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Welding and welded connections

Soudage et assemblages soudés

Schweissung und Schweissverbindungen

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INTRODUCTION

A graphical composition is given in fig. 1 of all existing welding processes. A symbolic indication of every system explains the characteristics of the various processes.

Welded connections, as seen from the point of view of the I.A.B.S.E. Congress, include so many examples and ideas that it might be preferred to give indications and examples for the constructional engineer and designer in close connection with the welding-shop manager and the welding operation as well. This means how to make a welded structure satisfactory in a technical and economical way. This paper deals with the following aspects:

(1) Welding and riveting, seen from the point of view of the constructional engineer and the designer.
(2) Constructive elements and profiles for welded construction.
(3) Materials and their preparation for welded construction—electrodes.
(4) Co-operation between the designer and the welding-shop manager.

The paper also deals with the problem of the waste of electrodes.

WELDING AND RIVETING SEEN FROM THE POINT OF VIEW OF THE CONSTRUCTIONAL ENGINEER AND THE DESIGNER

Attention may be drawn to the fact that great failures, damages, large cracks, broken constructions, not only in bridge building but also in shipbuilding, boiler-making, etc., are even more due to unsatisfactory design and construction than to the quality of the weld and the execution of welding in the workshop.

In bridge building, field welding often causes difficulties and defects to which reference will be made later.

This paper will draw special attention to the very important task of the constructional engineer, the designer and the man who makes the drawings.

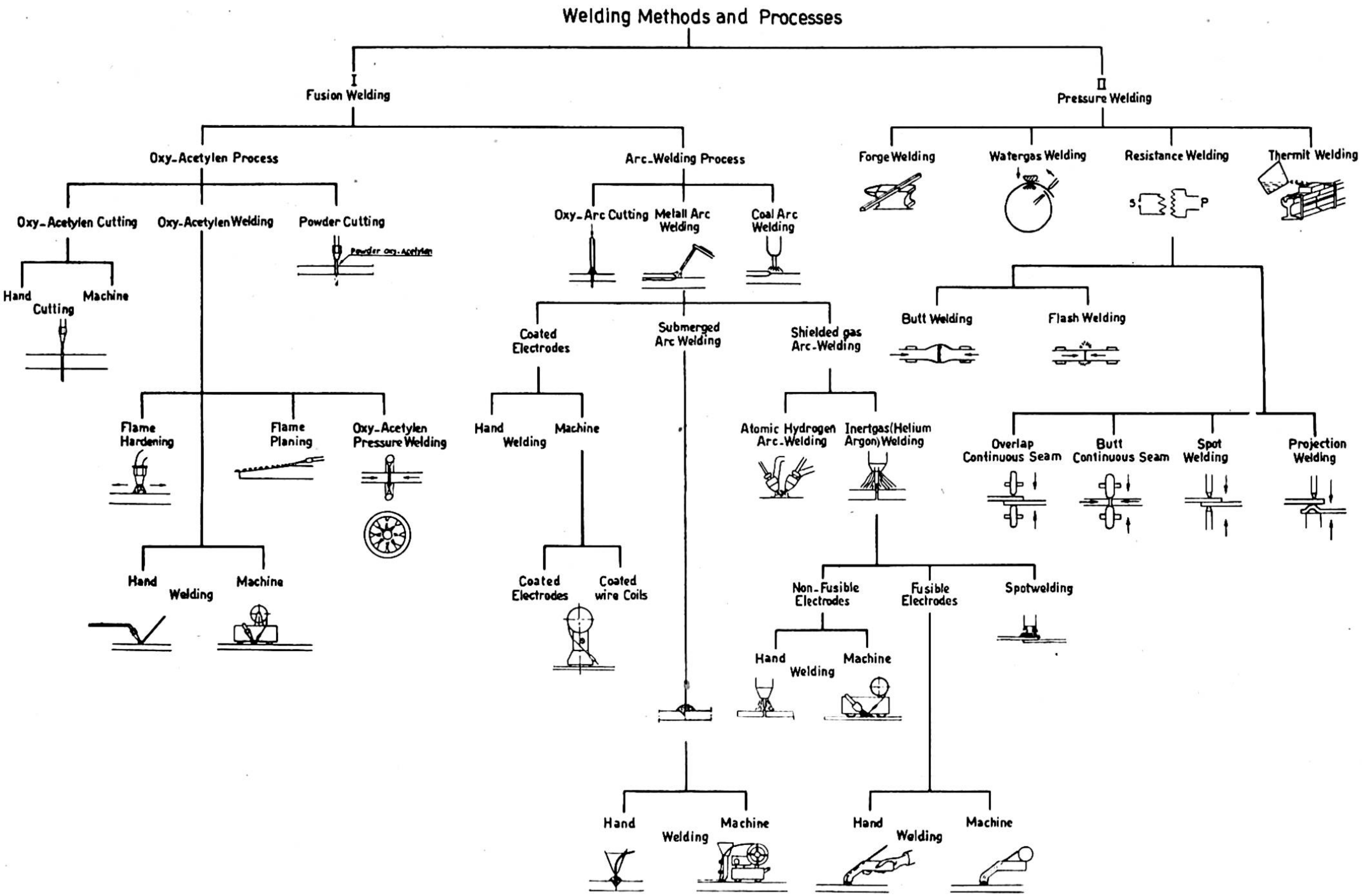


Fig. 1

Note: In the above drawing Stud-Arc Welding has been omitted

The already known principle for the constructional engineer and the designer, but at the same time of the greatest difficulty to them, is to free themselves completely from "thinking" in riveted construction and to make the design for the welded construction so that it is satisfactory in a technical as well as in an economical way. It is well known that the design for riveted construction, leaving out the rivets, gives very unsatisfactory results when welded.

All over the world special attention is paid to the skill and instruction of welders, and so we are now today rather well equipped with skilled welders and every day there are new and good welders schooled and trained; but far more necessary is the task of the skilled technicians and welding engineers to open schools and training courses for constructional engineers, designers and draughtsmen.

Attention may be drawn to a few questions closely connected with those things the constructional engineer and the designer, as well as the draughtsmen, have to be familiar with in order to avoid difficulties in the welding-shop or to prevent damage later on. Among these are:

(1) How many welds are found in a drawing which can never be reached by the electrode of the welder, because the man who made the design and the drawing does not know anything about practical welding?

(2) Too few constructional engineers and designers know how to make their structures so as to avoid concentration of stresses by avoiding concentration of welds or crossing of welds.

(3) How many designers know that high stresses are caused by sharp corners and that these stresses can be avoided by rounded corners and flowing lines in the structural parts which are to be connected?

(4) What does the constructional engineer and designer know of the influence of fatigue load and notch-effect and its serious consequences on the construction, and what does he know about the principles for making a choice of the many types of welded joints?

(5) What does the constructional engineer and designer know of the materials he is using in his structures in connection with welding and what does he know of the different types of electrodes and their application to the materials which have to be welded in the structure he has designed?

These points are only a few of the hundreds of questions that may be laid before the constructional engineer, the designer and the draughtsman, not only about the structure itself, but also about the way the welds are indicated in the drawing. It is therefore, as already mentioned, of the greatest importance to organise training courses for constructional engineers and designers, for once knowing what welding involves, they will never again make ridiculous mistakes in designs and drawings.

As to the training courses, it is the author's experience that those gentlemen who follow the training also have to do exercises in practical welding, and that they take very great interest in it. Some of the subjects for technical training of constructional engineers and designers, as well as for draughtsmen, may be given as follows:

(1) The principles of welding and welding systems.
(2) The knowledge of welded joints and the execution of welded joints.
(3) The knowledge of electrodes and their application.
(4) The knowledge of materials and their application.
(5) The knowledge of shrinkage, with their stresses and deformations.
(6) The knowledge of the mechanical testing of materials and weld-metal.
(7) The knowledge of fatigue-load influence on the design of a structure.

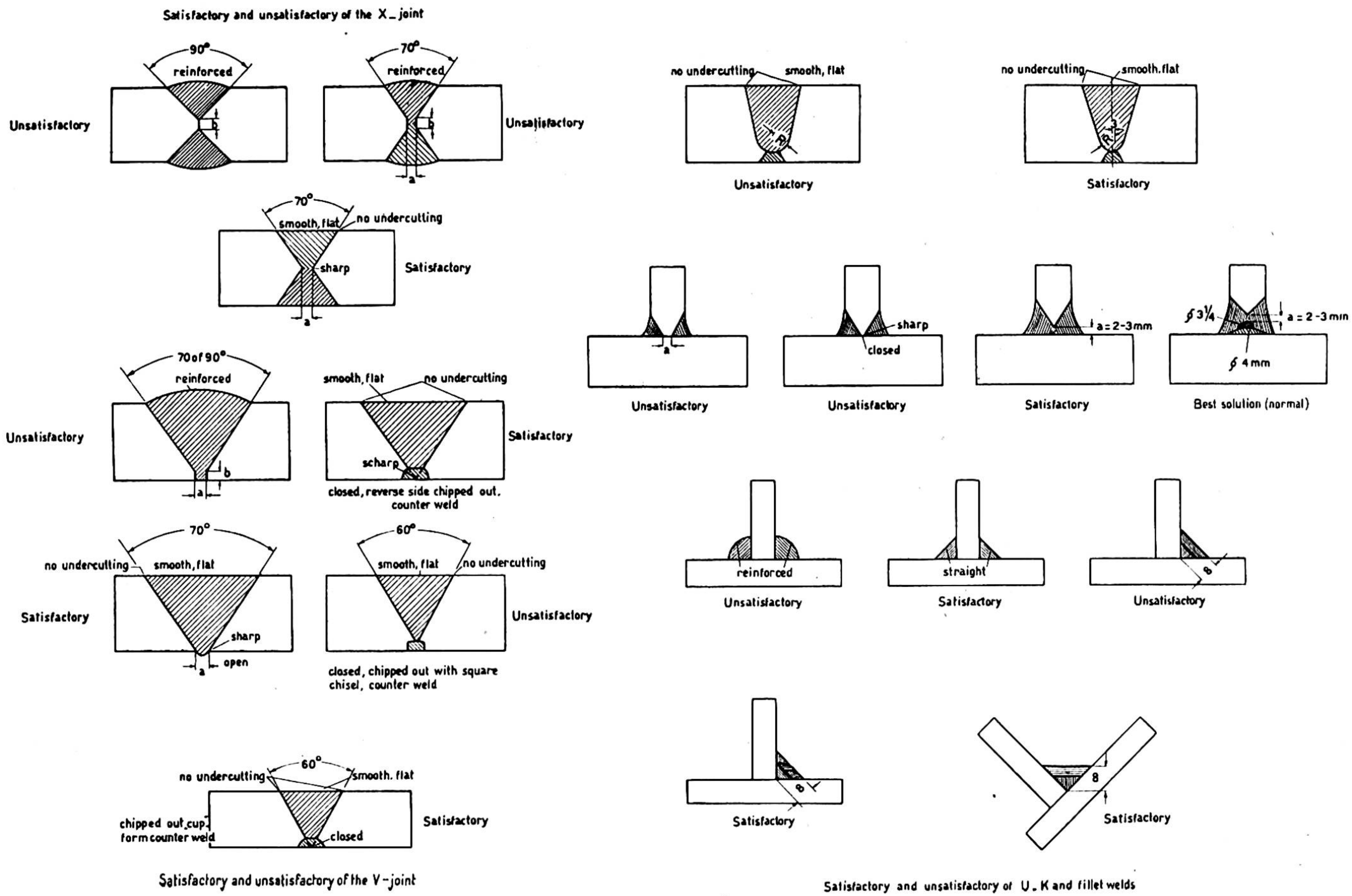

Satisfactory and unsatisfactory of the X_joint
90°
reinforced
Unsatisfactory
b
70°
reinforced
Unsatisfactory
b
a
70°
smooth, flat
no undercutting
sharp
Satisfactory
a
70 of 90°
reinforced
Unsatisfactory
b
a
smooth, flat
no undercutting
Satisfactory
scharp
closed, reverse side chipped out, counter weld
70°
no undercutting
smooth, flat
Satisfactory
sharp
a
open
60°
smooth, flat
no undercutting
Unsatisfactory
closed, chipped out with square chisel, counter weld
60°
no undercutting
smooth. flat
chipped out cup form counter weld
Satisfactory
closed
Satisfactory and unsatisfactory of the V-joint
no undercutting
smooth, flat
Unsatisfactory
no undercutting
smooth. flat
Satisfactory
a
Unsatisfactory
sharp
closed
Unsatisfactory
a = 2-3mm
Satisfactory
a = 2-3 mm
ϕ 4 mm
Best solution (normal)
reinforced
Unsatisfactory
straight
Satisfactory
8
Unsatisfactory
8
Satisfactory
8
Satisfactory
Satisfactory and unsatisfactory of U. K and fillet welds

Fig. 2

Strict attention has not only to be paid to the training of constructional engineers and designers, but also to those engineers and technicians who have the supervision, survey and control of welded structures in their charge. For these gentlemen also show very often a great lack of knowledge about welding and welded construction which very often leads to severe differences of opinion.

To illustrate the way in which designers indicate on the drawings several types of welded joints, fig. 2 gives examples of satisfactory and unsatisfactory methods.

CONSTRUCTIVE ELEMENTS AND PROFILES FOR WELDED STRUCTURES

Although this subject belongs to the programme of schooling and training of constructional engineers and designers mentioned before, it is worth while to pay special attention to it.

Constructional engineers and designers have to learn to make use of the most fundamental structural elements for welded construction. These elements are, generally, the "plate" and the "tube." They have to learn how to handle these elements in construction and design in order to obtain sufficiently light and rigid structures, and they have to free themselves from the feeling and idea that the heavy and solid structure is the safe one.

Moreover the constructional engineer and designer has to know and be familiar with everything connected with the execution of the welding, and above all things he has to know how the welding operation in his own workshop is managed and executed, and therefore he has to build up close co-operation with his welding-shop manager.

Relating to the above-mentioned fundamental construction elements, plate and tube, it may be mentioned that light and rigid structures can be obtained if the material used for the structural elements is placed as much as possible on the outside of the cross-section and as far as possible from the neutral line.

Following these rules the designer comes to the hollow construction elements known as the "tube" and the "box." These elements may be rolled as tubes or built up as boxes by welding out of plate or strip.

In Table I several types of structural elements are given for comparison. As to the rigidity, mentioned in the Table, it may be mentioned that the rigidity: $R=P/f$ kg./μ where f represents bending through 0·001 mm.

Conclusions from Table I

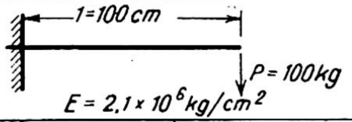
Deflection, rigidity and moment of inertia are for all hollow construction elements much higher compared with the solid elements, notwithstanding that the weight of the hollow elements is much lower. But from this conclusion it may not be assumed that in all circumstances the tube or box is to be preferred and shows better results for structural elements.

In Table II two hollow elements are compared with one solid element. From Table II the conclusion may be drawn that hollow elements show less resistance against normal bending and the solid profile shows the greatest resistance against bending. On the other hand, the hollow elements show very great resistance against torsion; the solid element shows very low resistance against torsion. It has to be kept in mind that weights per metre length for all three elements of Table II are equal.

In connection with the construction and design of a certain subject attention may be drawn to the dynamic rigidity, and though this may not often occur in steel

TABLE I

Load system



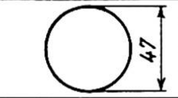
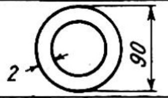
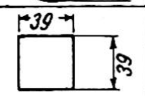
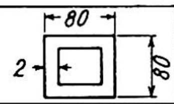
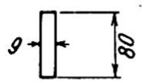
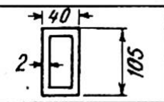
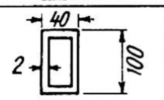
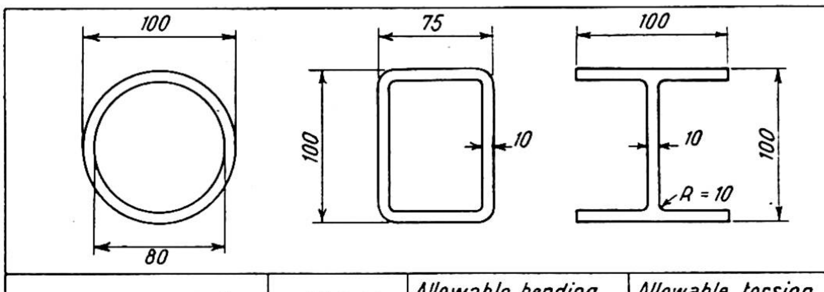
Form of cross section	Moment of inertia	Deflection	Rigidity	Weight
	cm^4	cm	kg/μ	kg/m
	24	0,66	0,15	13,6
	53	0,30	0,33	4,3
	19,3	0,82	0,12	12
	63	0,25	0,40	4,9
	38,4	0,41	0,24	5,7
	78	0,20	0,50	4,4
	68	0,23	0,43	4,2

TABLE II



Form cross section	Weight	Allowable bending moment	Allowable torsion moment
	kg/m	cm – kg	cm – kg
Circumferencial tube	22	58σ allowb.	116τ allowb.
Rectangular tube	22	67σ allowb.	113τ allowb.
H-beam	22	90σ allowb.	10τ allowb.

construction it is worth-while to mention it. The dynamic rigidity can be given in the following formula:

$$R' = n^2 \times m$$

In this formula n is the vibration number and m the weight in kg./sec.^{2}/m.

Fig. 3 gives a graphical relation between weight and vibration number. From this graph may be drawn the conclusion that in the lower zone (rigid light constructions) small variations of m cause great variations of n.

In the zone of the rigid heavy constructions m has to be given great variation in order to obtain even small variations of n. Building up structures with a high value for n means making rigid and light structures. This can be obtained in the design by making the free length of the vibration parts as short as possible and the distance of these parts to the neutral line as great as possible, which rule can be written as follows:

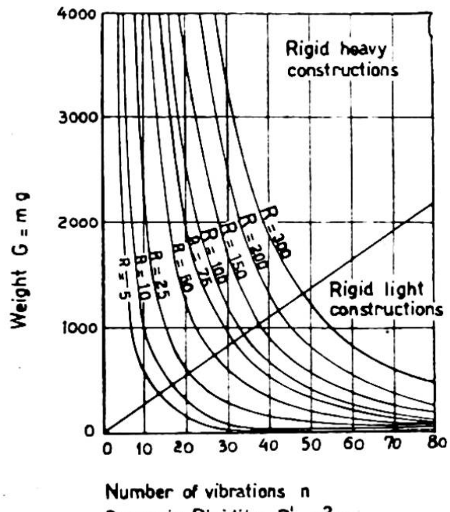


Fig. 3

MAKE DESIGNS AS COMPACT AS POSSIBLE

MATERIALS AND THEIR PREPARATION FOR WELDED CONSTRUCTION—ELECTRODES

With regard to the materials handled by the constructional engineer and the designer it has to be kept in mind that the weldability of the material is one of the most important things for obtaining satisfactory technical results. So for structures, especially in bridge building, low-carbon Siemens-Martin mild steel is the best metal to be used. Moreover it has to be kept in mind that for this metal the content of carbon, phosphorus and sulphur has to be low, and to give some figures, they may be indicated as follows:

Carbon	0·15–0·20 %
Phosphorus	0·05 %
Sulphur	0·04 %

For the preparation of welded structures and welded joints figs. 4, 5, 6 and 7 give a few examples of design and preparation of these structures and joints.

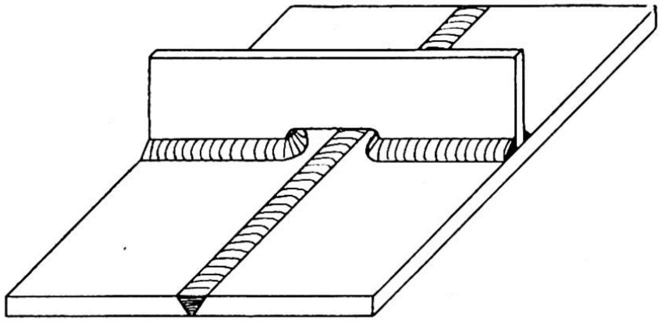
Fig. 4 will show the designer how to avoid concentrations of stresses in welded structures when welds have to cross each other.

Fig. 5 will give ideas of several welded structures causing notch-effects or not, concentrations of stresses or not. These ideas for structures may be extended to welded work submitted to fatigue load or dynamic load.

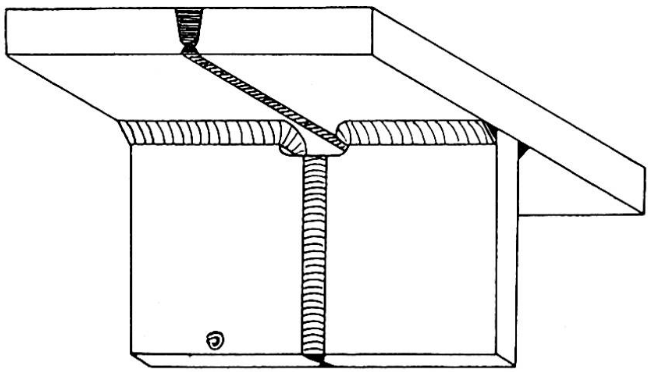
Figs. 6 and 7 show the preparation and execution of the welding of a butt-joint in an H-beam. Attention is drawn to the preparation of the flange and the hole in the web to enable the counter weld in the flange to be done so that the notch-effect in the root of the V-joint of the flange is avoided.

Fig. 8 gives an idea of the construction and design for riveting and welding of the corner of a joist. No further explanation of this example is necessary, as it explains itself, especially the simplicity of the welded construction.

For electrodes it is necessary that constructional engineers and designers should



Crossing V-joint and fillet welds without concentration of stresses



Crossing U-joint and X-joint without concentration of stresses

Fig. 4

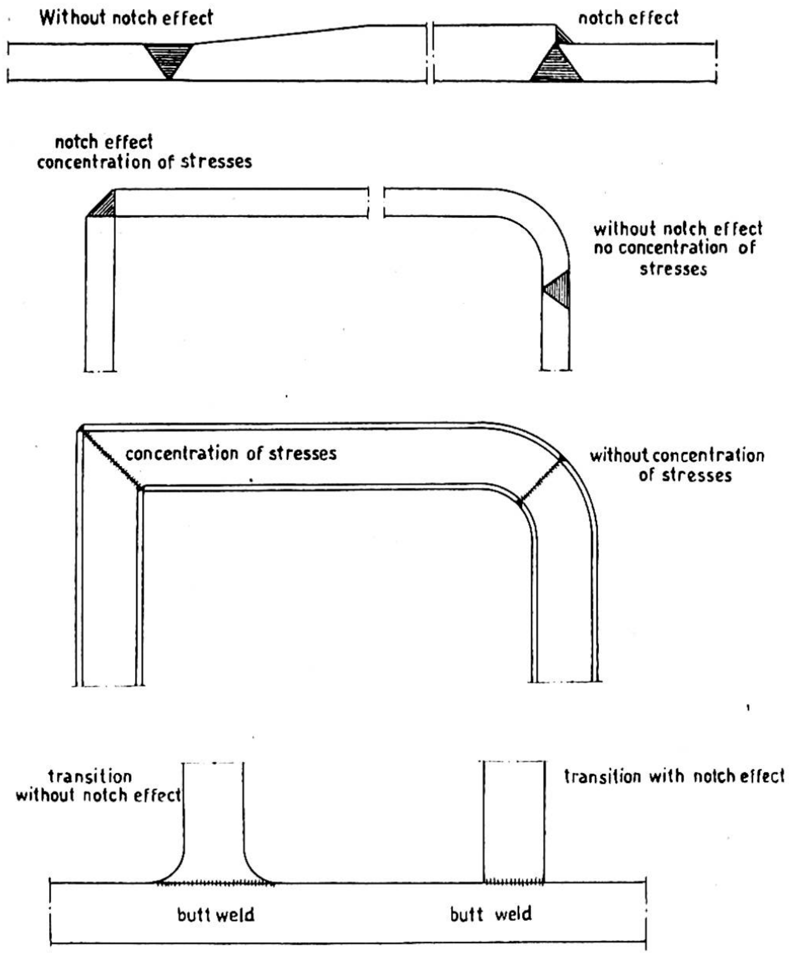
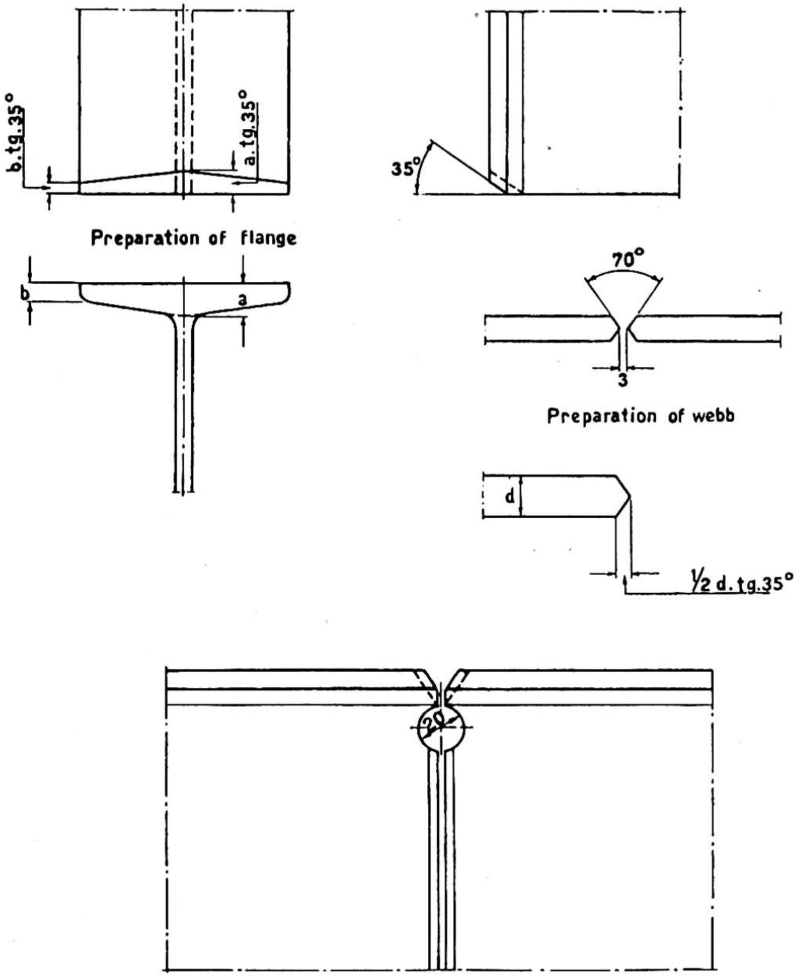
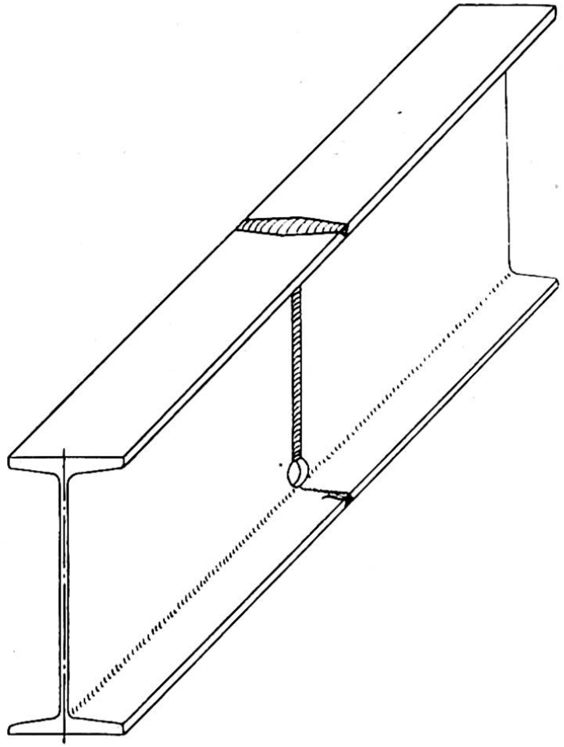


Fig. 5



Preparation for butt-welding of H-beams

Fig. 6



Welded Butt Joint H-beam

Fig. 7

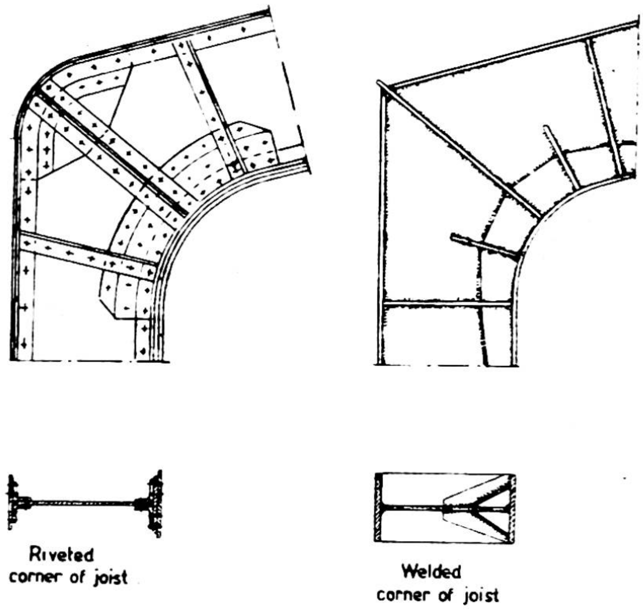


Fig. 8

have a knowledge of the different types of electrodes used for welding several specimens of steel, but they need also the necessary knowledge about what combination of diameters can be used for different types of joints. It is impossible within the scope of this paper to handle more details of this subject.

In this paper attention may be drawn to the rather new idea of the combination of riveting and welding. It is well known, of course, that riveting and welding should never be combined in one structure to carry together one load. Furthermore it is well known that the framework type of construction is not suitable for welding. On the other hand, it is necessary to know that field welding very often causes not only difficulties but also unsatisfactory welding results. Attention is therefore drawn to framework construction and design with welded frame-girders and riveted trussed joist-plates. Fig. 9 outlines an example of this form of construction. A railway bridge in the Netherlands was built on this system in 1943.

Many more samples of satisfactory designs for welded structures might be given, but it is impossible in the scope of this paper to go into more details of this subject.

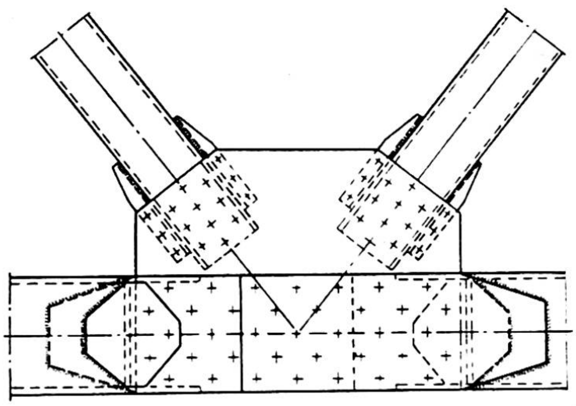


Fig. 9. Detail of trussed girder. Welded box-girders; riveted field connections

Co-operation between designer and the welding-shop manager

As already mentioned, the greatest difficulty for the constructional engineer and the designer is to free themselves from thinking in terms of riveted construction and to switch over to real welded construction.

As the workshop in almost all factories is a good deal ahead in welding technique and they often have to change the designs and drawings, it is of the greatest importance that the constructional engineer and the designer build up close co-operation with the welding-shop manager. Very satisfactory results and great enthusiasm for welded construction have come from the co-operation of the constructional engineer and the workshop manager.

When a new subject or structure has to be built or designed for welding, there is only one way to achieve satisfactory results. Make a model out of wood or cardboard so that its parts can be dismantled and can be shaped in an easy way. In building up the structure in this way, exchanging opinions and discussing things such as the sequence of welding, the possibility of shrinkage, the avoidance of notch-effects and the unnecessary concentration of stresses, will lead to a welded construction that shows satisfactory results in a technical as well as in an economical way.

Efficiency of welding—Wasting of electrodes

It is very common in workshops for stub-ends of electrodes, 6 to 8 cm. long, to be thrown away by the welders.

Hardly any one realises how much money is thrown away in stub-ends of electrodes. This may be illustrated by a simple example.

If we take for example, a country with a consumption of 200,000,000 electrodes a year for welding jobs all over the country, it is possible to calculate from this figure interesting things. If every welder throws away from these 200,000,000 electrodes only *one centimetre more than necessary*, there is thrown away a total of 200,000,000 centimetres; that means 2,000 kilometres of electrode-lengths, or if calculated in electrodes with an average length of 40 cm. per electrode, this means a waste of 5,000,000 electrodes a year. Calculating an average price of 5 cents per electrode this is an expense of 250,000 Dutch guilders (£25,000). This very high figure for waste is calculated on stub-ends that have *only one centimetre too much*. What can be said of the stub-ends from 6 to 8 centimetres in length found in almost every workshop?

Summary

Special attention is drawn to the fact that there is a great lack of knowledge about welding and welding technique among constructional engineers and designers. Many of the serious failures with welded constructions are caused by unsatisfactory design of the construction.

The waste of electrodes is far greater than directors, managers and welders realise.

Résumé

L'auteur attire particulièrement l'attention sur les graves lacunes que l'on constate chez les ingénieurs et les constructeurs en matière de connaissances sur la technique du soudage. De nombreux accidents graves qui sont survenus à des constructions soudées sont dûs à une conception inadéquate.

L'usure des électrodes est beaucoup plus importante que les services de direction, les entrepreneurs et les soudeurs ne le pensent.

Zusammenfassung

Der Verfasser macht besonders darauf aufmerksam, dass bei den Ingenieuren und Konstrukteuren ein grosser Mangel an Kenntnissen über Schweissung und Schweisstechnik vorhanden ist. Der Grund vieler grosser Schadenfälle bei geschweissten Konstruktionen liegt in ihrer unbefriedigenden konstruktiven Durchbildung.

Der Verlust von Elektroden ist viel grösser als Direktoren, Unternehmer und Schweisser sich vorstellen.