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Il faut à la fois de l'audace et de la prudence, sans que ni l'une ni l'autre de ces deux qualités ne soit poussée à l'excès.

JAMES CALDWELL,
Chartered Civil Engineer, London.

Welding by means of the oxy-acetylene blow-pipe has not met with much support in Great Britain for the assembly and the reinforcement of steel bridges, but has been most extensively applied to the purpose of cutting shapes in new work and the removal of defective steel members.

Electric welded construction on the other hand has developed into general practice during recent years and therefore this report deals exclusively with the application of electric arc welding to steel structures.

In reviewing the present position of electric arc welding as applied to the fabrication and erection of structural steelwork it is of interest to recall the early steps in the development of the process and its application.

Historical Progress

The carbon arc process was introduced in 1885, the arc being maintained through the medium of a carbon pencil and metal added by means of a filler rod. In 1890 carbon was replaced by a soft iron wire, thus eliminating the necessity for the filler rod and what is commonly known as " bare-wire welding " was introduced. The process is substantially the same to-day except for improvements in the welding equipment and the analysis of the wire.

In 1907 the first light coated electrode was introduced by covering the wire with a thin coating of paste in order to stabilize the arc. A close study was made at that time of the metallurgical side of the problem, and in 1911 the first heavy coated electrode was produced in Great Britain.

As confidence in the process grew, the welding of steel structures became a practical proposition. British welding engineers, faced with conservatism and unfavourable regulations in their own country, were forced to go further afield to introduce their ideas. The results and progress of their initial pioneering have been particularly marked in Europe[1] and Australia, and their work throughout has been based on the application of the heavy coated electrode. In America welding engineers have progressed on parallel lines and to a more advanced degree in the quantity of welded steelwork erected, but the bulk of their work has been carried out with bare-wire welding. The differentiation is important in view of the marked variation in characteristics of design and methods of fabrication produced by the two processes in their respective spheres.

The British welding engineer, in pinning his faith to the heavy coated electrode, maintains that the production of a metallurgically sound weld under practical conditions should not depend entirely on the skill of the operator,

1. Belgium and Switzerland.

but as far as possible on the natural function of the electrode during fusion In other words he considers that a suitable covering should be provided on the electrode to form an active slag that will (1) clean the surface of the parent plates from oxide during welding : (2) protect the weld metal whilst molten from atmospheric gases and therefore prevent oxide and nitride defects from forming in the metal ; and (3) melt at a low temperature and thereby not be trapped in the weld metal as slag inclusions. Considering the extensive practical experience of American engineers in the erection of steel structures with bare-wire welding, the marked tendency apparent in the U. S. A. during the last 18 months to employ heavy coated electrodes provides some justification that the claims of European engineers are sound in this connection.

Design

It is certain that success in welding constructions depends very largely on the initiative shown by the designer and his ability to break away from existing practice developed essentially for riveting.

Bare-wire welded structures of the opentruss type, with their general use of the simple lapped joint and rolled steel sections, do not appear to differ very largely in form from riveted structures. On the other hand in Europe there is a more advanced tendency to design welded structures on a monolithic basis with a general use of butt welded joints, even in main members.

A further characteristic of considerable importance and individual to structure welded with heavy coated electrodes, is the general application of light single run fillet welds. This practice, although of comparatively recent introduction, has been successfully developed to an advanced degree both in Switzerland and Australia. The linear strength of a fillet weld is approximately proportional to the square root of the linear volume of weld metal deposited, so that the economic advantages of the light single run fillet weld are paramount. A further asset is that welding contractional stresses are reduced to a minimum, but what may perhaps be regarded as the most important advantage, is the fact that the soudness of a weld can be judged by expert visual inspection, provided that correctly constituted heavy coated electrodes are applied. Thus the problem of control and inspection is solved in a simple, economical and efficient manner.

Building Regulations and Investigations.

One of the most important developments in welded structural steelwork in recent years is the movement on the part of public bodies to draft regulations for its control. Under the usual forms of building regulations, no methods may be used which are not definitely sanctioned with appropriate specifications and provisions for inspection. Therefore, the essential first step is to get welding recognised, naturally with safeguards for its proper execution. Welding committees have been formed in many parts of the world, and their research engineers are submitting welded construction to a more exacting scrutiny in many respects than has ever been made of riveted construction in the past. It may be ventured that more is now known of the behaviour of welded joints than the behaviour of riveted joints. There have been cases of the failure of riveted joints which have passed the scrutiny of boiler insurance inspector and hydraulic tests, traceable to the faulty manipulation of hydraulic riveters. Hence it is inaccurate to say that riveted joints can always be guaranteed after inspection by established methods.

In framing regulations one of the most important factors to be considered is the subject of " allowable stresses" or " factor of safety. " Needless to say most public bodies are inclined to err on the side of safety by specifying low allowable stresses. Whilst this is quite justifiable within reason, it should be borne in mind that the specification of a too high factor of safety is quite sufficient in itself to prohibit or seriously limit the welding of structural steelwork on economic grounds.

The recent report of the Structural Steel Welding Committee of the American Bureau of Welding states that the average ultimate tensile strength they obtained on butt welds (bare-wire) was 22.1 tons sq. in., on which the proposed allowable working stress of 5.8 tons per sq. in gives a factor of 3.81, which they assume to be satisfactory, as it compares with their normal steelwork factor of 3.1/3.

The generally accepted purpose of a " factor of safety " is to keep the load stresses well below the yield point, to allow a margin for indeterminate stresses, and for practical variations in materials and workmanship. Provided suitable specifications are drawn up to control the ability of the operator, electrodes, design and preparation of material, etc., there would appear little reason to anticipate greater variation in the quality and workmanship in welding than riveting. In other words it would not appear unreasonable to assume practically the same factor for welding as for riveting or the steel itself.

In Great Britain, for a 28/30 tons per sq. in. steel we have an allowable working stress in tension of 8.0 tons per sq. in (i. e., a factor of 3.5). It is generally recognised, and has been proved by test, that owing to the unequal distribution of stress induced in tension members by riveted joints, the actual breaking strength is reduced by 20 per cent., so that the effective factor of safety is 2.8 and not 3.5. In compression the allowable working stress is 6.5 tons per sq. in., which when compared with the yield strength of the steel 18.0 tons per sq. in. (the point of failure in compression) shows a factor of safety of 2.77, which is roughly the same as that for tension, The calculations assume that the shearing strength of the rivets bears a definite relation to the tensile strength of the parts joined ; often it is assumed that the two are equal. This strength does not come into full play unless all the rivets are equally good fits in their holes. The 20 per cent. reduction is meant to allow for possible departure from this condition ; it may sometimes be insufficient. Under these circumstances a factor for welding equal to that for the steel, or at the most 4.0 would appear to be ample.

In published results of recent investigations it would appear that much importance is attached to the determination of the static strengths of welded joints. Such values are of secondary importance except for use in design. Factors that deserve more attention are the resistance of welded joints to dynamic stresses, corrosion, solidity and ductility in the weld metal, and above all " consistency under practical conditions. " The future of welded steelwork must depend to a very large extent on its consistency under practical working conditions ; in other words on its reliability.

The main factors controlling economic and consistent welded production include intelligent design, sound organization and welding procedure, thoroughly trained operators and inspectors, and the employment of correct welding equipment and electrodes.

These factors would appear to present much more fruitful fields for investigation and subsequent control than the physical properties, of various types of welds, which are meaningless unless they forecast with a reasonable degree of accuracy the results that one may expect to obtain in practice.

Strengthening of Steel Structures by Welding.

The application of electric welding to the strengthening of steel structures has offered a valuable solution to railway and municipal engineers faced with the problem of coping with increased trafic loads and depreciation due to corrosion. Well over hundred bridges have been strengthened by welding on Australian railways, and quite a considerable amount of important work has been carried out in Great Britain. Similar operations are either in progress or contemplated in India, South Africa and certain of the Crown Colonies.

The main advantages claimed for the application of electric welding to the strengthening of bridges are briefly :

1. — In some cases the only alternative to strengthening by welding is complete renewal.

2. — Cost is invariably much less than when other methods of reinforcement are employed.

3. — Delays to traffic passing over the bridges are avoided or greatly reduced.

4. — In most cases underpinning or staging is unnecessary, and on principle the existing structure is not weakened or disturbed by the replacement of members and rivets in the initial stages as is often the case with alternative methods.

The strengthening of structures by welding may be divided into three broad classes :

1. — The reinforcement of riveting or riveted joints in which the welding and riveting act conjointly in carrying the stresses, as in the strengthening of lattice girder connections or plate girder flange angle and web splice riveting.

2. — The reinforcement of existing members by welding on additional plates or sections.

3. — The strengthening of girders by increasing their depth or by adding new members such as extra ties struts or cross girders, etc.

Combination of riveted and welded construction.

The question is sometimes raised as to how riveting and welding act in conjunction with each other, or in other words : " What is the strength of a riveted and welded joint?"

It is quite possible for a riveted connection to be reinforced by welding, and for the welding to bear the whole of the load and fracture before the riveting comes into play, due to the presence of " slip " in the rivets. In the case of an existing bridge, however, it must be borne in mind that the members are already bearing their dead load before the welding is applied, and furthermore it would appear safe to assume that the initial " slip " in the riveted joints has already been taken up owing to the continual variation in the stresses transmitted and the natural vibration of the structure. It has been found that the strength of a combined welded and riveted joint may be estimated as the ultimate strength of the welding plus the yield point strength of the riveting.

In strengthening lattice girder joints it is necessary to ensure that the additional stresses carried by the welding are transmitted across the joint to the member of either side; that is to say, clear of the sections that are weakened by the existing rivet holes, and this may entail the use of extra gusset plates.

Annexes auxquelles M. Caldwell se réfère et qui ont été déjà publiées :

Anhänge, auf die sich Herr Caldwell bezieht, und die bereits veröffentlicht worden sind :

Annexes to which M. Caldwell refers and which have been previously published :

H. E. Grove, Construction Engineer, Melbourne " Welded Steel Structures in Australia" (Electric Welding, June 1932).

H. B. Hanna, Plant Engineer, Toronto,
" Electric Welded Factory Building in Canada at Peterborough Works, Toronto" (Electric Welding, June 1932).

Rupert Worley, Chartered Civil Engineer, Hamilton and James R. Baird, Civil Engineer, Hamilton,
" Arc Welding Employed on the Hamilton (New Zealand) Stand Pipe Reservoir " (Electric Welding, June 1932).

Wilfred D. Chapman, Railway Construction Engineer, Melbourne,
" Notes on Arc Welding of Bridgework in Australia " (Electric Welding, June 1932).

Traduction.

L'emploi du procédé de soudure au chalumeau oxy-acétylénique n'a pas reçu, en Angleterre, un développement considérable en ce qui concerne l'assemblage et le renforcement des ponts métalliques; par contre, ce procédé a été beaucoup employé pour le découpage dans les travaux neufs et pour l'enlèvement des éléments de charpentes défectueux.

Par ailleurs, au cours de ces dernières années, la construction soudée électriquement s'est beaucoup développée ; c'est la raison pour laquelle nous nous