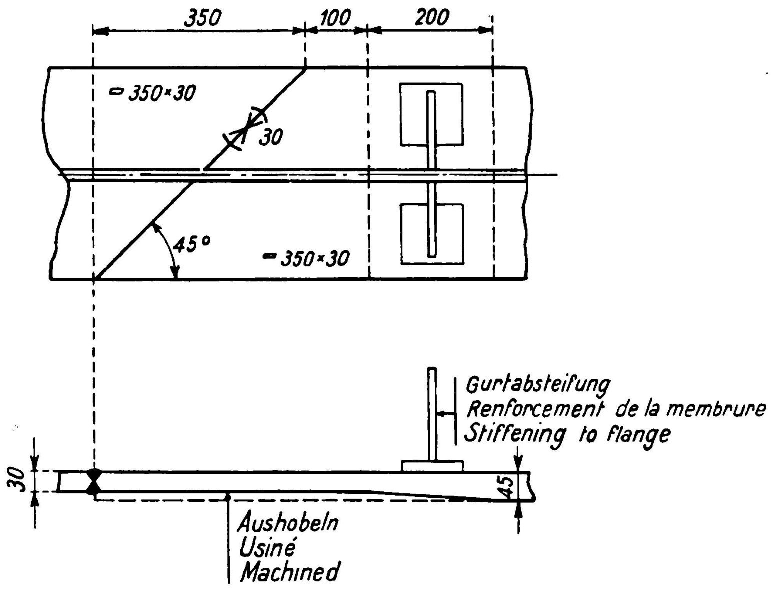


Fig. 11 d.

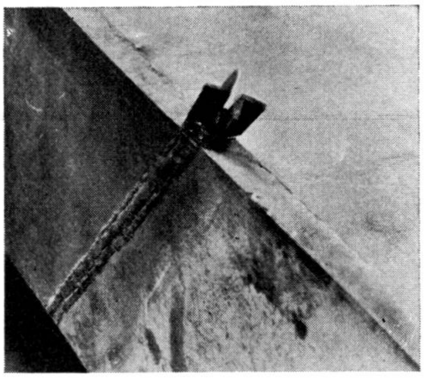
Fig. 11.

Flange joints.

by a cover plate; the objection to this, apart from the expense of fitting, is the considerable unilateral shrinkage of the V-weld which must be expected to occur.

The wedge-shaped form of joint shown at c has been used with succes, but has the disadvantages that it entails a sudden change in direction at the point of the wedge and is expensive to make.

The straight or skew form of joint shown at d and further detailed in Fig. 11 has been extensively adopted in practice; here the thicker plate is planed away to ensure more gradual transition. By contrast with this design, which is suited for dynamically loaded structures, another form in which the thick plate is not planed is considered satisfactory for use in building work. Measurements made on joints of this kind have shown that the working procedure adopted in making the double-V-weld has no great influence over the shrinkage stresses. To avoid any undesirable consequences due to the crater effect in the sides of



Fig, 12.
Oblique flange joint

Fig. 13.
Main signal cabin overbridge, Central Station Zurich.

the ends of the plates, the device shown in Fig. 12 was adopted with success: the ends of the welds were brought out of the cross section on to small angles tacked on, and these were afterwards sawn off.

An application in which the advantage of welding is beyond challenge, both structurally and economically, is that of rigid frame construction. Here welding is unsurpassed as a means of fitting the shape to the flow of stress while requiring a minimum of material and a minimum number of members. Fig. 13 shows a structure of very recent date wherein the advantages of welding for frame construction have been fully developed: this is a signal gantry 75,56 m in length at the main station of the Swiss Federal Railways in Zurich. The interlocking gear is carried on a central section 5,3 m wide and the gangways 2 m wide connect with this on either side. The figure serves to illustrate the good appearance of welded structures both as a whole and in their details.

As already remarked in the introduction, only a beginning has been made in the application of welding to framed structures, and here it is mainly problems of statical loading that have arisen. Some experiments in welded construction have been made in connection with roof structures, for various purposes, over large halls, as for instance in a hall of the passenger aerodrome of Zurich-Dubendorf; here butt welds were applied in conformity with the riveted type of design.

The constructional development of welded frames must be governed, on the one hand, by economic considerations, and on the other hand by the need for attaining an undeflected flow of stress. For lattice members it is desirable to avoid the use of compound sections with their expensive longitudinal seams and to draw upon the highly developed technique of the rolling mill for suitable rolled bars: considerations of warping and shrinkage stresses will weigh in the same direction. In the design of panel points the imitation of riveted forms by merely substituting fillet welds for the rivets must be abandoned. With the new forms of construction utilising butt welds an undeflected flow of stress from one member to another can be secured if the panel point is properly made.

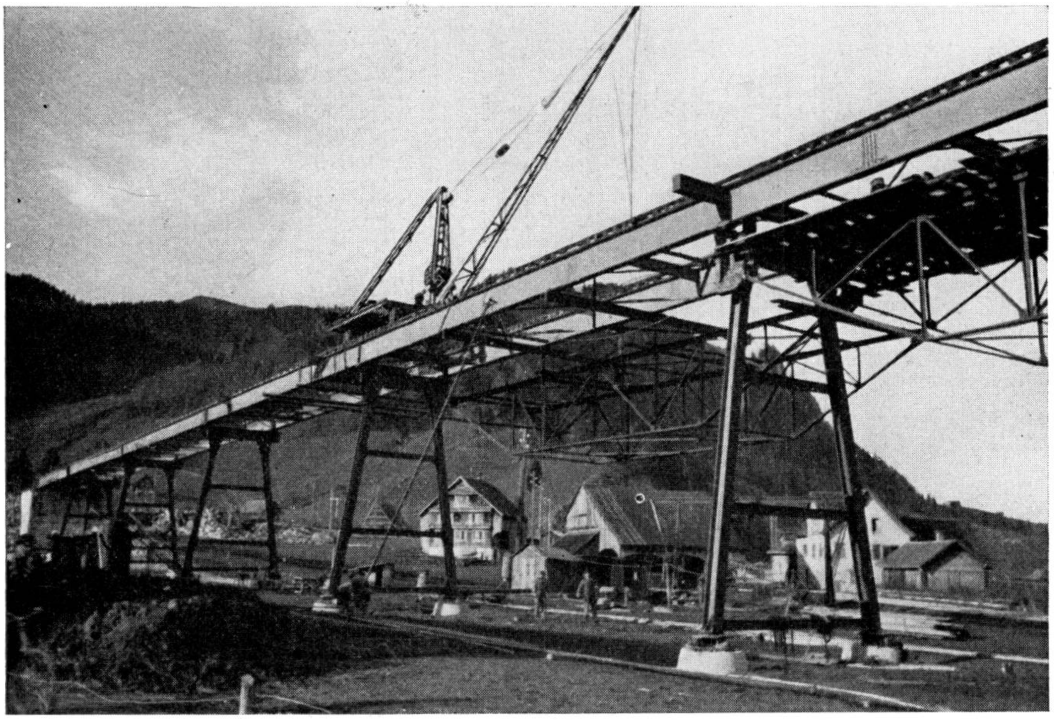


Fig. 14.

Viaduct Steinbach, Etzel Hydro-electric scheme.

Welding has found no scope in the construction of supports for overhead electrical lines, because, in Switzerland, these high-tension lines are being provided either in the foothills or in high mountainous country for reasons of aesthetics, and this makes it essential to be able to take them to pieces for transport. Welding has, however, been applied to a limited extent to the supports of electrical conductors in the electrification of the Swiss railways.

In the field of crane building, a number of loading gantries have been carried out in welded form, but the construction of these determined by the interests of engineering research and not by economic considerations.

In the field of containers, welding has obtained a strong foothold in the construction of bunkers and silos for a great variety of purposes. At the moment a set of silos for malt and coal of approximately 4,500 cu. m capacity is in course of construction in Zurich, consisting entirely of welded circular silos.

The application of welding to the strengthening of existing bridges has been limited to a few cases on the Swiss Federal Railways, on account of the uncertainty which exists regarding the perfection of the collaboration between the existing rivets and the added reinforcement.

In Switzerland, entirely welded new construction has not recently developed as much as in other countries, owing to considerations of the fatigue resistance of welded members. On the other hand the welding of individual parts and the effort to simplify them has become general throughout the constructional steelwork industry. An example of welded work built up from parts is afforded by the viaducts over the storage reservoir of the Etzelwerk A.-G.: Fig. 14 shows two of these, the Steinbacher viaduct 412 m long by 6 m road width and the Willerzeller viaduct 1 115 m long by 4,5 m wide. The superstructures consist of rolled broad flange beams, to portions of which flange plates are welded, and of transoms with welded corners and headpieces. Site connections are riveted.

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