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III c

Inspection and control of welded joints.

Prüfung der Schweißnähte.

Contrôle des soudures.

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IIIc 1

Testing and Control in the Electric Welding of Ordinary Steels.

Prüfungs- und Überwachungsverfahren für die elektrische Schweißung der gewöhnlichen Stähle.

Méthodes d'essais et de contrôle de la soudure électrique des aciers ordinaires.

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Electric arc welding or resistance welding of those types of steel which are normally used in the construction of bridges and building frames is no longer considered a matter of any difficulty, but the economy, facility and aesthetic advantages of these methods are leading to their continued extension, and there arises a proportionately greater need to improve the methods of testing and controlling such work.

As a rule, specifications in regard to electric welding cover only the acceptance of electrodes, the control of the operatives and the examination of the beads deposited or of the spots welded. A conscientious designer, however, is under a grave legal and moral responsibility, which requires that he should be far more severe and exhaustive in his efforts so to control the work as to ensure success.

I. Electric arc welding.

Methods of use.

In Belgium the electric arc welding of mild steels (37—44 and 42—50 kg/mm²) and of semi-hard structural steels (St. 52, MS 60—70, C 58—65, etc.) is scarcely ever carried out otherwise than with protected electrodes of the coated or covered types. For load-bearing connections the use of bare wire electrodes has been given up on account of the brittleness and risk of oxidation of metal so deposited, which is due to the oxides and nitrides included in it (such as particles of SiO_2) or dissolved therein (FeO and nitrides up to 0,12 %).

Alternating current is generally employed in preference to direct current as the variations serve to provoke a violent agitation of the molten metal which eliminates slag and air bubbles. Its use requires that the arc should be kept short so as to ensure stability, and this produces large numbers of small drops of metal due to the concentration of the heat and the effective protection of the metal being melted. Heavy currents are especially sought after, provided the arc can be kept stable, as they allow the speed of welding to be considerably increased, thus reducing the cost and also minimising internal stresses; at the same time better penetration, and the desposition of a sound metal free from inclusions, are ensured.

Choice of electrodes.

The choice of suitable electrodes for any given job is a problem of the first importance, though too often left to the arbitrary decision of the commercial side. This choice depends on the nature of the steel to be welded, the type of connections (whether rigid, semi-elastic or elastic), the position of the stress-resisting element (butt, frontal, lateral, oblique or combined forms of weld), the position in space (horizontal, vertical or overhead seams), the place where the welding work is to be carried out (in the workshop or on the site), and even the atmospheric conditions.

The type of electrode having been decided upon, it is well to adopt the largest diameter compatible with the thickness of the pieces to be welded and the positions of the seams, for, given a suitable current density, the speed of welding increases directly with the efficiency of the materials and labour used and the internal stresses are correspondingly reduced.

Labour.

Good results depend largely on the quality and conscientiousness of the welding operators and of their supervisors. The health of the men should be checked by frequent medical inspections, and all arrangements should be made to ensure that the work is carried on under hygienic and comfortable conditions. At the beginning or end of every week, or at the most every fortnight, each welder should be required to make a sample plate (Fig. 1) which should be subjected to cold bending tests, and also cruciform specimens which must be found capable of fracture without damage to the seams, and the fracture should be examined macrographically (Fig. 2).

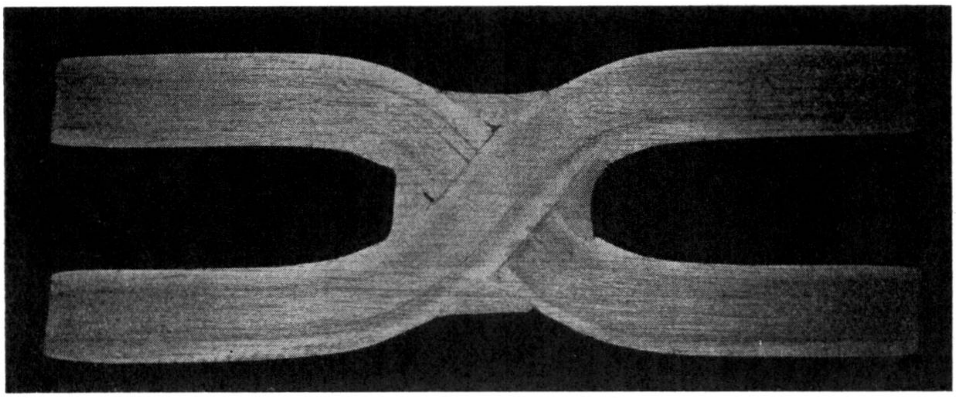
Weld metal.

The weld metal should be investigated as regards its chemical analysis (to afford a check on uniformity of quality), micrographical analysis of its structure (showing the influence of working methods on the size of grain, the penetration and presence of inclusions), macrographical analysis to show its condition of purity (inclusions, porosity, severe mechanical tests to indicate its physical characteristics (elongations at fracture being the criterion of quality, Figs. 3 and 4). See Figs. 5, 6, 7 and 8 which show an example of welding carried out on Ougrée carbon steel (58—65 kg/mm^2) using Arcos Stabilend electrodes.

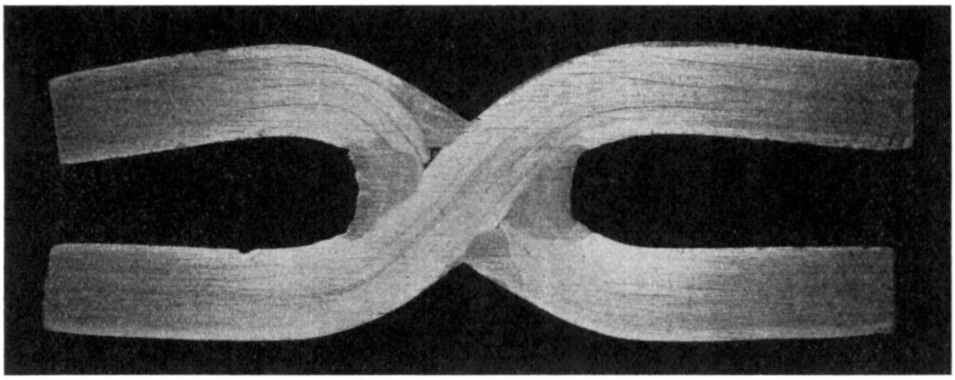
Welded connections.

The designer is concerned not only with the characteristics of the deposited metal, but also with the resistance of the welded joint as such to stress and to the corrosive agents in the atmosphere.

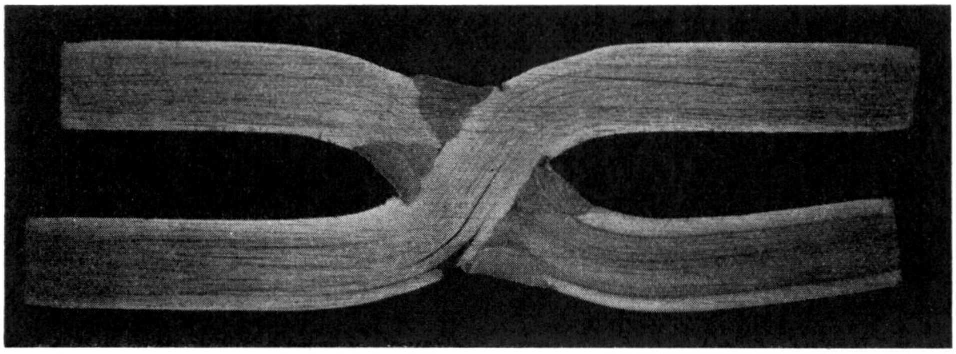
From this point of view specimens taken for the purpose of studying the weldability of a steel offer great advantages because, while approximating to the actual working conditions, they yield accurate results as regards behaviour in tension (including the determination of the elastic limits) and resistance to impact (Mesnager or Charpy resilience specimens).



Welds made with electrodes of 4 mm diameter and 190 amperes current.



Bevelled welds made with electrodes of 6 mm diameter and 250 amperes current.



Bevelled welds made with electrodes of 8 mm diameter and 500 amperes current.

Fig. 1.

Cruciform specimens: the seams must remain intact after crushing.

The next step is to check the strength of the different types of weld beads, adopted by the drawing-office under the conditions of execution which actually obtain, and under the conditions of stress which they will actually receive, and to study the nature of the strains which they will undergo after reaching their elastic

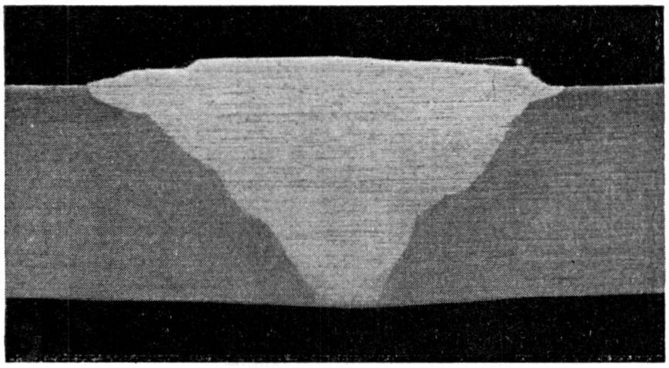


Fig. 2a.
Examination of a welded joint.

Chemical analysis.

Steel of 58—65 kg/mm² ultimate strength.		Metal deposited with „Arcos Stabilend" electrodes.	
C.	0.310	C.	0.080
Mn.	0.836	Mn.	0.430
P.	0.060	P.	0.014
Si.	0.075	Si.	0.015
S.	0.037	S.	0.032

Mechanical tests.

Breaking stress	58 kg/mm²	50 kg/mm²
Elastic limit	38 kg/mm²	36 kg/mm²
Elongation at fracture	24 %	28 %
Resilience	6 kgm/cm²	10.6 kgm/cm²

Average results of 80 tests.

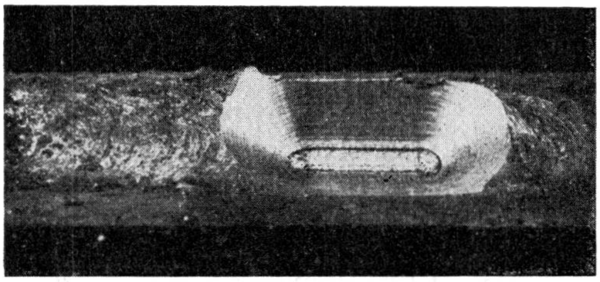


Fig. 2b.
Examinations by boring.

Fig. 2.
Examination of a specimen welded with alternating current using "Arcos Stabilend" electrodes; parent metal is of steel 58—65 kg/mm² ultimate strength.

Acceptance plate for steel of 37—44 kg/mm² (24 tests).

Breaking stress	min.	50 kg/mm²
	max.	56 kg/mm²
	average	54 kg/mm²
Resilience	min.	8.9 kgm/cm²
	max.	12.6 kgm/cm²
	average	11 kgm/cm²

Bending over mandril dia. = 3 · e, good at 180°.

Acceptance plate for steel of 58—65 kg/mm² (24 tests).

Breaking stress	min.	55 kg/mm²
	max.	69 kg/mm²
	average	58.5 kg/mm²
Resilience	min.	5.52 kgm/cm²
	max.	8.27 kgm/cm²
	average	6.7 kgm/cm²

Bending over mandril dia. = 5 · e, good at 180°.

Fig. 3.

Without heat treatment. After normalising treatment.

Weld metal.

Weld joint.

Close to joint.

Raw metal.

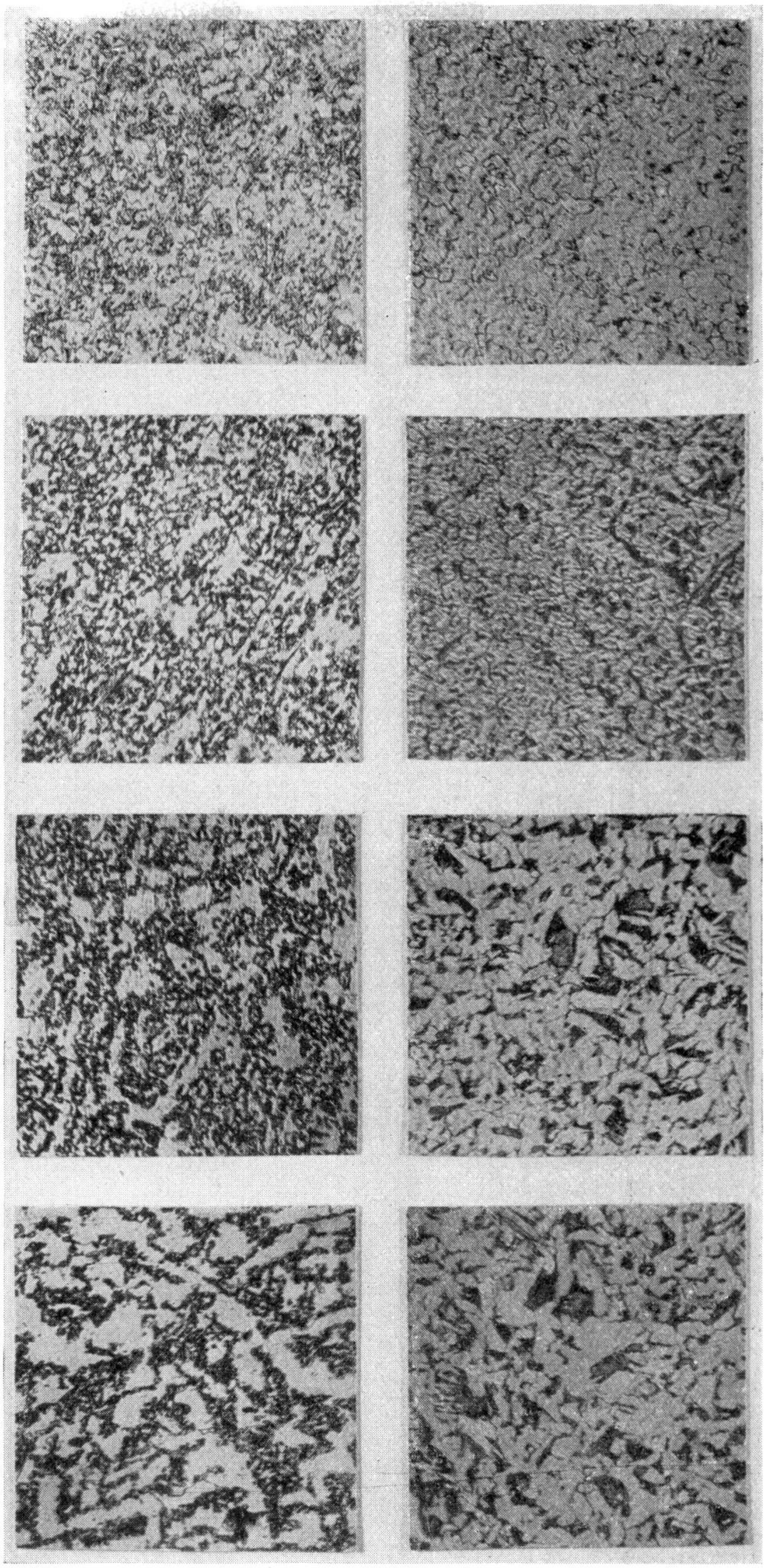


Fig. 4.

Micrographical study of a welded joint.

Carbon steel of 58—65 kg/mm². Electrode: "Arcos Stabilend".

limit. The distribution of the stresses may be studied by the tensometric method, either on a small scale model or on a model of the size adopted by Professor *Campus* for investigating the welded intersections of the frameworks for the Institut de Chimie et de Génie Civil at the University of Liége.

The first check is afforded by visual inspection of the weld beads on the part of a specialised supervisor. The welds are stamped by the welder with an identi-

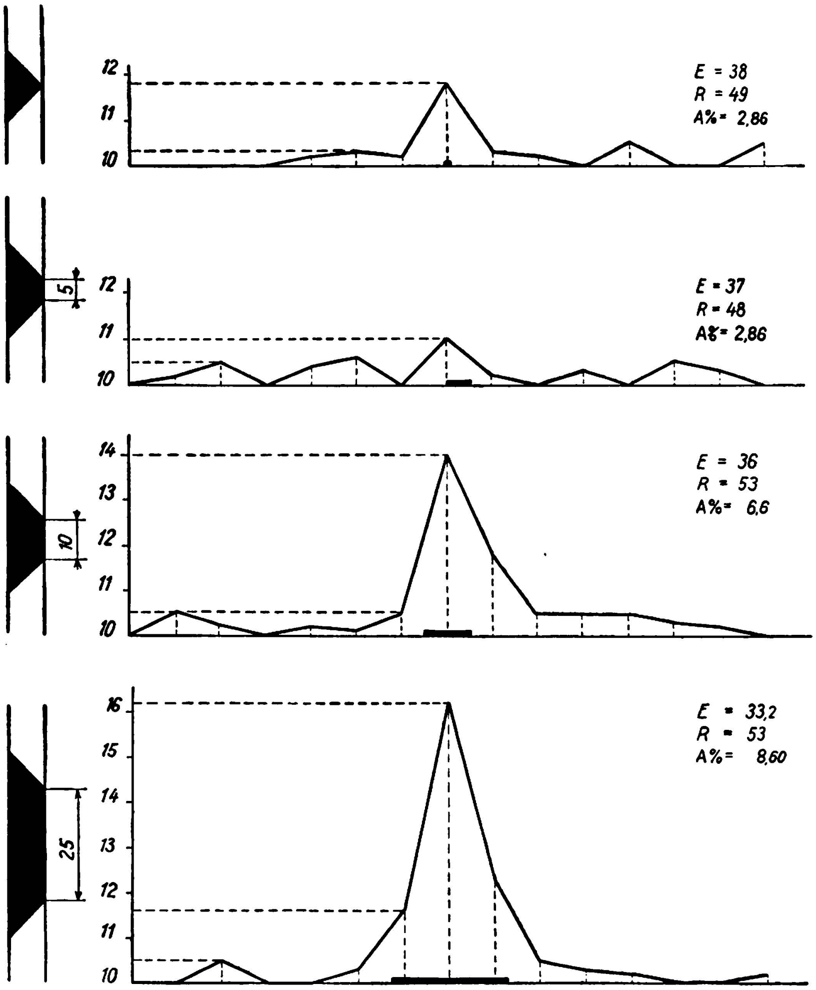


Fig. 5.

Tensile tests on flat specimens of 100 mm² cross section, 140 mm long, with varying amounts of weld, measurements of elongation being made at every 10 mm. Carbon steel 58—65 kg/mm². Arcos-Stabilend electrodes. The distribution of the elongation, and the smallness of its total amount, should be noticed. A control specimen cut from plate gave 20 %.

fying number, which makes him responsible for his work and enables defects to be traced to him, even if they do not appear until a long time afterwards. A record of these marks is kept in a special register with all relevant information.

Borings made into the weld seams with a drill may be made to yield useful information at the beginning of a job for the purpose of checking penetration, etc., but at later stages this destructive method possesses no more than a secondary interest due to its moral effect on the workman who knows that his work is being checked in this way.

The use of the stethoscope is not effective in the applications here considered.

Control by means of the magnetograph can be made to yield very valuable information in special cases, particularly in the advance examination of butt welded specimens. The method consists in using a magnet to produce a magnetic field and in studying the deviations imposed on the lines of force by the presence of the weld or in measuring the variations of this field. Any increase in the magnetic resistance of the weld due to faulty zones (cracks, air bubbles, coagulations), is made apparent in the lines of force of the spectrum.

In examining pieces of small dimensions remarkable results may be obtained with the Giraudi patent "metalloscope". Here the intensity of the field has to be made so great as to bring it to saturation, and a liquid which carries magnetic metallic oxides in suspension is poured over the pieces, becoming attracted to those points where the flux is dispersed in the surrounding air. In this way a pattern is projected on the surface which corresponds to any defects existing below.

The radio-metallographic method of control, which is the only effective one to be made practicable up to the present time, consists of photographing the weld lines with the aid of X-rays. The intensity of the rays must be regulated as a function of the thickness of the pieces and of the dimensions of the defects to be detected. The Phillips "Metallix" macroradiographic apparatus, either fixed or mounted on a motor trailer, gives a penetration of the X-rays amounting to 80 mm through steel. The electronic intensity is regulated by a rheostat, and complete protection is afforded to the operator (Figs. 9, 10, 11 and 12).

II. Spot welding.

Principles of use.

Electric resistance welding by the spot system is at present scarcely applied to bridges and building frames, except in the construction of beams, grillages and secondary members, but its use is continually extending.

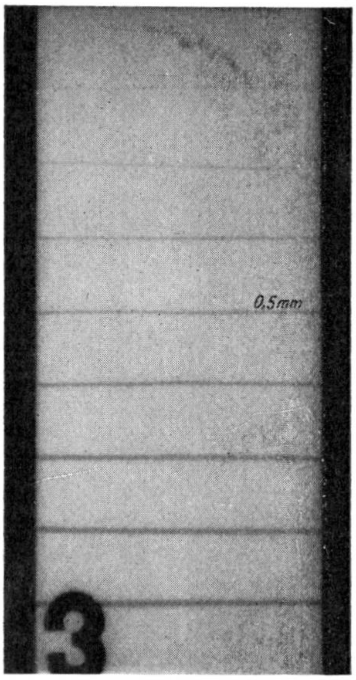
The proper execution of a spot weld depends on three conditions: the temperature of the welded zone, the time taken and the pressure exerted on the pieces to be joined during and after the operation.

It is difficult to measure the temperature of the metal in the neighbourhood of the weld directly. The time of welding has to be extremely small ($^1/_{50}$ of a second for rustless steels "18/8", with a view to the avoidance of certain chemical transformations in the metal) and it has to be varied according to the condition of the pieces. The pressure is kept constant for a given case and is regulated by mechanical, pneumatic, hydraulic or electrical means.

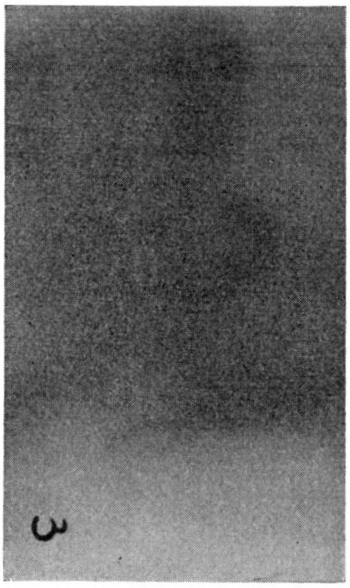
The best results are obtained by using very heavy pressures during the short time that the circuit is closed, and automatically releasing them as soon as the current is interrupted.

Control.

Excellent results are obtained through control of the weld by suitable switches designed to break the current at the proper time. Constant time switches will not always compensate for irregularities when the resistance varies in accordance with the state of oxidation of the pieces and with variations in starting, for their

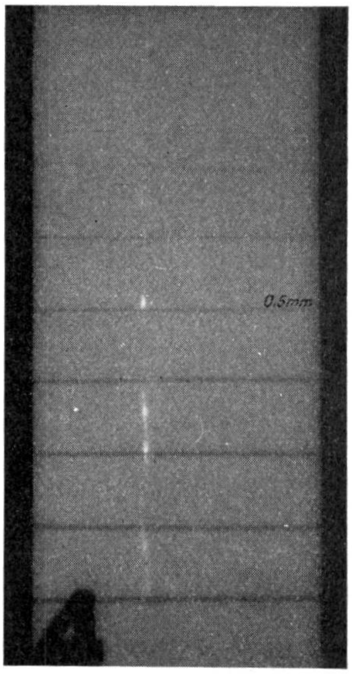


X-ray photograph.
(Exposure: 10 minutes. 70 KV. 4 m A.
Detection of faults down to 0.1 mm).

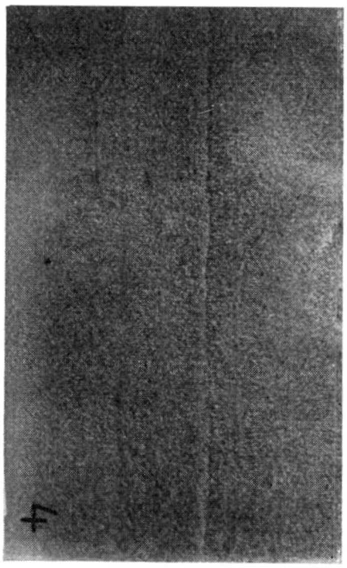


Magnetic spectrum.

Fig. 6.
Welded V-joint. Thickness 10 mm. Electrodes Esab. O.K. 47. Mild steel.
Sound weld.

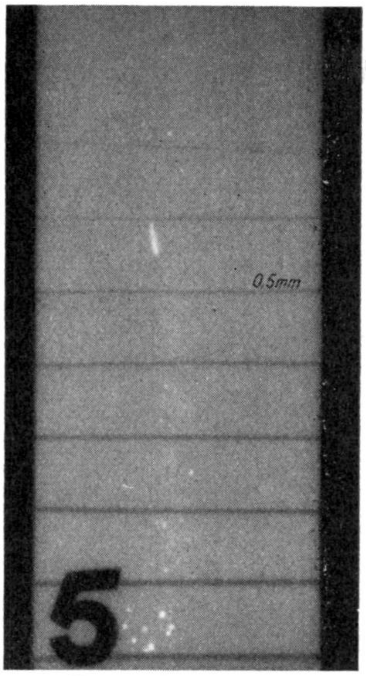


X-ray photograph.
(Exposure: 15 minutes. 70 KV. 4 m A.)

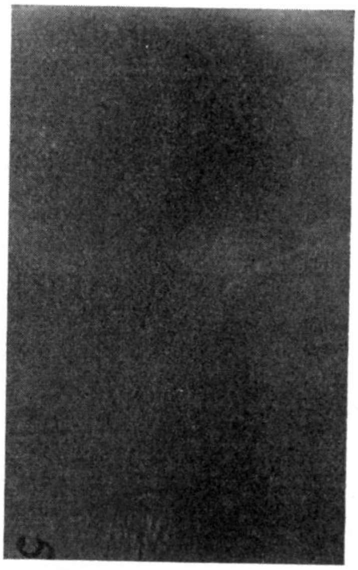


Magnetic spectrum.

Fig. 7.
Welded V-joint. Thickness 10 mm. Electrodes: Esab. O.K. 47.
Carbon steel of 58—65 kg/mm^2 ultimate strength. A longitudinal shrinkage crack will be noticed.
Externally the weld appeared perfect.



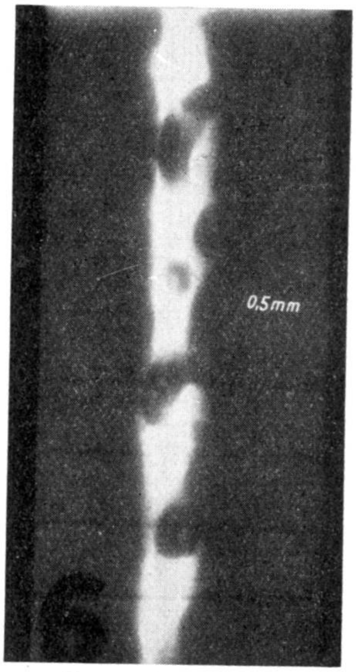
X-ray photograph.
(Exposure: 15 minutes. 70 KV. 4 m A.)



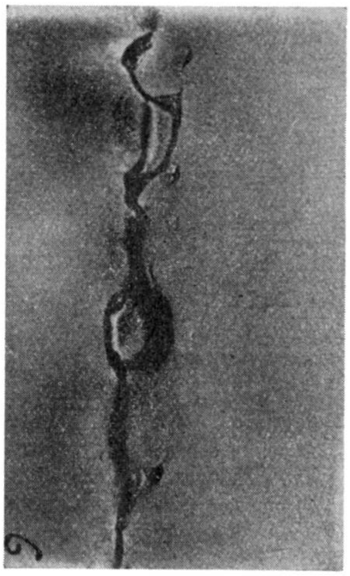
Magnetic spectrum.

Fig. 8.

Welded V-joint. Thickness 10 mm. Electrodes: Arcos-Veloxend.
Pores of the order of 0.1 to 0.2 mm due to excessive strength of current.



X-ray photograph.
(Detection of faults down to > 0.3 mm.
Exposure: 4 seconds. 90 KV. 4 m A.)



Magnetic spectrum.

Fig. 9.

Welded V-joint. Thickness 10 mm. Electrodes: Arcos-Veloxend.
A void will be noticed running the whole length of the seam, with drops of metal enclosed in slag.

efficiency depends on the assumption that the welding temperature will remain constant over two successive operations, and this is not the case unless the induced electromotive force in the secondary remains constant, and unless the sum of the contact resistances between the work and the electrodes is the same at every instant. The latter condition does not hold good unless the plates are absolutely clean, so as to offer both a constant striking resistance and a constant voltage drop.

Constant-minimum-current switches operate by cutting of the current as soon as its intensity passing through the weld reaches a pre-determined value. Their adjustment is delicate and they are at the mercy of the supply voltage.

Ampere-second integrating switches work by cutting of the supply current as soon as a pre-determined total of ampere-second has passed through the machine. It has been found that the ratio between the current passing through the transformer and the energy put into the weld varies constantly, and depends essentially on the surface condition of the pieces, on the pressure, and on the variation of the latter during the welding operation.

Watt-meter switches serve to measure the correct amount of power supplied to the machine, or some function of this power. They are preferably included in the secondary circuit at the electrodes, since in that way they give more precise indications, but they necessitate a current transformer and a complicated form of connection.

A recording alarm controller is available which makes an arc on a ribbon of paper to represent a function of the power supplied in welding each spot, which serves as a criterion of quality. In case of any accident, bad contact, badly connected conductors, faulty regulations, drop in voltage, etc. an alarm bell rings which attracts the attention of the operator, and the welding machine automatically stops until the conditions are put right.

Only clean pieces of work, as far as possible milled or sanded, should be used for welding.

The welded spots.

The welded spots should be examined in the laboratory by micrographical analysis, especially where steels containing copper, nickel or chromium are being

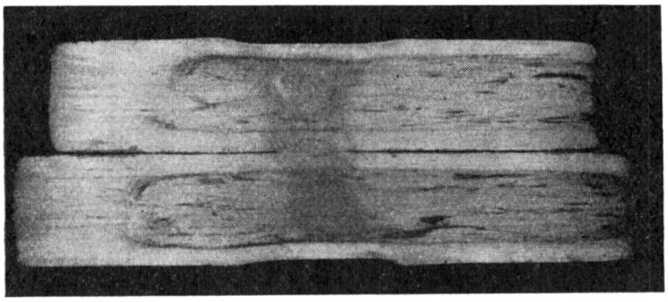


Fig. 10a.
Macro-photograph of a spot weld. Steel 42—50 kg/mm².

used. Any impurities which may be present in the contact zone remain embedded in the molten metal and become concentrated (Fig. 10).

Preliminary punching tests are necessary, and uniformity of results may be assured by using the modern forms of apparatus provided with watt-metric switches.

Raw metal. Metal in welded zone.

Fig. 10 b.

Micro-photographic study of a spot weld. Steel 42—50 kg/mm².

As the time of welding is always relatively short and consequently the cost per spot is small, a large number of spots are used ,so as to be able to work with a low working stress. The indication drawn from practice is that for thicknesses of up to about twice 10 mm the reliability of welding is of the same order as that of the corresponding rivetted work.

IIIc 2

The Testing of Welded Bridges and Structures.

Prüfung der geschweißten Brücken und Hochbauten.

Contrôle des ponts et charpentes soudés.

F. Campus,
Professeur à l'Université de Liége, Directeur du Laboratoire d'Essais du Génie Civil.

In the case of welded structures the necessity for control is not limited to the quality of the welds themselves, but includes closer supervision of the nature and treatment of the steel than is usual in rivetted work. This is a consideration to which, perhaps, not enough attention has been paid, and it is the clue to many difficulties and failures.

Here the author has in mind not only the quality of the steel as defined by the ordinary tests, but the fact that the steel must be subjected to tests of weldability — tests which are metallographic as well as mechanical, and which are designed to ensure the best possible connection between a given parent metal and a given weld metal. Even at this early stage it is necessary that due account should be taken of the special characteristics of the structure to be built.

The special shapes in which members, made from steel described as weldable, are incorporated in a job demand careful consideration. Welded construction has not overlooked the possible advantages of using rolled pieces, such as joists or flats, in unusually large dimensions or thicknesses. Now the metallurgical production of these pieces is a matter of some nicety, and the thermal and mechanical operations which they undergo during their manufacture may confer upon them unknown properties, resulting in an individuality which may be bad, or open to abuse. The subsequent welding of these pieces may influence them unfavourably. Moreover, welded members of this kind are frequently made the object of considerable preparatory work, such as cutting with the blow-pipe into shapes which are often complicated, and these operations may be enough to affect them adversely, even before welding is begun. If the defects are serious they will be detected and the piece will be scrapped, but what is more disturbing is the fact that a small defect may admit of being repaired or hidden. Within the range of the defects liable to arise before or after welding some may exist which are invisible, such as undetected cracks — for how otherwise can one account for the formation of visible cracks not appearing until long after the structure has been tested and put into service? Such cracks may not appear under load, and may show no sign of being the result of fatigue, but may be entirely of the kind here contemplated. As a rule, moreover, such cracks do not appear instantaneously, but only after a varying period of time has elapsed since the treatment which gives rise to them.

In the cases that have come to the author's notice it has been the exception for such a crack to occur in the weld itself. Generally speaking they appear in the parent metal, and though it might be supposed that the control exercised over the quality of the welding would exclude such a possibility, they may make their appearance many months after acceptance of the material.

It will be seen, then, that welded construction necessitates qualities in the pieces to be connected as definite as those characterising the methods used for connecting them. The process of manufacturing the steel, the method of rolling, the dimensions of the pieces, any subsequent heat treatment: all these points are as important to the structure as the quality of the welds. The same is true of the methods of fabrication, such as shearing, cutting, drilling, etc. Many instances of cracking — sometimes long delayed — have been the result of these operations, especially where they have given rise to origins of cracks. Wherever possible, therefore, drilling should be preferred to punching, sawing or hot cutting, to shearing etc. At least the ragged edges left by cutting should be milled or ground away, punched holes should be reamered out, etc.: in fact the metal should be nursed to the utmost extent that is economically possible. Finally, the sizes and shapes of the elements, their shaping and tooling, are all matters closely connected with the character of the structure as a whole; the preconditions of safety and control are determined, in their respective importance, by the design of the job as a whole. The use of welding in bridges and steel frames introduces complexities which amount to a revolution comparable with that brought about in masonry construction by the introduction of reinforced concrete.

Indeed, this analogy with the peculiarities of reinforced concrete holds good from more than one point of view. So far as the question of control is concerned, it serves very well to illustrate the distinction between control over the quality of the welds and control over the welded structure. Here the relatively longer experience of reinforced concrete practice is of value as a guard against illusions and exaggerations: for a long time past control over the quality of cement and concrete has been practised, but control over reinforced concrete structures is a more complicated matter, in reference to which it would be possible to paraphrase nearly everything which has been stated above regarding welded structures. Present practice in the control of reinforced concrete structures may usefully serve as a guide to the development, as well as moderating the requirements, of control over welded structures.

When all is said, control over the quality of the welds remains a primary element in the safety of bridges and frames using this method of connection. The available methods have been pointed out in the first part of this paper, but their practical application to bridges and frames is exposed to various difficulties which arise from the complication of these structures, and indeed amount, in some cases, to impossibilities. It has to be admitted that welding as applied to bridges and frames cannot be made the subject of so perfect a control as is applied to simpler work, such as tanks and pieces of moderate size which are mass-produced, rail joints, certain special mechanical constructions, and the like. This enumeration suggests, moreover, that a control of the kind here envisaged is not actually a necessity in large structures: or, if it is preferred to express the matter in another way, the economics of welding as applied to bridges and frames should be based on the idea that control is not absolute, but is relative and imperfect. Wisdom consists, then, in seeking and obtaining safety notwithstanding such imperfection; and this is perfectly feasible. This attitude is one which necessitates a special study of structural forms and connections; and it may be anticipated that the least reliable element in the structure as a whole will not be the welding, despite all the admitted imperfection of the latter. The remark, already made, as to the greater frequency with which cracks are found in the parent metal than in the weld metal lends weight to this principle and provides its practical justification. The principle may, indeed, be enunciated in a concise form by the dictum that fracture must never occur in the joint.. This is a condition which is perfectly feasible, and which in well-designed structures is in fact realised even under dynamic tests, a result which cannot be obtained by rivetting.

If this conception of the matter is adequate — an assumption which time must decide, and which is at least provisionally acceptable — it will still be useful and necessary to impose the most stringent possible guarantees on the quality of the welding, by adopting a system not very distantly allied to that which is practised in reinforced concrete work, and which indeed, is even now capable of higher accuracy than the latter.

Such methods are in fact already generally applied, differing as between one country and another, or between one job and another, only in details. They consist in a series of precautions laid down in specifications or regulations with the intention of giving guarantees, which shall for practical purposes be effective and adequate. For the sake of discussion the author proposes here to summarise the conditions applied to structures erected under his charge in Belgium in 1932, 1933 and 1934; conditions based on principles contained in a specification published at the beginning of 1932 which was the first official document of the kind in Belgium, from which the regulations, as finally published in Belgium, differ scarcely at all.

The fundamental conditions rest upon the principle governing the safety of joints as stated above, and these are followed by measures of control over the quality of the weld metal. On the hypothesis (which was true of the case under consideration) that special steel is to be used, this control must at the same time serve as an actual test of weldability. The steels employed were of the grade 42/50 (Belgian Government type) and 58/65; and in the latter case metallographical tests of weldability were carried out. The tests for acceptance of electrodes comprised the following:

1) A tensile test on cylindrical specimens of 10 mm diameter consisting entirely of the deposited metal and serving to determine the breaking stress, the apparent elastic limit, the elongation as measured between gauge points 50 mm apart, and the reduction in area.

2) A test for resilience, carried out on a Mesnager specimen of the small type which was cut from the mass of deposited weld metal. Alternatively, tests were carried out on specimens connected by a V weld in which the notch was placed

either at the top or the bottom of the V, or along the bisecting line. The parent metal was steel 42/50 or stêel 58/65. These tests, which were less regular, support a recommendation of that form of specimen in which the notch is cut in an adequate volume of weld metal, at a sufficient distance from the parent metal. The specimens consisting of a simple V weld may be suitable as a tests of weldability, but it is necessary to define carefully the position of the notch, in relation to the very limited volume of the weld metal.

3) A bending test carried out on a steel plate of 42/50 steel 10 mm thick after working, 200 mm long, and 40 to 70 mm (averaged 50 mm) wide, containing a V weld which was required to be bent over a mandril of 30 mm diameter until the two ends were parallel (180°), the weld being exactly on the axis of the bend and the point of the V being in contact with the mandril. (This last test might be omitted or might be used solely for the qualifying of welders.)

The tests used for approving welders (already trained and qualified) included the following:

1) A bending test as described above, and in cases where steel 58/65 was to be used a similar test carried out on a mandril of 75 mm instead of 30 mm diameter. The specimens may be welded either horizontally or vertically according to the nature of the jobs to be carried out.

2) A somewhat special kind of bending test made on a cruciform specimen similar to that laid down in the German regulations. The cross has two branches of 150 mm total length, 100 mm wide and 15 mm thick. One branch consists of two pieces welded to one another by angle welds, either single or K. This cross is subsequently flattened in a press along one of its diagonals, first until the two branches are parallel and are 30 mm apart, and then 15 mm only. The parent metal was steel 42/50. This test is relatively severe, especially in the case of V or K welds. The welds on these crosses were carried out horizontally or vertically according to the conditions.

After qualification the welders were periodically subjected to control tests, which consisted of ordinary bending specimens in according with 1) above. It is desirable, with all bending specimens, especially those used for the qualification of welders, to add a metallographic test or a series of hardness tests with the Brinell or Rockwell hardness measuring instrument, to examine after sawing in two, or to use X-rays. The hardness test is useful as a means of checking the quality of the parent metal and of detecting any possible heat treatment that may have been applied to the specimens, while the sawing or X-ray test serves to reveal the degree of regularity and the detailed quality of the weld.

The welders having thus been checked, an organisation was established for identifying any given weld in the job by reference to a register in which all the welds carried out by the different welders were accurately recorded together with any relevant observations. Control over the intensity of the welding current by reference to ammeters, which is practised from time to time, may be generalised as considered necessary. Though these methods for the acceptance of materials, the qualification of welders and the supervision of the work, afford no absolute guarantee, there can be no doubt that they are far in advance of those practised for the control of reinforced concrete work. Concrete workers have for long not been subjected to any qualifying tests, and even the vibration of concrete is not made subject to personal guarantees comparable to thôse enforced in the welding of bridges and frames.

Many forms of control are possible after the welds have been carried out, the simplest being to check the dimensions of the angle fillets by means of gauges in convenient sets. In the case of V and X welds the actual shaping of the pieces to be joined, which is checked before welding, serves to determine the dimensions of the welds. It is necessary, also, to check whether any relative displacement or deformations of the pieces to be connected has occurred.

There follows an examination of the appearance of the weld, and this may be rather misleading unless the peculiarities of the welder are known. Certain features require special notice, such as the craters, the beginnings of the runs and the cut made into the parent metal. Acoustic testing with a hammer, even using a stethoscope, is not an effective method, except in the case of a serious defect which would be visible to the naked eye.

Non-destructive methods of inspection such as by magnetoscopic and radiographic apparatus, etc., often seem inconvenient and unsuitable for general use on the site or even in the fabricating shop, but this application so far as possible is certainly to be desired. The paper by M. *Berthold* opens up some interesting ideas, but it implies an organisation which would not suit the conditions in all countries, and its general adoption is problematical. Magnetoscopic examination would appear to be fallacious. The method suggested by *Schmuckler*, making use of check borings, is practical enough but of limited scope. It has been applied to the structures mentioned above, but as these consisted of steel 58/65 parent metal with hard welds it was difficult to bore the weld beads and the operations were somewhat slow and costly. Altogether 73 such tests were carried out in 595 tons of steelwork (1 test for 8 tons). Out of 73 tests 5 showed important defects such as holes of notable size at the bottom of the angle fillets, and 9 showed slight defects such as small air bubbles. A few cracks in transverse welds connecting plates to the flanges of beams were noticed in the shops these welds having been made in very cold weather, and also in a few unimportant welds at the ends of the rail-bearing beams.

This control, which was made pretty extensive both in the shops and on the site — not a usual practice in Belgium — showed that notwithstanding the precautions taken to guarantee the quality of materials and the labour, the welds contained a moderate percentage of imperfections. This conclusion justifies the opinion put forward that it is necessary to take account of contingencies of this kind when designing welded structures if adequate safety is to be ensured. As stated at the beginning, the parent metal may have as many defects as weld: a fact disclosed by the *Baumann* results and by macrographical and micrographical examinations and also by such occurrences in welded structures as the doubled [or foliated] plates, internal stresses, local cold working effects, beginning of cracks, over heating, etc.

It is no bad thing that the designer should have impressed upon him the idea that the materials he has to use in his work are not perfect. Such an idea is preferable to fallacious belief in a perfection which cannot be realised, and serves also to moderate the reliance placed on that delicate and ambiguous phenomenon known as adaptation. It requires, for the design and execution of welded work, technicians of high education and high personal and professional qualities. Moreover, the strictness of a control which may be absolute but is necessarily *a posteriori* must be qualified, in the practical construction of bridges and frames, by the admission of a certain tolerance, or reasonable regard for the interests to be served. This is the upshot of M. *Berthold*'s remarks on the subject of X-ray testing. For safe and economical construction — which is the engineer's ideal — the aim should be to exercise control over welding by the use of methods which are adequate, without being excessive. The most useful form of control will undoubtedly be the behaviour of the structures in service, especially in the case of bridges, and this may be checked by periodical inspections of the welds using whatever means are preferred, analogously to the periodical inspection of rivets.

(Five slides which are not reproduced here were shown at the meeting of the Congress.)

IIIc 3

Quality Control in Welding.

Prüfung der Güte der Schweißungen.

Contrôle de la qualité des soudures.

A. Goelzer,

Directeur de la Société Secrom, Paris.

To obtain good results in welded structural work, control over the quality of the welds is essential, for the situation is one in which a relatively new method of forming connections has to defend itself against all possible risk of failure. The specifications and regulations which govern welding lay down certain tests which are designed to control the quality of welds as conveniently as possible. Since the quality of a weld depends firstly on the intrinsic qualities of the weld metal and secondly on the skill of the operator, there arises a need for the following tests, as laid down in the relevant French regulations.

a) *Tests of weld metal.*

These tests are for tensile strength and for resilience. The specimens are taken in the first place from the same metal as is used for the electrodes and are cast in a steel mould. The tensile tests are required to give the following results:

	Parent metal	
	Ac 42	Ac 54
Minimum tensile strength	38 kg/mm²	48 kg/mm²
Minimum elongation at fracture measured between gauge points	15 %	12 %

At the same time the resilience must not be less than 8 kg/cm³.

b) *Tests on welded joints.*

These tests serve to control both the quality of the weld metal and the proper execution of the welded work. They include tensile tests and bendig tests to be carried out on specimens made by butt welding flat plates to one another.

The tensile tests must give a value of not less than 42 kg/mm² if the parent metal is "steel 42" and not less than 54 kg/mm² if the parent metal is "steel 54". The fracture obtained from the weld must show neither air bubbles, dark zones, slag incusions nor scoria.

The bending test is made over two cylindrical supports 100 mm in diameter placed at 150 mm centres, the weld being at an equal distance from either support and the opening of the V being downward. By means of clamps applied on the right of the weld a press is operated and until the two branches of the welded plates form an angle of 60°. There must then appear no flaw or crack on the tension side of either the weld or the parent metal.

These different methods of control may be combined with the examinations for appointment of welding workmen. From a practical point of view the best guarantee is not to employ any workmen without adequate training, and to test their skill by periodical examinations.

Apart from the more or less official point of view described above, various attempts have been made to perfect direct methods of inspection which will serve the purpose of identifying such defects as are liable to arise in the miniature metallurgical operations which appertain to welding. The chief of these methods are the following[1]:

Radiographic examination.

Radiography is applied to welds by means either of radium or of radon. It may be recalled that radium is transformed into radon by the emission of α rays which consist of atoms of helium carrying double positive charges in rapid motion. The radon in turn is transformed into radium B, and thence into radium C, by the emission of β and γ rays respectively. The β rays consist of electrons in very rapid motion. The high velocity α and β rays are physiologically dangerous and cannot be used for purposes of radiography; they can be screened off by the use of copper, silver or platinum bombs which allow the γ rays to pass through. By means of radiography it is possible, for instance, to photograph welds in hollow bodies by placing a suitable capsule inside the piece to be photographed.

Magnetographic examination.

The magnetographic method of examination, due to Professor *Roux* of the Ecole Centrale des Arts et Manufactures, is based on the following principle. If a sheet of metal covered by a sheet of paper is placed over a magnet and iron fillings are scattered over the paper the result is to form a magnetic spectrum, the character of which is well known. If, now, the single sheet of metal is replaced by two sheets properly welded together — that is to say without air bubbles or defects of any kind — the line of welding is revealed by the spectrum, because the magnetic permeability of the weld metal differs from that of the sheet in consequence of the greater thickness of the latter. If the weld has been well made the spectrum of the line of welding is regular and is free from any kind of anomaly, but each of the common faults of welding may be recognised by a characteristic figure; for instance, if there is a lack of penetration, which is a fairly frequent fault, a black line appears, due to the increase in density of the lines of force in the thinner portions. Again, if there

[1] See «La soudure à l'arc électrique et la soudure à l'hydrogène atomique» by Dr. *Maurice Lebrun'* of the University of Paris.

is a complete absence of welding at the middle of the thickness intended to be welded, a more distinct black band appears.

The magnetographic method allows of welds bein examined in their actual positions provided that the piece to be examined is not too massive, but it is not possible, for instance, to examine in this way the hull of a large ship. In order to retain a record of such examinations use may be made of transparent paper covered with an adhesive solution on to which the filings are thrown. The method can be worked in any position, and portable apparatus has been developed for use in checking welded work on the site.

Magneto-acoustic examination.

The complement to the Roux method is the use of listening apparatus, and this nomises to yield results of considerable interest. The device consists in creating a magnetic field in a welded plate by means of an electro-magnet and inserting in this field a small coil to which a periodic motion is imparted. By this means a tension is induced in the coil, which is proportional to the variation in the magnetic field along the weld over which the coil is moved. Such induced tensions give rise to harmonic waves, and the latter are strengthened by an amplifier, similar to those used in wireless apparatus, and detected in a headphone. The disadvantage of the magneto-acoustic method is that the recognition of possible defects in the welds is made to depend on a personal factor.

Direct examination by boring.

This method consists in the use of a special form of milling tool to withdraw from the metal a small cylinder which may be subjected to macrographical examination. The Schmuckler tool has been specially devised for this kind of examination. The advantage of the method is that it gives a direct control which cannot be disputed; its disadvantage is that it can only be performed by drilling in depth.

Mention will now be made of two practical methods that can be applied to electric arc welding.

Control of the electrical characteristics of the arc.

A defect common to the methods explained above is that they afford a check only on *a posteriori*. It is possible, however, to control the welding while it is actually being performed, by reference to the characteristics of the arc and to the strength of current in amperes. (There is nothing to be gained by checking the difference in potential across the terminals of the arc.)

Without going so far as to use a recording ammeter, there are also portable apparatus, which do not involve any interference with the electric circuit but allow the current to be checked at any given moment. These instruments work equally well with direct and alternating currents.

If the current is correct in relation to the diameter of the electrode there is a certainty that all the metal which is deposited will be actually welded. There may still, of course, be discontinuities in the weld, but that is a defect which can easily be detected by an hydraulic test.

To adopt this method is to pass from checking the deposited metal to checking the workman who deposits the metal; a further step is to note the time it takes him to do so.

Control of welding time.

By means of a shunt an electric clock may be introduced into the welding circuit for the purpose of registering exactly how long the welder is at work. The time is measured in hundredths of an hour. The clock stops during the periods that the welder is not at work, and even during the periods that the electrode is short-circuited.

The control tests mentioned above relate only to the breaking strength against statical forces, and to measurements of resilience. For some time past a good deal of attention has also been given to fatigue tests on welded specimens. These tests are designed to throw light on the unfavourable effects from the point of view of resistance to fatigue that may be caused by welding.

The systematic researches of Mons. *Dutilleul*, a marine engineer, have shown that whenever a reduction in the fatigue strength has been detected in welds, by comparison with sound plate, the cause has nearly always been the existence of air bubbles in the welds, that is to say, porosity.

There is some tendency to look upon fatigue resistance as an absolute criterion. It would appear, however, that its chief importance is in relation to pieces which will actually be subject in service to alternating stresses repeated an indefinite number of times, as occurs in aeronautical and mechanical work; on the other hand, so far as contemporary structural engineering is concerned, the value of fatigue tests is open to a great deal of question. It may further be remarked, in this connection, that very often the fatigue strength and the resilience vary in opposite directions.

IIIc 4

Workshop Control of Welding.

Werkstattprüfung der Schweißung.

Le contrôle des soudures à l'atelier.

W. Heigh,

Welding Superintendent, Babcock & Wilcox, LTD., Glasgow.

Fundamentally, if the electrodes used have the essential characteristics, the control of the quality of welding depends on control of welders.

Procedures must be established for all welding conditions, and when those are tested and proved satisfactory the methods of making the weld should thereafter be a drill which the welder learns by heart.

It may be of interest to state that it is found that such a method not only obtains consistent welding but speeds up the actual operation. The reason is fairly apparent. When the welder knows exactly what to do he wastes no time in thinking out how it should be done.

The principal part of every procedure is the first run, whether the weld be a fillet weld or a butt weld. It takes a higher degree of skill to make the first run in any weld in any position (horizontal, vertical or overhead) than is necessary for subsequent runs. The usual faults in first runs are lack of penetration and cracking. Even cracking may be controlled to some extent by the skill of the welder.

It is usually found desirable to concentrate training of the welder on the elimination of slag pockets and lack-of-fusion lines. Procedures are chosen to suit.

The best methods of observing the degree of skill obtained is by taking a Radiograph of a butt weld or etching a number of sections from any kind of weld. Those are shown to the welder.

The value of those methods of showing a welder the faults in his work is much greater than that of all others, because they both give him a comprehensible picture. Sets of figures of mechanical tests are meaningless to the operator, at least at this stage. The only other picture of the inside of a weld which can be offered is obtained by breaking a weld and offering the break to the welder with the necessary explanations. The explanations usually confuse the simple facts and quite frequently the slag pockets are not revealed even to the trained observer. X-ray photographs and etching of sections are the most convincing methods of showing a welder his faults.

Given a close training in standard drills or procedures — by gradual steps from the horizontal to the overhead, and finally by composite drills for welding a butt weld and a fillet weld an a pipe of small diameter in a fixed position —

the mechanical results of welders tests is found to be invariably quite good. The only failures met with in a large concern using 130 welders have been with men who to be finally dispensed with as no suitable for employment as welders.

The principal deficiency in men who are incapable of being welders appears to be that they cannot see the weld they are making, or cannot see it intelligently perhaps a species of colour blindness in some cases and merely lack of intelligence in others.

Mechanical results in vertical and overhead position welds invariably passed the specifications for the class of work in which the electrodes and welders concerned were employed. Also, the only variation in the test results appear to depend entirely on the class of electrode used.

While the methods described are used to train men in making welds in vessels and pipes operating at pressures of upwards of 1000 lbs/sq. in. it is found that the degree of excellence acquired through time enables us to get good quality and fast welding on all kinds of work with the welders who have gone through the whole training.

IIIc 5

The Testing of Welds.

Über die Prüfung von Schweißnähten.

Le contrôle des soudures.

Dr. Ing. habil. A. Matting,
Professor an der Technischen Hochschule Hannover.

The importance of the personal element in welding makes it necessary that careful supervision should be supplemented by testing of the seams, and apart from this the welders themselves must be subjected to tests at regular intervals (see for instance DIN 4100). Such testing must be carried out rapidly and by simple means, and must yield conclusive results.

The bending test is very simple, and is carried out in Germany as indicated in Figs. 1—3. The scientific value of this test is a matter of dispute[1] since it is subject to very wide variations (as in the bending test, the quenching bending test, etc.) which have a considerable effect on the values obtained. In spite of much criticism the test is widely applied, especially in workshops. For high quality welds it has not been found to constitute a sufficient criterion.[2]

The tensile test is principally of importance in laboratory work. Various types of test specimen are adopted, the usual one for butt welds being that shown in Fig. 4. In the round notch bar breakage is forced to take place within the weld seam, and if the protrusion is smoothed down this serves as a test of the material. The prismatic form of bar which allows breakage to take place also in the transition zone or in the material itself, is intended as a test of workmanship. The determination of yield point and elongation is difficult and uncertain.

In structural steelwork great use is made of the cruciform test specimen which serves for testing fillet seams (Fig. 5). The requirements are closely defined in DIN 4100.

The significance of fatigue bending and fatigue tensile tests is being more and more recognised. With proper design, seams free from defects, and a gradual transition between the parent metal and the weld metal,[3] values of 15 kg/cm^2 are being obtained and even exceeded. Properly formed welded connections are as good as or even better than rivetted connections.[4] No standardised dimensions of specimen for fatigue tests have as yet been established.

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[1] *G. Fiek* and *A. Matting:* Autogene Metallbearbeitung 27 (1934), N° 4, p. 61.

[2] *A. Matting* and *H. Otte:* Ibid 29 (1936), N° 19, p. 289.

[3] *A. Matting* and *G. Oldenburg:* Elektroschweißung 7 (1936), N° 6, p. 108.

[4] *O. Kommerell:* Erläuterungen zu den Vorschriften für geschweißte Stahlbauten. II. Vollwandige Eisenbahnbrücken. Wilhelm Ernst & Sohn, Berlin 1936.

Hardness tests serve, in the first place, for the examination of deposition welding. The notched bar impact test (Fig. 6) is carried out in the case of structural steelwork under DIN 1913 only for the purpose of testing electrodes in the case of heavily loaded welded connections. This test is preferred as an acceptance test for the use of welding rods, the value required being between 5 and 7 kgm/cm², and as a rule this is obtained without any difficulty.[5]

For the assessment of welding rods, apart from the mechanical and technological method of testing, the bead test (Fig. 7) is also used, in order to indicate whether such rods can be used also for welding in difficult positions. Welding rods for gas welding and also bare electrodes as a rule give a good bead, but this characteristic may be impaired as the carbon content increases, and it is more difficult to obtain good beads with covered electrodes, especially if the covering is thick, though excellent results have sometimes been obtained. In testing the adhesion of covered electrodes in accordance with DIN 1913 use is now made of vertical fillet seams, one half of the length being deposited upwards and one half downwards. The bead allows conclusions to be drawn as to the performance of the welding rod in overhead welding at the same time.

Specimens composed entirely of weld metal have not hitherto been much used. The determination of deformability in welded specimens is difficult and unreliable. A proposal to carry out measurements of elongation on cruciform specimens[6] is now being investigated. In the stretching test,[7] Fig. 8, a proportional bar with a longitudinal weld seam is used, the proportion of the total cross section occupied by the weld being about 30 %. The specimen is stretched in a tensile testing machine until the capacity of the weld for elongation is used up. The difference in elongation between different kinds of welding rod, the effect exerted by the nature of the material and the effect due to the welding method may in this way be readily estimated. Specimens without a reinforcement as a rule give from 2 to 3 % higher values of elongation. This form of specimen has not yet come into general use.

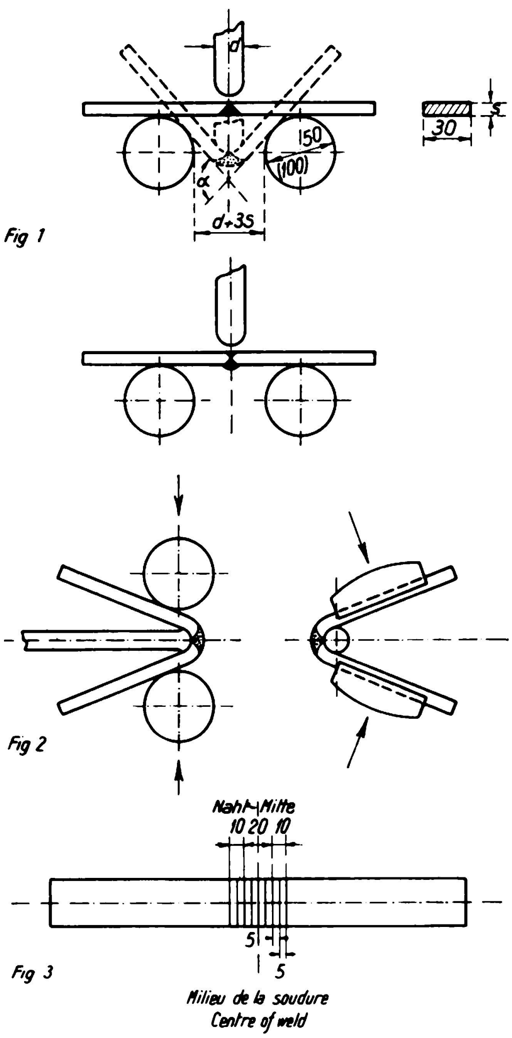
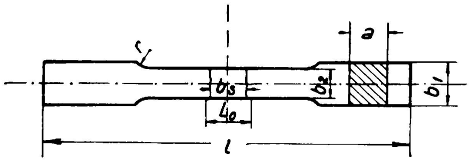


Fig. 1—3.
Arrangement of bending test in accordance with the provisional DIN standard.
DVM A 121.

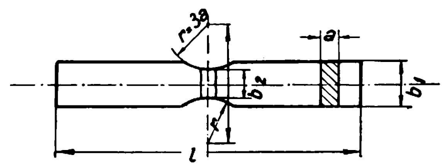
[5] *P. Bardtke* and *Matting:* Autogene Metallbearbeitung 26 (1933), N°18, p. 279 and N°19, p. 290.
[6] *H. Blomberg:* Elektroschweißung 6 (1935), N° 4, p. 61.
[7] *A. Matting:* Elektroschweißung 7 (1936), N° 3, p. 53.

These are the methods of testing which enable both welders and forms of welding connections to be easily supervised, and examples of these are provided by the wedge and angle tests shown in Fig. 9. More accurate indications are not required in these cases. Frequently, also, specimens are cut out from the current work in hand, and are subjected to suitable destructive tests.



Thickness a	10[1] to 25	over 25 to 35	over 35 to 45
Length of bar l	250	300	350
Gauge length Lo	should equal the width of weld $b_s + 5$ to 10 mm		
b_1	30	35	40
b_2	20	25	30
r	15	20	25

[1] For a = 6 mm the DVL test bar is to be used.



Thickness a	6	8	10	12	14	16	18	20
Length of bar l	250	250	250	250	250	250	250	250
b_1	18	24	30	36	42	48	54	60
b_2	12	16	20	24	28	32	36	40
r	18	24	30	36	42	48	54	60

Fig. 4.

Shapes of tensile test bars according to the provisional DIN standard. DVM A 120.

No numerical relationships can, of course, be obtained between the various methods of testing welded connections, except those between strength, elongation and hardness in the case of carbon steels. In the case of welds the conversion figure, that is to say the ratio of the breaking stress to the hardness number, is not 0.36 but is between 0.29 and 0.32.[8] The notched bar tenacity depends only on the structure and cannot be directly related either to the elongation at breakage or to the fatigue strength. There is also no satisfactory relationship between fatigue strength and tensile strength, yield points and elongation. There is, therefore, no way of avoiding the necessity for separate experiments to determine each of the properties it is desired to ascertain.

Examinations of the coarse structure, as illustrated in Fig. 10, are very suitable as a method of testing penetration and porosity, and for detecting slag inclusions. Microphotographs, as in Fig. 11, serve for amplifying such information and for detecting foreign matter. Special attention is now

[8] *A. Matting* and *H. Koch:* Elektroschweißung 5 (1934), N° 7, p. 127.

being paid to the behaviour of welded connections as regards corrosive influences.[9]

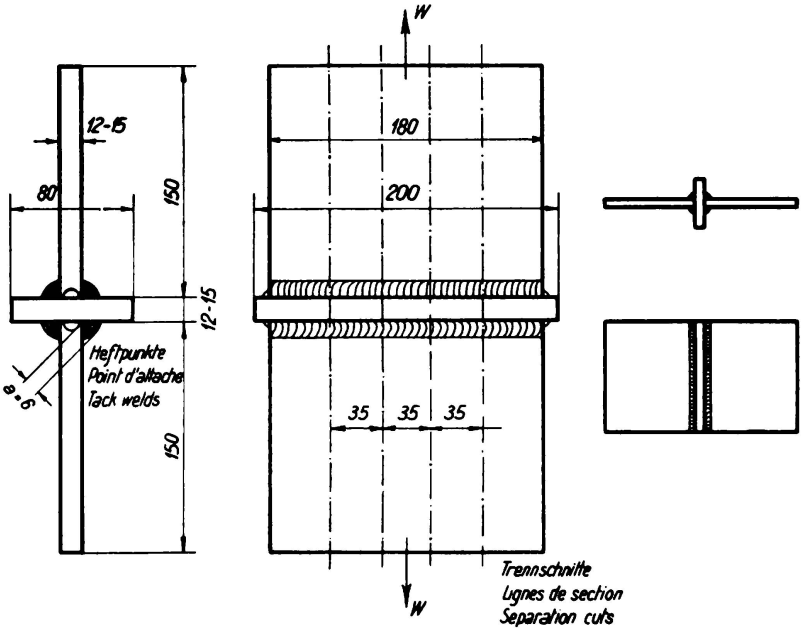


Fig. 5.

Testing of end fillet welds.

In order that, apart from considerations of safety, economic advantage may be realised from additional care taken in testing the welds, great importance

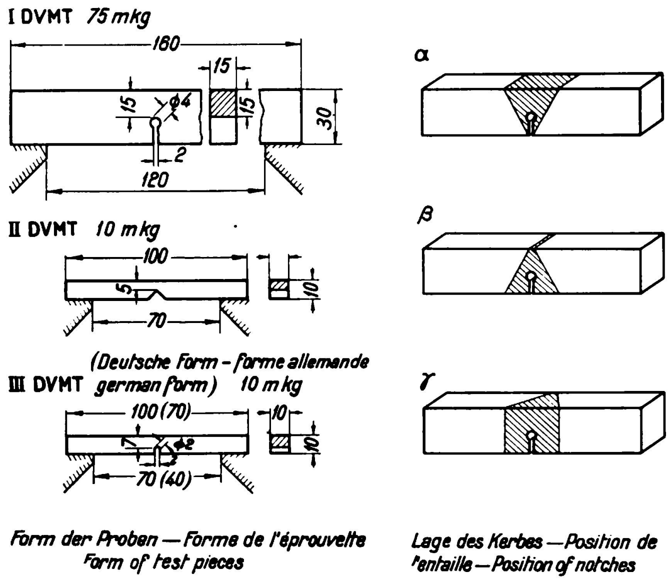


Fig. 6.

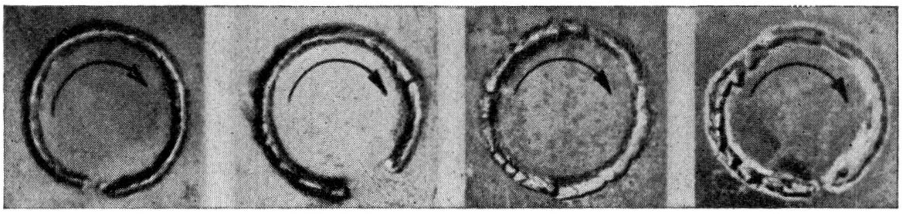
Notched impact bar specimens.

attaches to intelligent application and improvement of the testing methods.[10] The high demands which are now imposed upon weld seams have been rendered

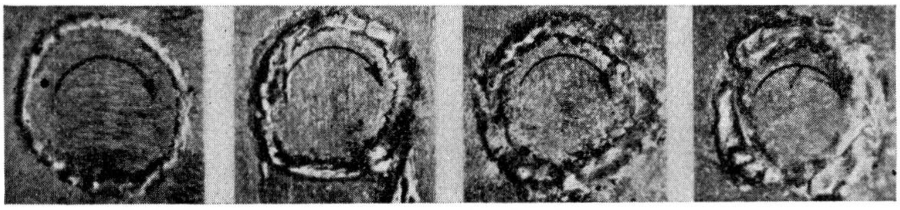
[9] *E. Diepschlag:* Autogene Metallbearbeitung 29 (1936), N° 8, p. 113.

[10] *H. Koch:* Stahlbau 9 (1936), N° 26, p. 206.

acceptable (apart from the improvement in human factor) only by the fact that it is possible to obtain seams of perfect quality.



90°	90°	90°	90°
bare	bare	covered	covered
— 4 mm dia.	— 5 mm dia.	— 4 mm dia.	— 4 mm dia.
			Overhead electrode.



45°	30°	15°	15°
covered	covered	covered	covered
— 4 mm dia.	— 6 mm dia.	— 8 mm dia.	— 12 mm dia.

Fig. 7.

Adhesion tests.

In the testing of finished work non-destructive methods are to be preferred to destructive. The act of weakening the seam by opening it up may indeed have an educational value, but apart from this it should be avoided except as a very rough and ready form of test.[11] The part affected can be rewelded, but in doing

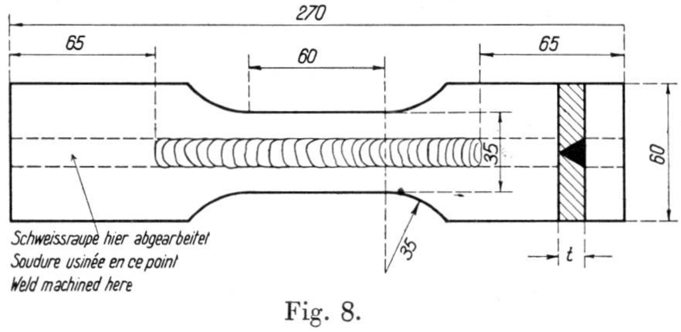


Fig. 8.

Tensile test bar.

this additional thermal stresses may arise, and moreover an unknown factor is introduced in place of the known (Fig. 12).

If the weld seam is not to suffer damage some non-destructive method of testing has to be adopted, and moreover this should be one which allows con-

[11] *R. Bernhard* and *A. Matting:* Stahlbau 5 (1932), N° 15, p. 114.

clusions to be drawn as to the quality of the seam. In the construction of containers, tests by water, air or steam pressure are possible, and in special cases

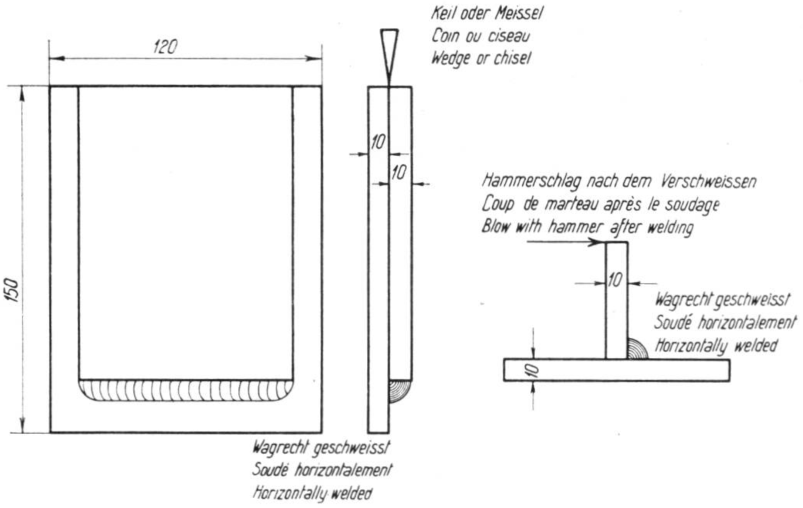


Fig. 9.
Wedgc and angle tests.

tests may be carried out by means of explosion within the containers, though these are of course destructive in their nature.[12] In welded structures the place of these

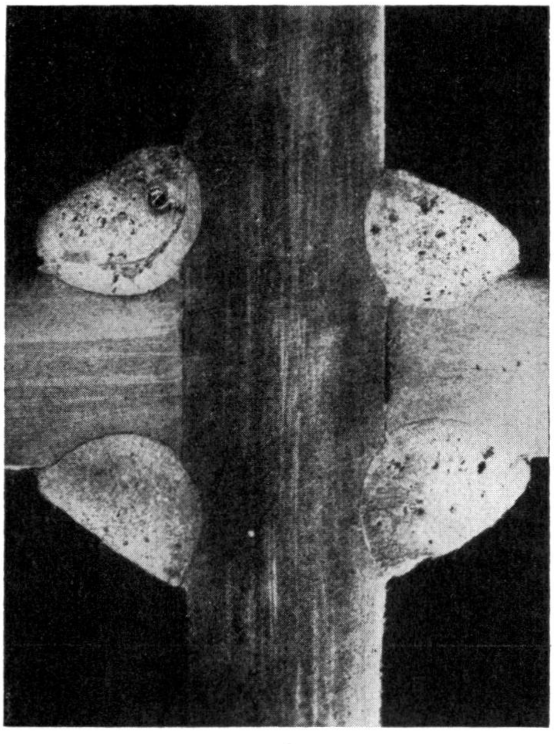


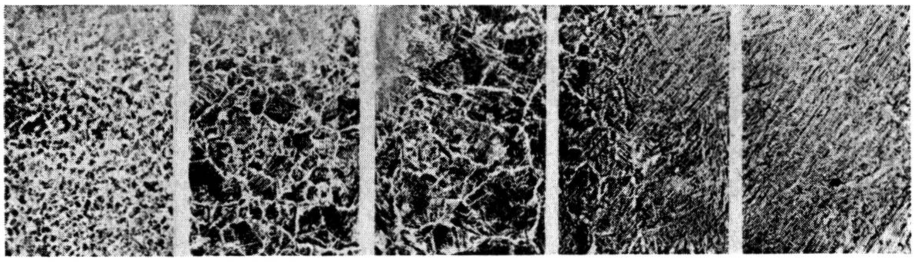
Fig. 10.
Coarse texture of fillet weld made with bare electrodes. Good penetration.

is taken by loading tests, or by fatigue tests combined with measurements of stress.[13]

[12] *E. C. Hutchinson:* Power, 7th Oct. 1930.

[13] *W. Rosteck:* Organ für die Fortschritte des Eisenbahnwesens 1934, Nos. 10 and 11, pp. 187 and 197.

Attempts to examine weld seams accoustically or by reference to electrical fields of stress have been without success, but magnetic methods have been more suc-



Gas fusion weld.

Parent metal Transition Weld

Electric arc weld.

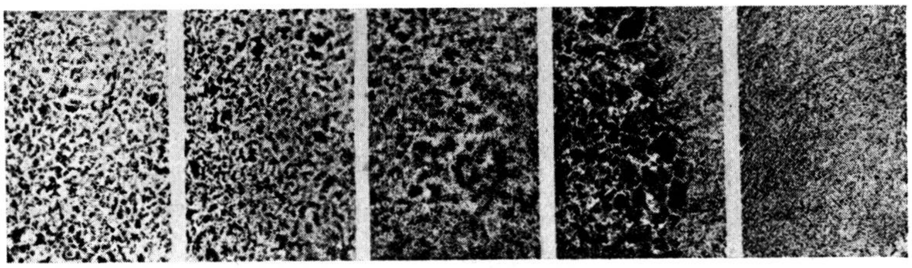
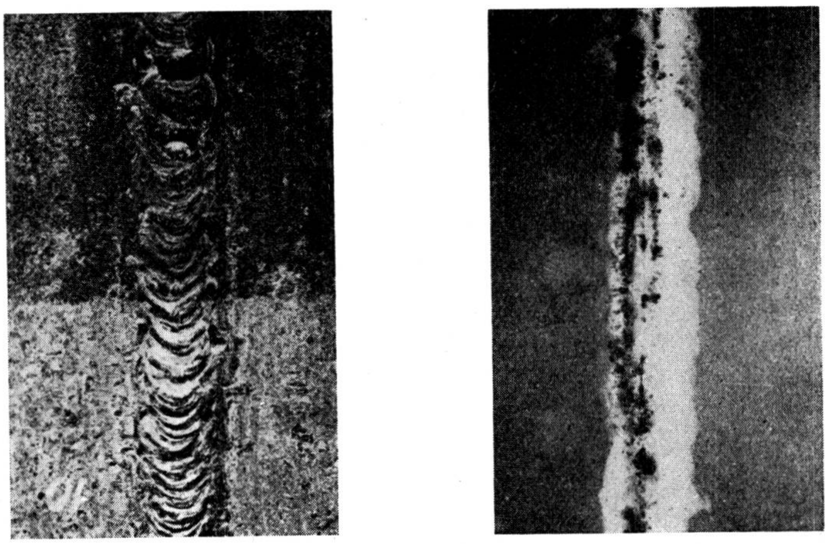


Fig. 11.

Fine texture of gas and arc welds.

cessful. In these the work is magnitised and iron filings are scattered upon it, the uniform arrangement of which would be disturbed if there are any hollow places, slag inclusions or defects of bond.



Elevation X-ray negative.

Fig. 12.

Bad arc weld.

In the author's opinion, however, the electro-magnetic acoustic method of testing welds has not fulfilled expectations.[14] The weld seams are here explored electromagnetically and the impulses of current are rendered audible in headphones. It is not, however possible to locate defects definitely by this means.

Much the best method of testing is by radiation, particularly by means of X-rays.[15] Gamma rays can also be used for testing,[16] but in structural steelwork this method does not come into question. In the examination of the coarse

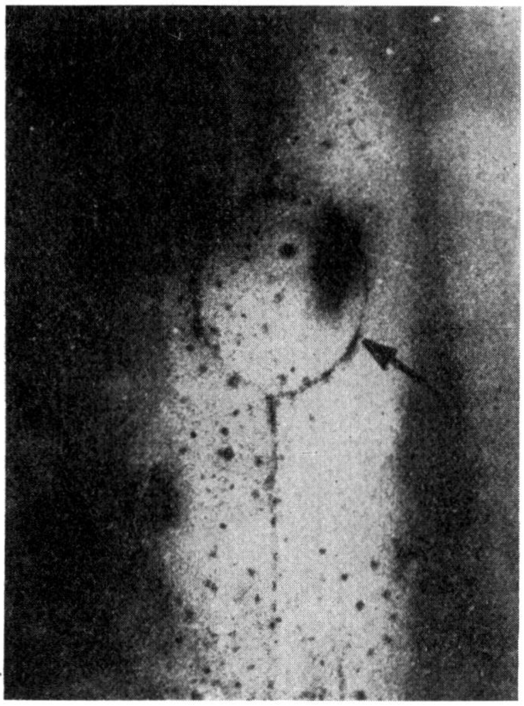


Fig. 13.

X-ray negative showing faulty welding of a hole.

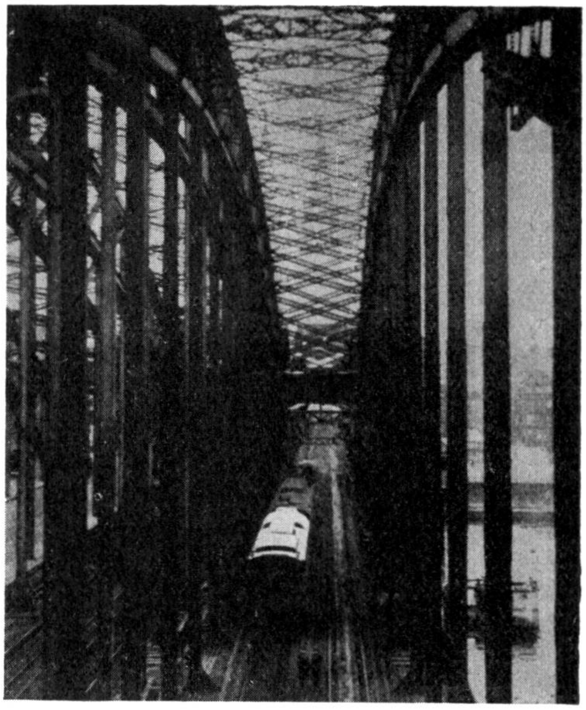


Fig. 14.

X-ray testing car on the Hohenzollern Bridge in Cologne.

structure by X-rays the image may be thrown directly on a screen or may be rendered visible on X-ray films provided the thickness of the work is not excessive (Fig. 13). Apparatus has been so developed that such tests may be carried out on the site and in actual service. Fig. 14 shows a portable X-ray testing set used for particularly difficult investigations. Figs. 15 and 16 show that X-ray tests may also be made on railway bridges. The limitations of X-ray technique lie in difficulties as regards apparatus, lack of sensitivity to faults, and the thickness of the material.

Non-destructive methods of testing may also be combined with destructive methods. It is a matter of dispute how far the results of non-destructive testing

[14] *S. Kießkalt:* Autogene Metallbearbeitung 27 (1934), N° 5, p. 65.

[15] *A. Matting:* Anwendung der Durchstrahlungsverfahren in der Technik. Akademische Verlagsanstalt m. b. H., Leipzig 1935, p. 51.

[16] *R. Berthold:* Z.V.D.I. 78 (1934), N° 6, p. 173.

can be linked up with those of direct testing.[17] By combining different methods of testing it is usually possible to obtain sufficiently conclusive results as to the structure of a weld seam.

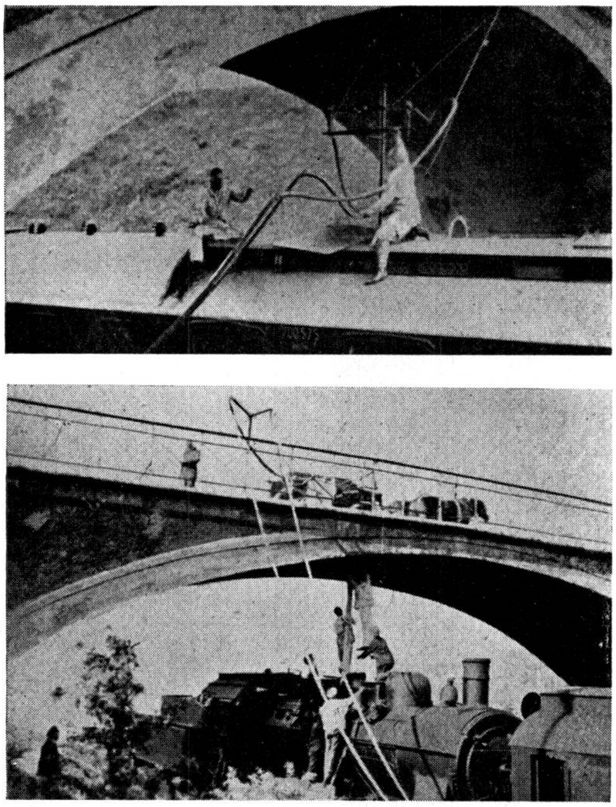


Fig. 15.
X-ray examination of a reinforced concrete bridge.

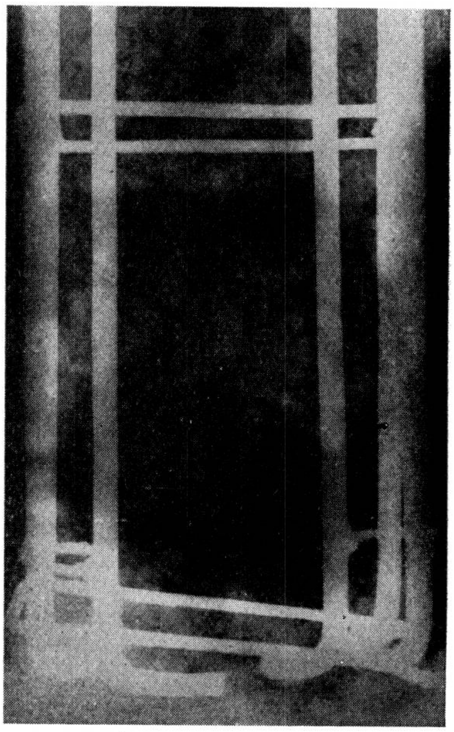


Fig. 16.
X-ray negatives of a reinforced concrete girder.

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[17] *A. Matting* and *C. Stieler:* Stahlbau 6 (1933), N° 24, p. 185.

IIIc 6

Examination of weld-seams.

Prüfung der Schweißnähte.

Essai et contrôle des cordons de soudure.

Dr. Ing. h. c. M. Roš,

Professeur à l'Ecole Polytechnique Fédérale et Président de la Direction du Laboratoire Fédéral d'Essai des Matériaux et Institut de Recherches pour l'Industrie, le Génie Civil et les Arts et Métiers, Zurich.

The examination includes:

1) Weld-rods (Electrodes),
2) Welders,
3) Welding-seams in the finished structure.

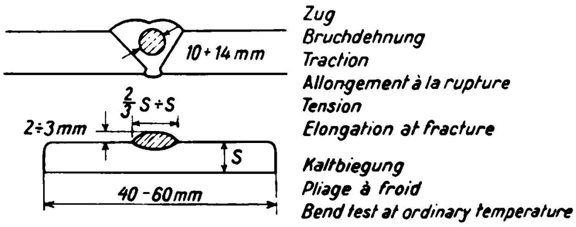


Fig. 1.

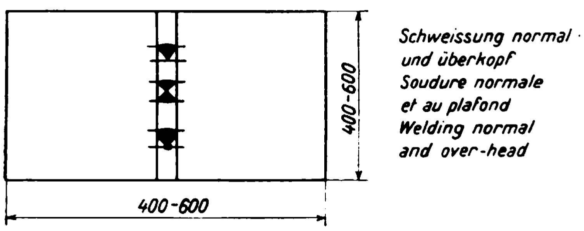


Fig. 2.

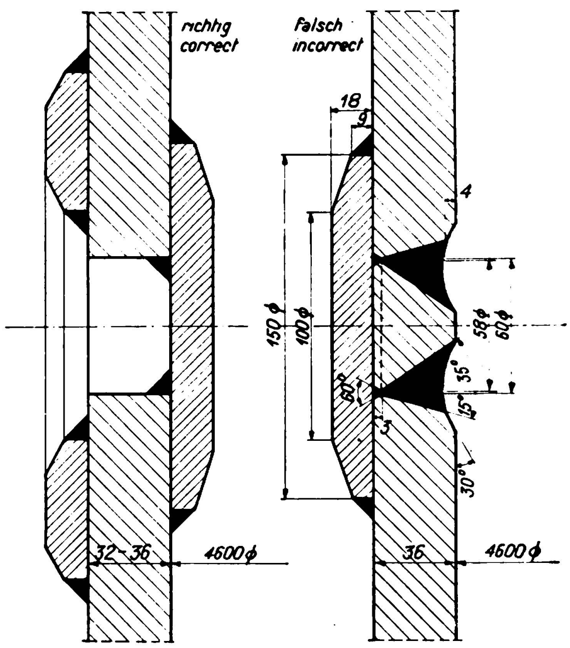


Fig. 3.

Correct and incorrect closure of place whence specimen has been removed, by welding.

1) *Weld-rods (Electrodes).* The melted weld-material is tested as regards strength, deformation-properties and sensibility with respect to quenching.

Test-piece taken from weld: — Weld material —

Required values:

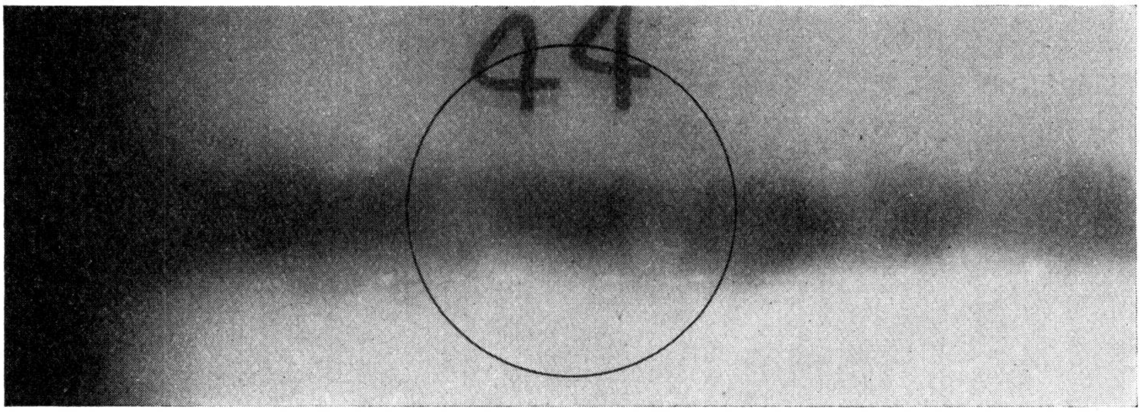
Brinell-hardness H = 115 to 160

Tensile-strength for steel as normally used in construction ($\beta_z = 36 - 44$ kg/mm², $C \leqq 0{,}15$ %): $\beta_z = 40 - 55$ kg/mm²,

elongation after rupture $\lambda_{10} = 15 - 25$ %.

Welding-"cords" laid down in thin layers — Sensibility with respect to quenching —

Flexure numeral: $K = 50 \cdot \frac{s}{r} = 32 - 48$.



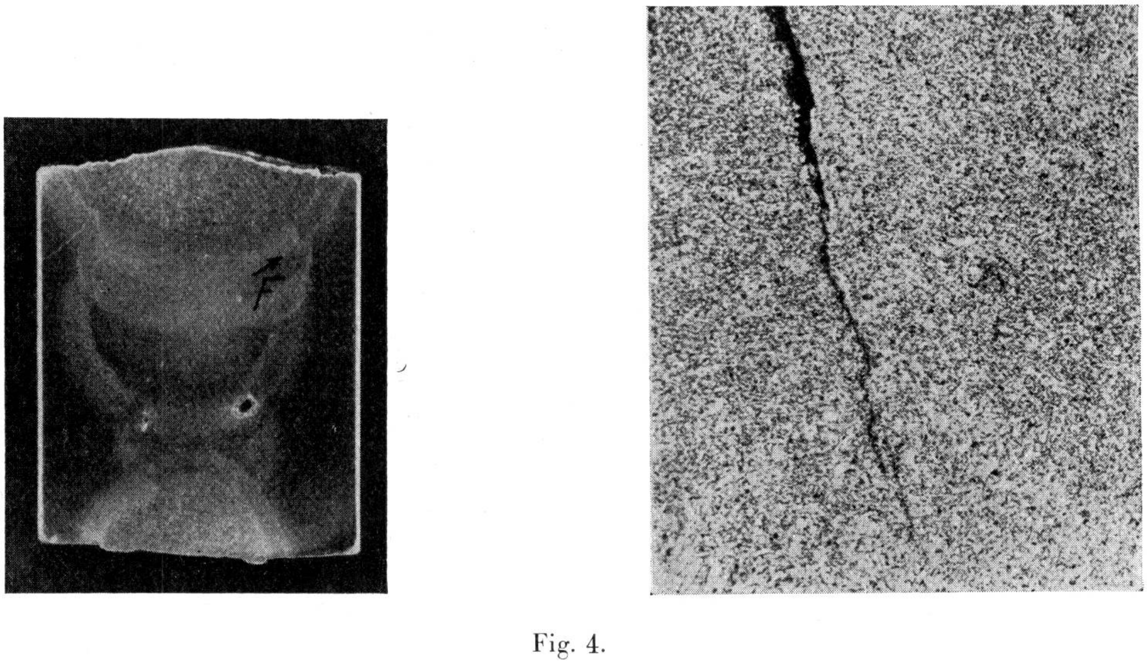


Fig. 4.

Microscopic crack in structure of weld metal, not detectable by x-rays.

Not compelling values:

Yield-point $\delta_s = 25 - 35$ kg/mm²

notch-tenacity of small normalised test-pieces EMPA $x \geqq 4$ mkg/cm².

For high-grade steels separate agreements.

2) *Welder.* — *Workshop.* Plates and bars, of very small and large thickness as used in construction, welded in form of butt- and cruciform joints in normal as well as overhead position were examined by means of X-rays and afterwards subjected to the following tests: coarse-(macro) and fine-(micro)-structure, hardness, tensile-strength, folding-flexure capacity, repeated stress-strength and — by way of exception — to notch — tenacity. The selection of the test-pieces is carried out according to the results of the X-ray examination.

Failures of bond are not admissible. The structure must be free from cracks. For steel as normally used in construction the following is required: Hardness numbers of cross-section $H = 115 - 160$ kg/mm², surface $H \leqq 180$ kg/mm²; tensile-strength — butt-joint — equal to that of the steel, $\beta_z = 36 - 44$ kg/mm², tensile-strength — cruciform — joint average value $\beta_z = 25$ kg/mm², minimum 22,5 kg/mm²; folding-flexure capacity $K = 20 - 28$ (plate thickness $\delta < 12$ mm), $K = 16 - 20$ ($\delta = 12 - 20$ mm) and $K = 12 - 16$ ($\delta > 20$ mm);

Repeated stress-strength — blunt-joint — $\sigma_U \geqq 15$ kg/mm² — normal position —
$\sigma_U \geqq 12$ kg/mm² — overhead —
Repeated stress-strength — cross-joint $\sigma_U \geqq 6$ kg/mm².

For high-grade and special-steels, requirements ad hoc.

3) *Welding-seams.* — *Finished structure.* Discs or bars of suitable shapes (round, oval), are be taken from the finished structure or structural element at suitable points and tested in a similar manner, to comply with the same requirements as regards strength and deformation, as described in the preceeding paragraph under „welders". The characteristic values obtained must be within the same limits; only very slight differences are admissible. The places from which the test-pieces are taken must be made good with particular care to avoid accumulations of weld-metal and to minimise internal and shrinkage stresses (Fig. 3).

X-ray examinations serve to disclose nonconnected spots, pores, slag inclusions and cracks, but they do not reveal the presence of very fine hair cracks which are often undesirable — Fig. 4. Frequently the X-ray examination must be carried out twice, firstly on the weld-seams after completion of the welding, secondly after removal (by shaping, grinding, cutting) of the unevenєss of the top-layers. This applies also to places whence test pieces have been removed.

IIIc 7

Some Examples of Welded Steelwork in Czechoslovakia.

Einige Beispiele von geschweißten Stahlkonstruktionen in der Tschechoslowakei.

Quelques exemples de constructions soudées en Tchécoslovaquie.

A. Brebera,

Ingénieur, Conseiller Supérieur au Ministère des Travaux Publics à Prague.

The applications of electric welding in the special fields of bridge and large building construction show a great deal of progress during the last few years, due to the introduction of this process. Thus in 1935 a number of large hangars covering a total area of 1500 m² were constructed, the most notable part of the construction being the girder of 50 m span over an entrance (Fig. 1) which serves to carry lattice trusses spaced at 10 m centres (Fig. 2).

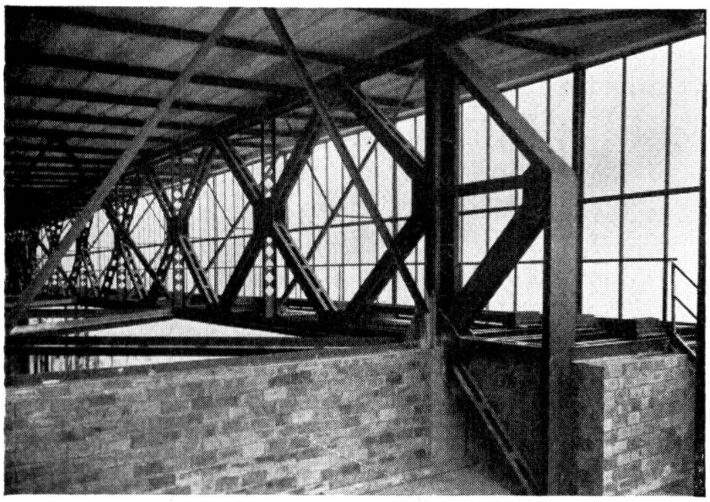


Fig. 1.

With a view to appraising the advantages of arc welding the whole design was worked out both for riveted and welded construction, and a comparison between the two solutions disclosed some interesting facts. At first the welded design for the 50 m span was based on the use of ordinary steel C 38, while the riveted design was made on the assumption that high tensile steel C 52 would be used; yet although in the second case the permissible stresses were taken 50 % higher than in the first, the weight of the girder worked out approximately the same in either.

As regards the actual supporting structure of the hangar for which ordinary steel C 38 was used in both cases, the saving in weight due to the adoption of welding worked out at 20 % (5,210 kg as against 6,500 kg). In view of these results, as well as economic considerations, the construction was, in fact, carried out in the ordinary steel C 38, electrically welded both in the fabricating shop and on the site.

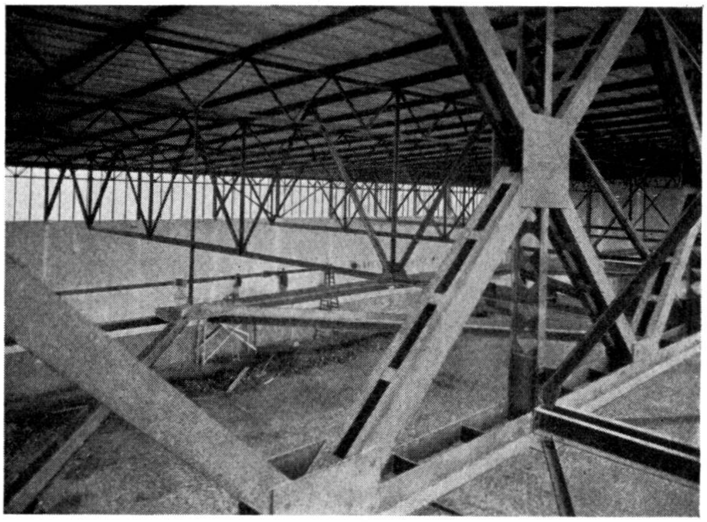


Fig. 2.

Two different types of electrodes were used in welding, giving the essentially different mechanical characteristics indicated by the minimum values specified as in Table I.

Table I.

Types of electrode	I	II
Tensile strength, in kg/mm^2	38	42
Elastic limit, in kg/mm^2	23	26
Elongation, %	12	20
Resilience (Mesnager), in kgm/cm^2	3	6

The use of Type I electrodes was authorised for various parts of the structure having a span of less than 15 m, as well as in side fillet seams of constructional members with a greater span, subject to a lower value for the permissible shear stress in these.

The maximum stresses allowed both in the parent steel and the weld metal are given in Table II in relation to the different stresses imposed.

Table II.

Permissible stresses	Parent metal	Weld metal	
		Type I	Type II
Tension	$\nu = 1200$ (1400) kg/cm^2	0.75 ν	0.85 ν
Compression . .	$\nu = 1200$ (1400) kg/cm^2	0.95 ν	1.00 ν
Shear	$\tau = 850$ (1000) kg/cm^2	0.60 ν	0.65 ν

Note. The values shown bracketed were allowed in cases where all external effects had been taken into account in the calculation, namely the effects of temperature and of wind pressure.

Before welding work was begun the types of weld seam and the welders were subjected to various tests, the specified minimum results of which are given in Tables III and IV.

Table III.

Tests for weld metal	Type of electrode I	Type of electrode II
Tensile strength, in kg/mm²	38	42
Shear strength, in kg/mm²	28	30
Bending angle, in degrees	120	180
Elongation, % . . . , ...	12	18

Table IV.

Tests for welders	Type of electrode I	Type of electrode II
Tensile strength, in kg/mm²	34	40
Shear strength, in kg/mm²	26	29
Bending angle, in degrees	90	120
Elongation, %	10	15

In the final design all the connections were worked out with a view to taking advantage of the latest improvements in welding technique. Considerable use was

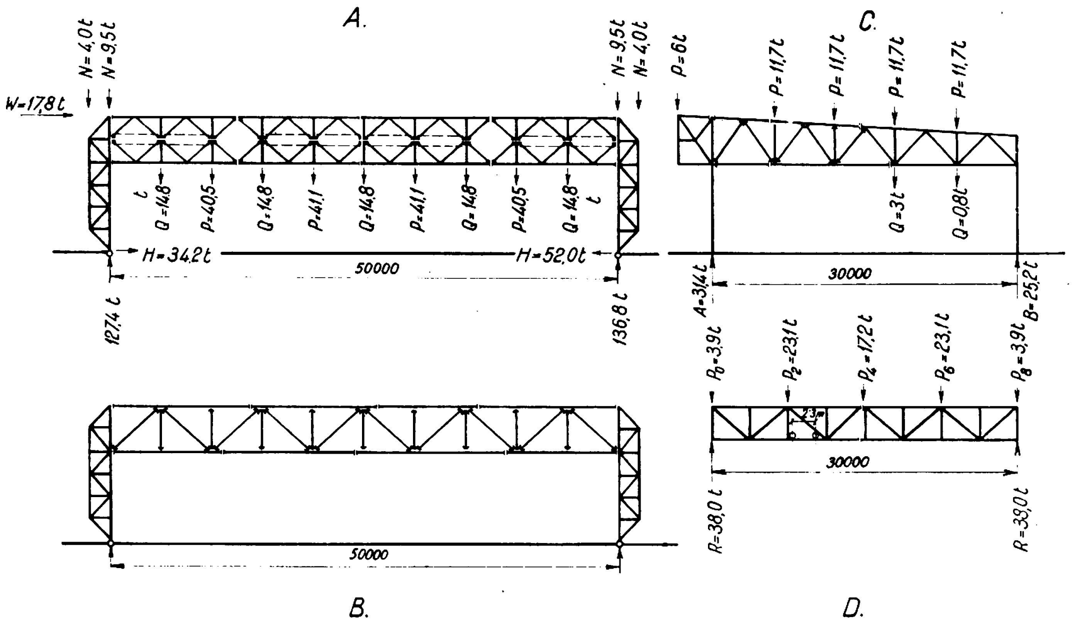


Fig. 3.

made of simple T sections obtained by cutting ordinary rolled joists in halves with the cutting blowpipe.

The boom member over the doorway was formed with a very simple cross section (500 × 500 mm plates and 100 × 180 × 18 mm angles) which was particularly well adapted to the conditions of stress arising therein, the total axial load in the boom being 318 tonnes.

Certain members such as the verticals of the girder over the doorway were formed of sections obtained by cutting ordinary rolled joists along a zig-zag line and then welding together the points of the two parts so separated after moving them opposite one another. In this inexpensive way it is possible to

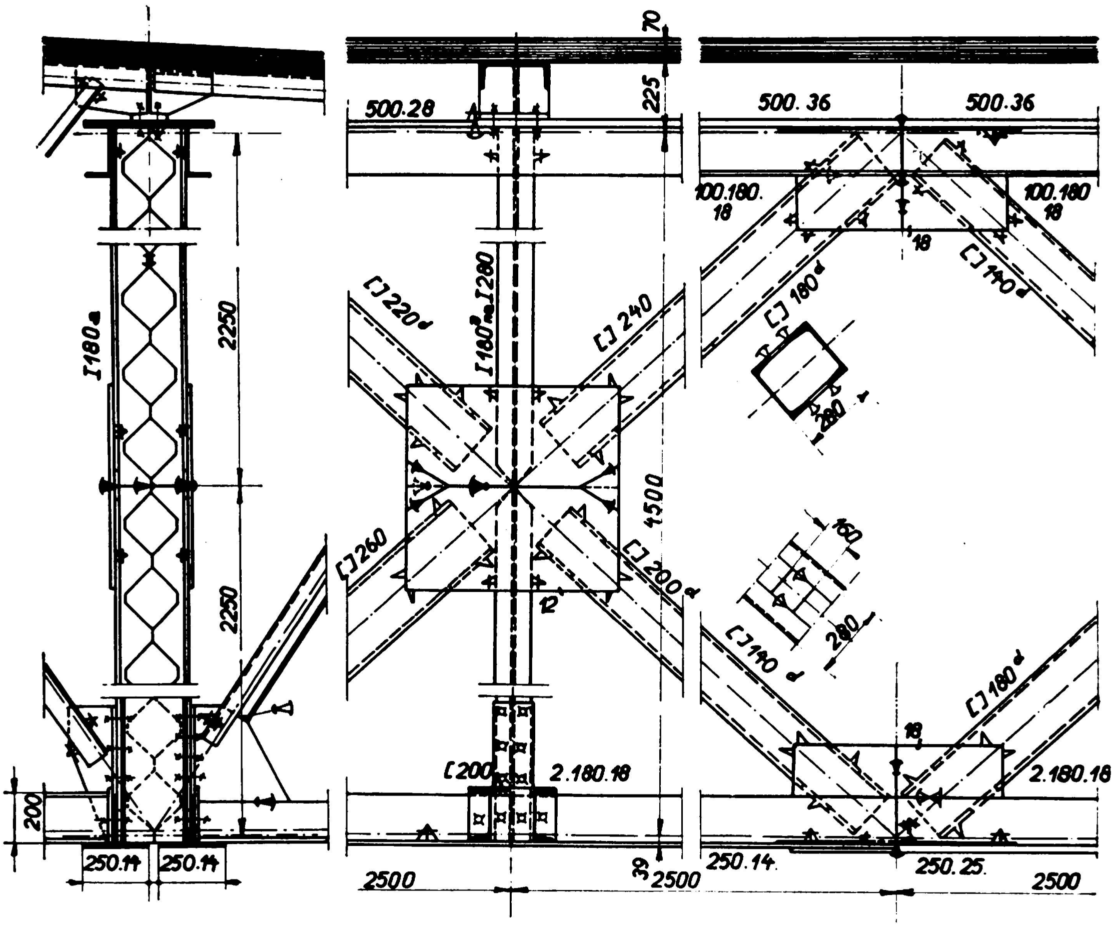


Fig. 4.

obtain an open webbed beam of the same weight as a normal beam but much more rigid.

For the most part, in connecting the various sections together, use was made of butt welds. The arrangement of the erection joints is shown in Fig. 3.

All the girders were assembled and welded on the ground, so far as possible in a horizontal position, before being offered up into their final positions and the last of the joints closed with them vertical. With a view to this procedure the erection welds were so arranged as to be easily accessible while being carried out.

The guiding idea in the design of the doorway was to reduce the number of site joints to a minimum. It was found possible to deliver the end verticals of the frame in single pieces, but the upper boom member (Fig. 4) was too long and too high for this to be done and had to be divided into a number of sections. In order to facilitate the assembly of these the lozenge type of

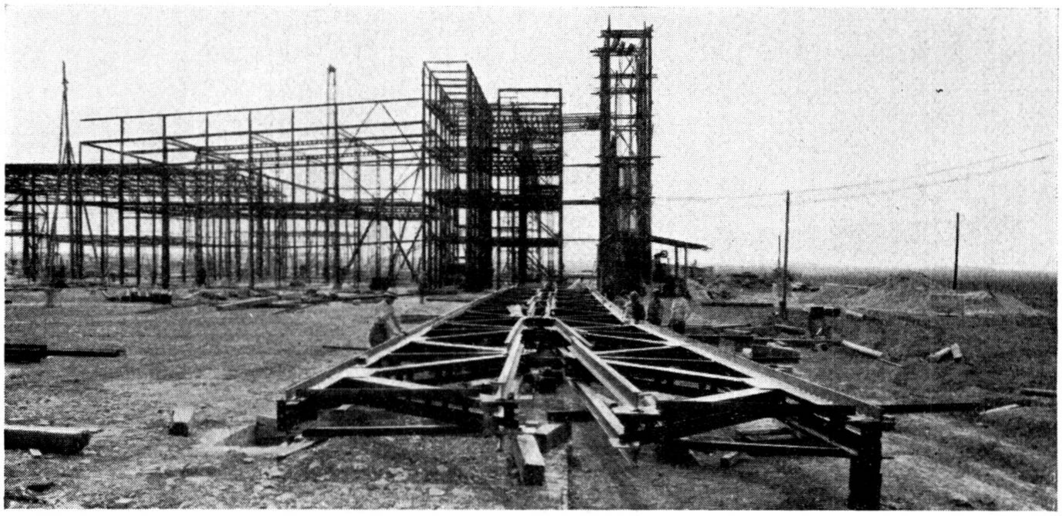


Fig. 5.

girder (Fig. 3) was adopted, thus reducing the number of sections to eight as against the 27 which would have been required with the usual triangular form (Fig. 3B).

With a view to rigidity combined with ease of transport, the various constituent parts were fitted to temporary boom members attached to central gussets, and, in an ingenious way, the roof trusses of the hangar were made to serve as booms (Fig. 5). The erection joists were placed in the boom members and in the central gussets as may be clearly seen in Fig. 3. The intersection of the diagonals is of some interest (Fig. 6). To facilitate the welding of the lower gusset the corresponding upper plate was notched, and its triangular complement was welded to the upper plate after the welding of the lower plate had been completed.

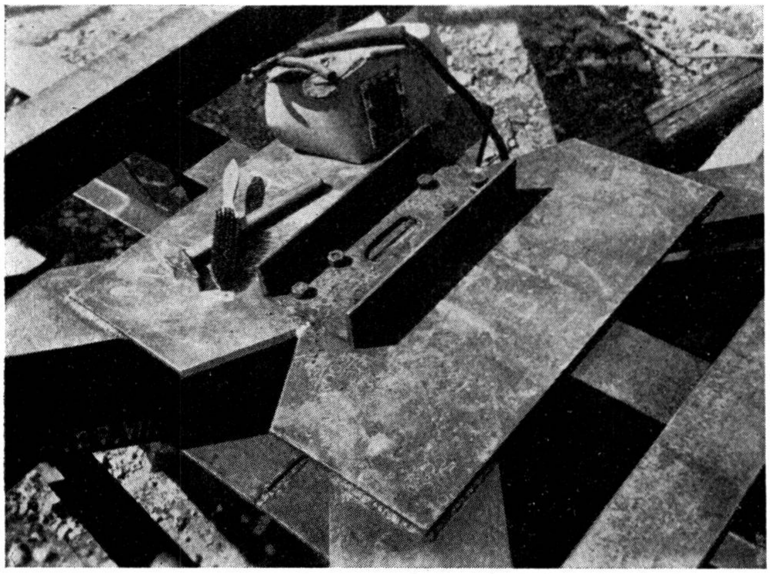


Fig. 6.

First the horizontal portions of the frame were assembled and clamped together with the aid of bolts in their correct positions; then the joints were tacked and completely welded in turn. Finally the auxiliary boom members were removed, and the footings were assembled and welded. The process of erection was begun by fitting the frames over the doorway, the whole frame, covering one span of 50 m and weighing 41.0 tonnes, being placed in position with the aid of erecting towers (Fig. 7), an operation which took four hours. The erection of the framework was then carried out in the usual way. Both in the shop and on the site the welding was done by means of direct current welding sets.

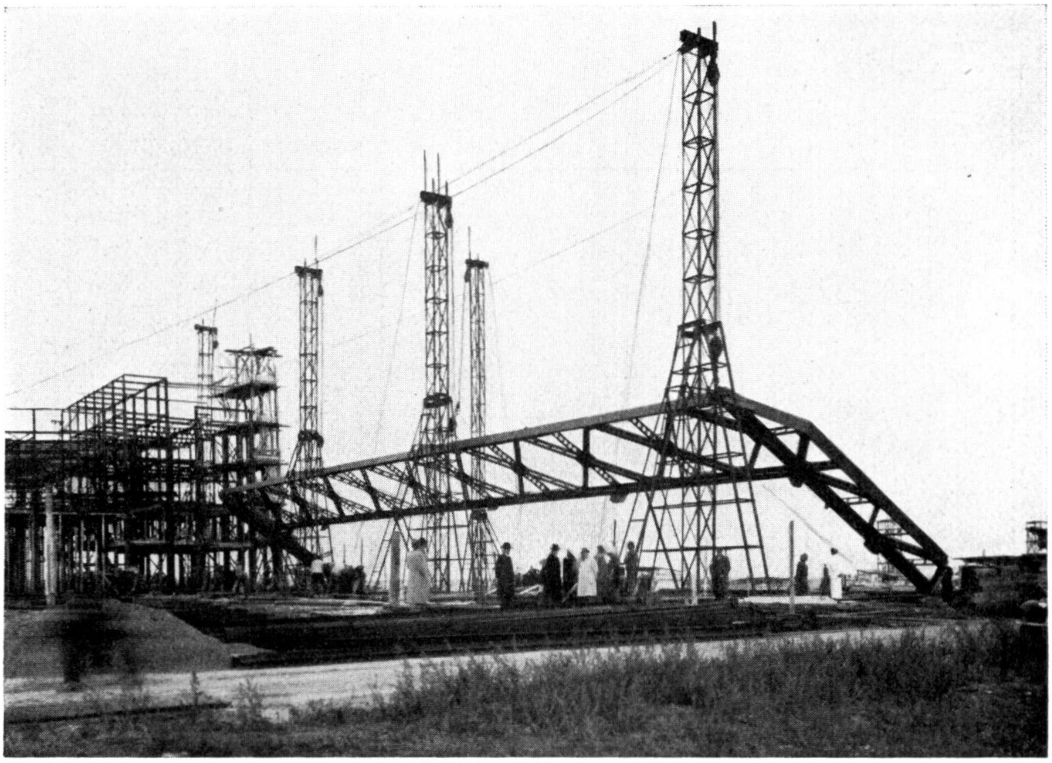


Fig. 7.

The construction of the steel frames was divided between the following two firms: —

S.A. des Anciens Etablissements Škoda, Pilsen.

Českomaravská-Kolben-Daněk, Prague.

The first mentioned firm made use of Böhler-B-Elite-KVA electrodes for welds of Type I, and of Arcos Stabilend electrodes for welds of Type II. The second firm made use of Elarc-Resistenz electrodes exclusively.

The average results obtained from the test specimens for electrodes, welds and welders are given in Table V, and against these results the prescribed minimum values have been included for comparison. Altogether 42 welders were tested in this way. It appears from the table that the minimum values, despite the high standard set, were easily obtained. The welding was closely supervised during the work, and on completion the welds were subjected to careful check and their dimensions accurately measured. A number of them were examined internally after drilling.

The design for the framework was carried out by the S.A. des Anciens Etablissements Škoda, Pilsen, with special attention to simplicity of execution both in the shops and on the job. The work was carried out under the control of the Bridge Department of the Ministry of Public Works.

Table V.

Acceptance test			Types of Electrodes I: Böhler B-Elite	I: Minimum required	II: Arcos stabil.	II: Elarc Resist.	II: Minimum required
for electrodes	elastic limit, in kg/mm²		30.9	23	35.0	40.0	26
	tensile strength, in kg/mm²		46.5	38	46.3	48.7	42
	elongation, %		21.6	12	24.9	23.6	20
	resilience, in kgm/mm²		4.3	3	8.5	9.7	6
for welds	tensile strength, in kg/mm²		44.7	38	48.5	46.3	42
	shear strength, in kg/mm²		34.1	28	34.6	37.1	30
for welders	tensile strength in kg/mm²	horizontal posn.	47.2	—	49.6	46.8	—
		vertical „	42.2	—	47.9	48.0	—
		overhead „	43.8	—	50.5	47.0	—
		average „	44.5	34	49.5	47.3	40
	shear strength in kg/mm²	horizontal „	33.3	—	33.3	35.7	—
		vertical „	33.7	—	35.7	36.1	—
		overhead „	31.3	—	35.1	34.2	—
		average „	33.1	26	34.8	35.3	29
for welds	I-shaped: tensile strength, in kg/mm²		—	—	46.6	47.6	42
	V-shaped: tensile strength, in kg/mm²		—	—	58.9	42.4	42

Another very large job was the welded construction of a road bridge of 52.005 m span (Fig. 8). Here the main girders were of the Vierendeel type without diagonals, this design being chosen mainly on aesthetic grounds but also because of the advantages it offers from the point of view of welding, and for the simplicity and rigidity of the intersections. Moreover in such a girder the secondary stresses are nil, whereas in a triangulated system they may vary between 10 to 15 % of the principal stresses, owing to the large sizes of gussets necessary at the intersections and to the system of calculation which has to be used.

Hence, using the same permissible stresses in the calculations, the true factor of safety is greater in the case of the Vierendeel girder, and finally bridges with Vierendeel main girders deflect much less than those with triangulated main girders on account of the great rigidity possessed by the intersections — a fact which is very important from the point of view of maintenance.

Hitherto the sole disadvantage attending the use of Vierendeel girders has been the difficulty of the statical calculations involved, but the Beggs-Blazek method of determining the influence line has completely removed this difficulty.[1] The advantage of this method lies in the fact that it is no longer necessary to rely on simplified assumptions and that the additional rigidity due to the fixation of the vertical members is automatically taken into account. The influence line can be accurately determined at any required point, and this makes it easy to check the conditions of stability.

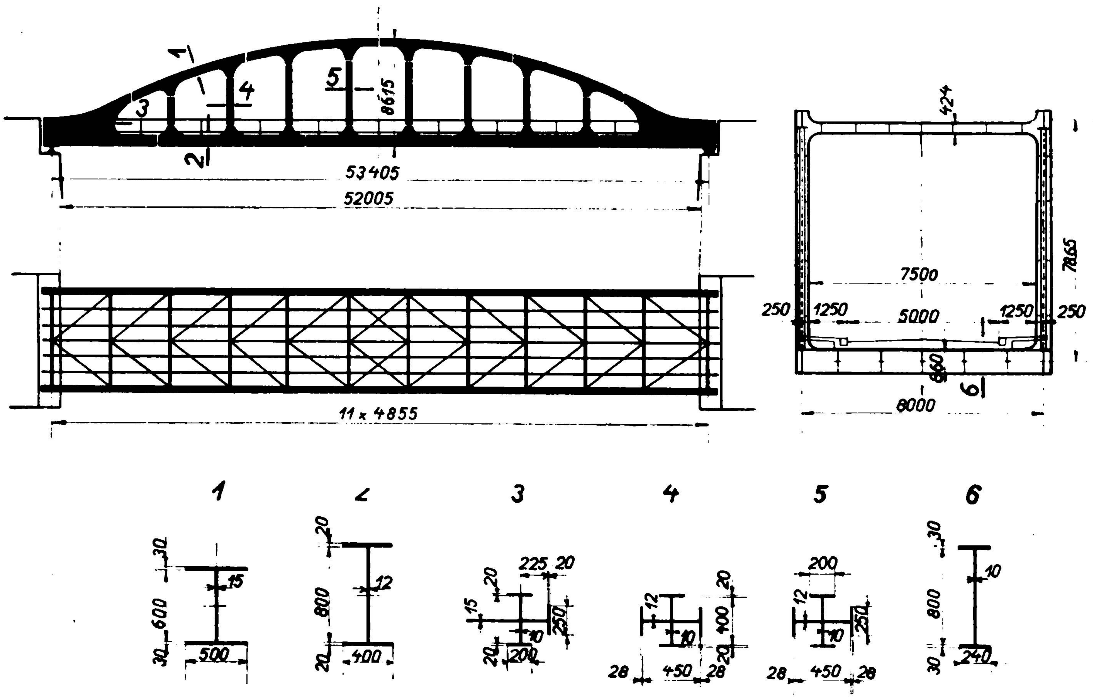


Fig. 8.

The girder is designed as hyperstatic to the 33rd degree.

In addition the results obtained in this way were checked by reference to an approximate calculation in which it was assumed that the moments of inertia of the booms were constant in all panels and dependent on the length of the bars; at the same time it was assumed that no loads were applied except in line with the vertical members. These assumptions reduced the degree of hyperstaticity to 11 and rendered the calculations easier. The whole of this work was carried out in ordinary steel C 38 and entirely by the use of welding both in the shop and on the site. The welding was done exclusively with Arcos Stabilend electrodes.

[1] Final Report, 1st Congress, I.A.B.S.E., p. 709.

The permissible stresses both for the parent steel and for the weld metal are indicated in Table VI.

Table VI.

Permissible stresses	Decking members		Main girder	
	Parent metal	Weld metal	Parent metal	Weld metal
Tension	$v = 850$ kg/cm²	0,75 v	870 + 3 l — maximum 1150 kg/cm² (1350 kg/cm²)	0.85 v
Compression		0,90 v		1.00 v
Shear	$\tau = 700$ (800) kg/cm²	0,50 v	700 (800) kg/cm²	0.60 v

Note. The values shown in brackets relate to the case where the calculations take account of all external forces (wind pressure).

For all the connecting welds the butt type has been preferred, and intersecting joints exposed to tensile stresses have been avoided on principle. Bracing members are connected to the verticals by means of butt welds. In order to avoid crowding the welds together the stiffeners of the bracings, booms and verticals have been holed at the angles, and this assists drainage.

The weight of the steel portion is 154 tonnes. The erection joints were arranged in such a way that the pieces could be delivered as large as possible (Fig. 8). The ends of the main girders, which are 9.293 m long and weigh 6.7 tonnes, were delivered to the site of the work in a single piece (Fig. 9).

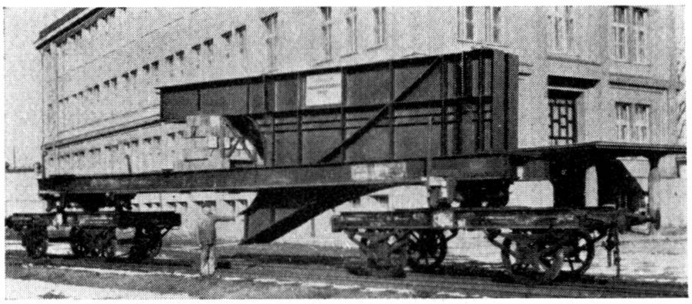


Fig. 9.

As the bridge was to be erected in spring time at the period of high water, the original intention was to carry out the welding immediately after the temporary erection by means of bolts had been completed, so that the welded points would be able, if necessary, to bear the dead weight of the structure in the event of the supporting falsework being damaged by the flood. The floor of the bridge was then to be welded in three sections, so as to lessen the stresses due to welding. The favourable weather encountered made it possible to modify these arrangements by welding the floor of the bridge to the lower boom members straight away, a procedure which helped to prevent the stresses due to the welding of the floor being transmitted to the main girders. Finally the verticals and other boom members were erected as soon as they had been welded in the shop (Figs. 10 to 12).

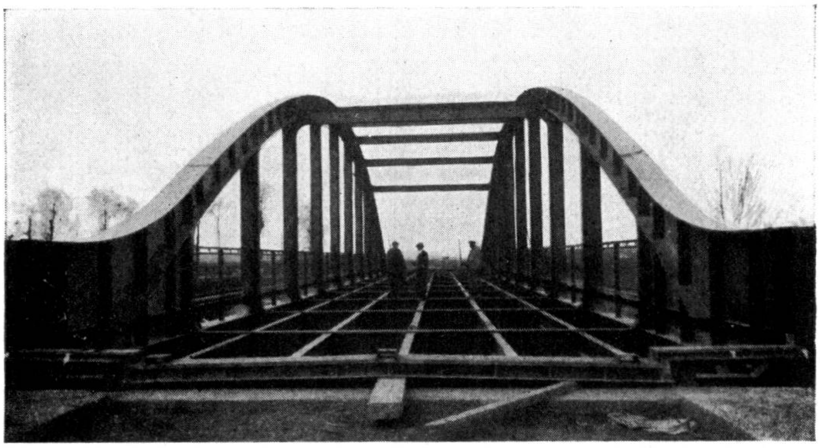


Fig. 10.

The main girders were given a maximum camber of 15 mm corresponding to the deflection under dead load together with half the life load.

In addition to the usual tests of steel, electrodes, welds and welders, fatigue tests were carried out. The fatigue limit for the weld was determined from *Wöhler*'s curve after carrying out eight tests to two million alternations of stress at 22 kg/mm² and also ten million alternations to 20.5 kg/mm². The tests were made on conical specimens in an Amsler fatigue testing machine.

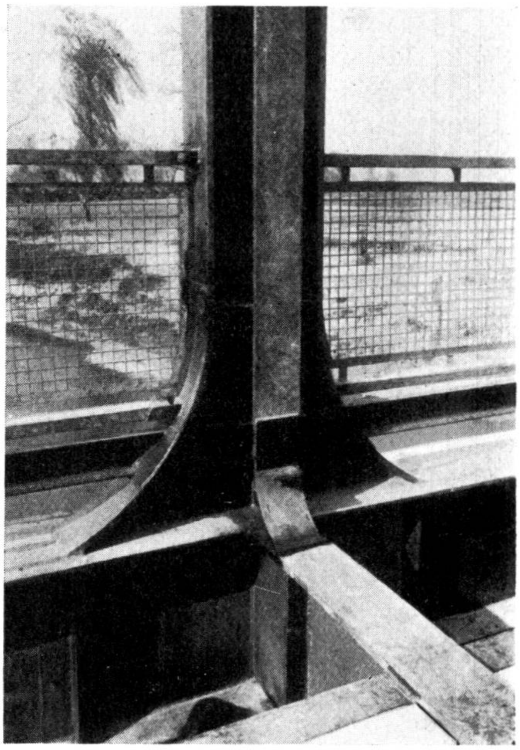


Fig. 11.

It further seemed advisable to carry out X-ray tests of the welds on a portion of the lower boom of the main girders (Fig. 13), and a model of the intersection of the lower boom was subjected to statical tests. These were carried out in the Laboratory for Testing Materials and Structures of the Czech College at Prague, enabling the stresses due to permanent loading and to assumed uniformly distributed live load to be calculated. Eventually it is intended to subject an intersection of this kind to fatigue test. When the whole structure is completed deflectometers will be applied to measure the deflections of the cross girders and main girders under stationary and moving loads.

The design of the bridge as a whole was carried out in the Bridge Department of the Ministry of Public Works, and the detailing of the final design as well as the construction of the work were entrusted to the S.A. des Anciens

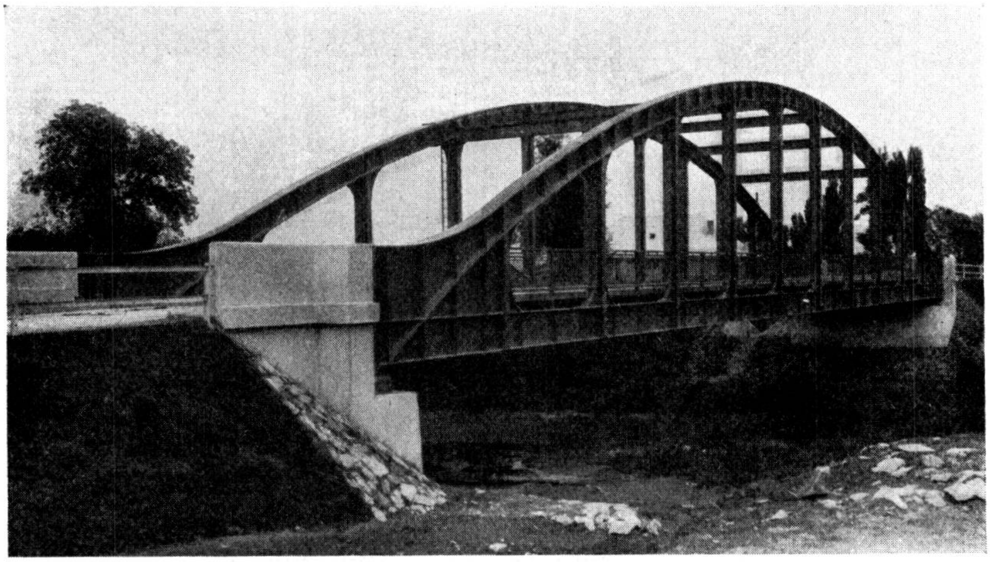


Fig. 12.

Etablissements Škoda, Pilsen, who completed the task to the entire satisfaction of the Ministry. The Bridge Department of the Ministry of Public Works were responsible for supervision.

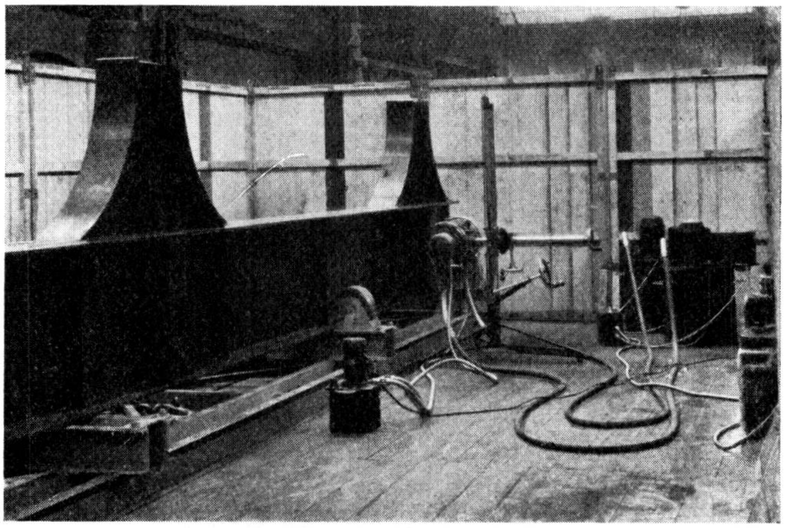


Fig. 13.

Finally Fig. 14 and Table VII give particulars of the principal welded road bridges in Czecho-Slovakia completed up to the present time.

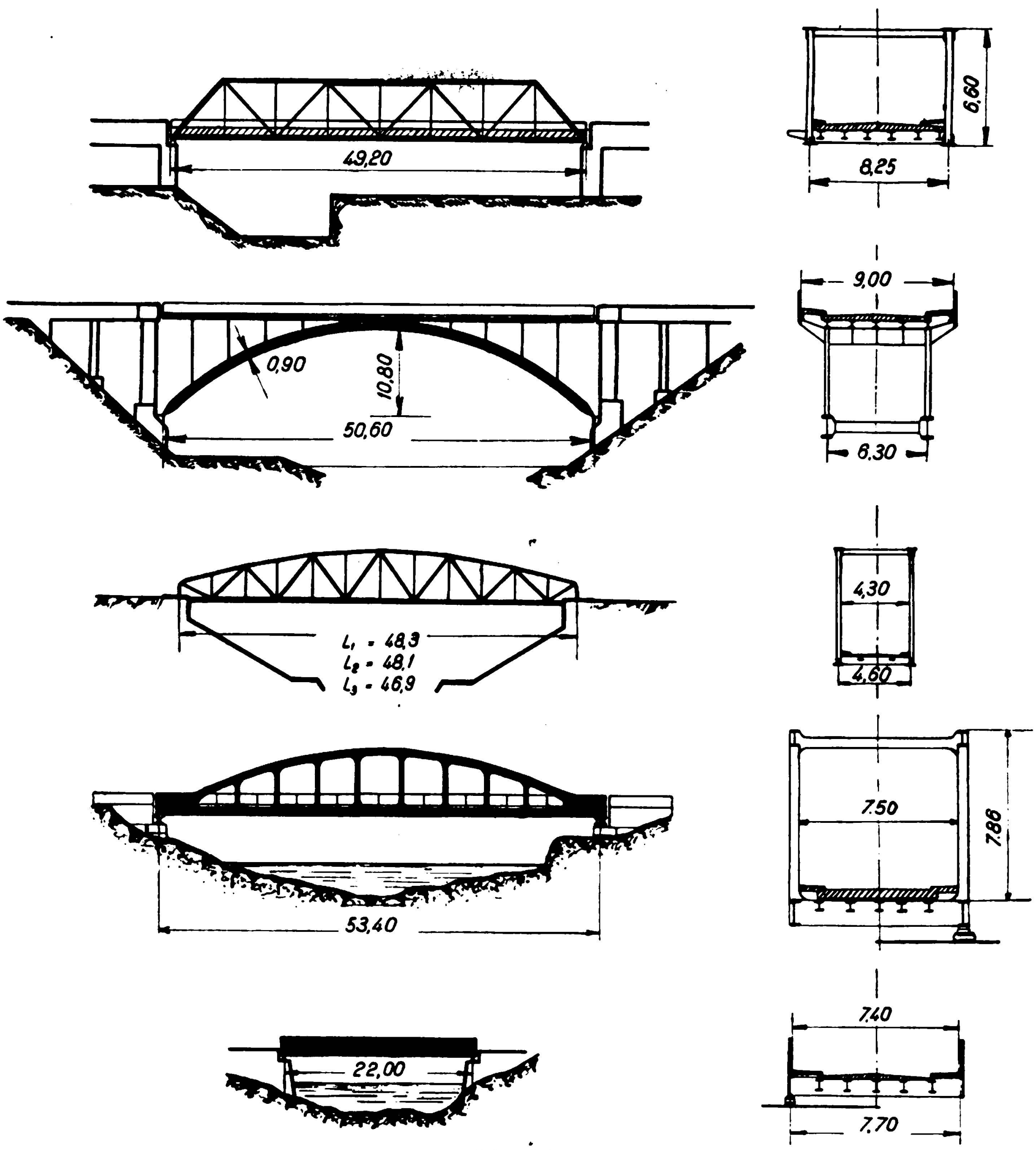


Fig. 14.

Table VII.

Bridge No.	Year of Construction	Span in m	Loading	Weight in tonnes	Construction
1.	1931	49.20	Class I	145.0	Škoda Works, Pilsen
2.	1933	50.60	„ I	111.0	„ „ „
3.	1933	22.00	„ I	37.6	„ „ „
		48.30	„ III	52.0	Českomaravska-Kolben – Daněk
4.	1934	48.10	„ III	52.0	Brno-Kralovopolská
		46.90	„ III	49.1	Škoda Works, Pilsen
5.	1936	53.40	„ I	157.0	„ „ „

Note: Class I corresponds to a uniformly distributed live load of 500 kg/m^2 or to a road roller weighing 22 tonnes.

Class III corresponds to a uniformly distributed live load of 340 kg/m^2 or to a wagon weighing 4 tonnes.

IIIc 8

The Calculation of Welds.

Berechnung der Schweißnähte.

Le calcul des soudures.

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In a brief verbal summary of his paper in Group IIIc on "The Calculation of Welds Assuming Constant Energy of Change of Shape" the author emphasised that in any statically indeterminate connection the direction of the force transmitted by a weld should be determined by reference to the plasticity theory.