The Needs of Research on the Application of Welding in Steel Building Structures

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Historical Review

The use of welding in steel structures is of fairly recent introduction, dating back not more than some twenty years. Research in this field is consequently in its early stages, and is far from having reached its final goal, the development of widely used standards of practice. In fact, a large welded steel structure is, at present, still regarded as something in the nature of a pioneer achievement.

Economic factors may have had some influence on the limitation of development of welded steel structures. The majority of firms are equipped and staffed for dealing with the older methods of structural connection—rivets and bolts—for which established practice and standardisation reduces costs of construction. Welding requires high quality workmanship by skilled and carefully trained operatives, the supply of which may be difficult to maintain. Some reluctance on the contractors' part to use welding was inevitable. There was, it is true, a vogue for welded steel structures about fifteen years ago, at least in some continental countries; but its successful employment was dependent on making full use of certain advantages of this method. The advantages offered by welding were reduction of weight and improvement in slenderness, economy and appearance. To achieve these benefits, however, great care was needed; and the method involved undoubted risks and offered limited benefits. Nevertheless, welded steel structures seemed in 1936 to have achieved a successful and promising start, when a number of sensational failures of welded bridges put an end not only to the further extension of the use but even to the use itself of the new technique. In the author's opinion, the publicity given to the cases was both a consequence and a proof of the uneasy situation above described.

During recent years, a cautious resumption of the advance in the use of welding in steel structures seems to be taking place, although, in the author's opinion, the conditions prevailing at the outbreak of the last war have not greatly altered. Welding, in general, has certainly come into widespread use, but not without some known set-backs; so that it has not become generally recognised that welding is a suitable method for application to steel structures. The possible advantages are as mentioned above, but the margin of advantage remains, perhaps, insufficiently attractive.

Factors Inhibiting Research

It is clear that the circumstances outlined above are not very conducive to the extension or financing of research, particularly as research in this field is time-consuming and expensive. It is noticeable that, en in the publications of the International Association Bridge and Structural Engineering, including the orts of three International Congresses, of 1932 ris), 1936 (Berlin) and 1948 (Liége), in which many ributions are to be found on the subject of welded l structures, few are, in fact, dealing with real arch on this subject.

There is also an inherent reason for this: research on the application of welding to steel structures cannot proceed independently; it has always been dependent on research on welding itself, and more recently, after the first sensational failures, on research on the weldability of steel and on brittle fractures. This gives rise to another vicious circle, in which sporadic research reacts unfavourably on the development of the technique, and the latter in turn impedes the wider prosecution of research.

The author's views may seem pessimistic to some people, but they are based on the experience of a man who, for eighteen years, has devoted much of his time to research in the field of welded steel structures, in which field he found few co-workers and but little assistance.

Present Possibilities of Welding

Research concerning welding itself is very well advanced and is being prosecuted vigorously, mainly by the welding industry itself. Gas welding and electric arc welding are in brisk competition; of the two, the latter process is more appropriate for steel structures. Spot welding, also, is the subject of active research work, and may be of interest for light structures of cold-formed sheet steel.

The quality of weld metal may be generally considered as satisfactory for all uses. The strength of single welds, statical as well as dynamical, is well known, and is reliable if the welds are sound and free from defects of any importance. This requires that the soundness of important welds can be determined with certainty by inspection. In this respect, also, sufficient and reliable progress has been made. A favourable factor in most cases of steel structures for buildings which are statically loaded and not subject to fatigue, is that defects in the welds have only insignificant effects on their strength, provided that the defect is not so great as to make the weld obviously unsound. Small cracks, even, may be inoffensive, providing that the structure is free from dangerous intrinsic restraints. Although, in the author's opinion, the influence of fatigue on welded steel bridges has been in some senses over-emphasised and imperfectly understood, it is nevertheless certain that the risks arising from defective welds are much larger for bridges than for building structures. The same applies to comparisons with welded ships and welded pressure vessels or boilers.

For the same reasons, the use of butt welds in buildings is much less satisfactory than is the case with structures in which they are more accessible, such as pressure vessels or bridges. Fillet welds may be generally permitted, providing they are not stressed normally to the steel sheet but are properly disposed. Their strength is sufficient and reliable, they are easier and cheaper to weld, less liable to develop cracks, and cause less distortion and general restraints. Tests and practice have proved that it is better to use continuous fillet welds of small section than interrupted fillet welds of large section, even if the former provide rather more than the requisite strength. Suitable weld metal will always be available.

The question of the weldability of structural mild steel is, in the author's opinion, wrongly approached. It is governed at present by the problem of brittle fractures, resulting from the impressions caused by failures of welded bridges, welded ships and welded pressure vessels or pipes. The bearing of these failures on the weldability of mild steel for building structures is not evident. The author has found no evidence of welded steel building structures undergoing serious failures or defects. Then again, even in case of riveted work, steel specifications are never the same for building structures, bridges, ships and pressure vessels or boilers.

Erroneous Ideas Regarding Welding

There is, in fact, a good deal of confusion of thought on this subject; and clear thinking is in no way helped by some demands that are put forward, such as, for instance, that it is the task of the metallurgist to produce a steel that the builder could use in welded structures without any risk of failure even when serious mistakes are made in their design and their erection. It is just such unreasonable demands that give rise to the situation of which the author complains.

The steel structure of the Civil Engineering Institute of the University of Liége was erected during the winter of 1932-33 in the form of continuous frames with rigid joints, made of 58/65 (kg./mm.^{2})C-Mn-Cu steel, entirely welded. The design was made originally for 42/50 (kg./mm.^{2}) steel, but the contractor, a Belgian steel firm, proposed the use of higher tensile strength steel, which for some years had been used successfully for part-welded sheet piles.

The steel was produced by the normal Thomas process. It was admitted on the basis of the good performance of the sheet piles and on the results of weldability tests, which were not usual at that time. The design was modified to agree with the higher strength of the steel, without essential changes. The erection was carried out without any incident of note occurring, and no defects arose subsequently. In 1944, the building was heavily bombarded by high explosive bombs and suffered heavy damage, but the latter was localised and did not lead to collapse. Although fourteen main frames out of a total of twenty-five were damaged, the repairs required only fifteen tons of new steel out of a total weight of five hundred and ninety-five tons. The repairs were carried out by the same contractor, who was, however, very reluctant to use steel of the same strength, arguing that it was not weldable—an opinion that was in complete contradiction with the conclusions to be drawn from the ease of erection of the original structure, and with its remarkable behaviour under a test of a severity that had never been foreseen. Finally, although very extensive provisions and precautions had been drawn up in order to minimise the effects of welding, the contractor agreed to do the work only if he could use a specially-prepared steel, with a strength of 56/65 (kg./mm.^{2}) and satisfying new specifications for high weldability. The repairs proceeded without any difficulty. In fact, of course, the steel that had been good enough for the original structure, and that still constituted five hundred and eighty tons of it, would also have been good enough for the fifteen tons for repair work. The elaborate precautions taken with regard to these fifteen tons of steel are also in contradiction to the fact that, in spite of predictions to the contrary, the original steel easily withstood the considerable amount of cold-working and other drastic treatments necessitated by the repairs. On the other hand, the new and much better steel, which was capable of withstanding the worst conceivable conditions, was not called upon to do so, since every effort to avoid such conditions had been made in planning the repairs.

It is unfortunate that such absurdities should arise as the result of scientific research; they serve to emphasise that research can be worse than useless if it is not accompanied by correct interpretation and rational application. Therefore, in the author's opinion, the contractor must be capable of taking decisions regarding the quality of the welds and also the quality of the steel. The responsibility for these decisions must also be taken by him, and this constitutes yet another stumbling-block. The designer and the builder of a welded steel structure should, moreover, have a good knowledge of welding and of steel, and of the effects of welding on steel.

The Real Field for Research

This opens a large field of research, the true one for welded steel structures. It has so far only been surveyed by pioneers. It calls for civil engineers having the above-mentioned knowledge; they are at present rare. It was, of course, a mistake to think that it would be easy to go over from the traditional use of rivets or bolts to welding. The differences are so fundamental that it is not sufficient merely to change equipment and workmanship; the whole mental approach to the task must first be changed. The author met an illustration of this in 1930, when he designed a steel structure for the Chemical and Metallurgical Institute of the University of Liége, in the form of riveted continuous frames. Alternative projects for a welded structure were requested from the contractors. Only one was submitted and, strangely enough, it was higher in weight and in cost than the original riveted design, and less satisfactory in appearance. The structure, of 1,817 tons, was eventually erected to the original design in normal Thomas steel of 42/50 (kg./mm.^{2}) strength. Incidentally, it is interesting to note that this structure, also, was bombed at the same time as the above-mentioned welded structure, but with few hits. Nevertheless, the proportional damage was heavier in the riveted structure than in the welded.

Basic Considerations—Research with the practical aim of standardising the development of welded steel structures for building has to take into consideration the same factors as apply with any structural method: efficiency, safety, economy and appearance. The first and the last points are particularly questions of design, and some research is certainly necessary to discover which are the most favourable forms for welded structures. For instance, the use of continuity leads to forms of the kind that have become usual in reinforced concrete, but with special and distinctive features. Research has been carried out, with good results, on welded continuous frames; further research has been carried out or is in progress on the connections. Even if research has not been extensive and general enough concerning the effects of continuity and the corresponding connections, the author's opinion is that they offer considerable advantages of efficiency and appearance, and also of safety and economy. Research must be continued in this direction, but the results that are already available (although not widely known) are readily capable of application to large structures.

Types of Joist—Research on new forms of rolled steel joists, which has often been advocated, has not developed to any great extent, and is, in fact, of but little immediate interest. Special sections would be of interest only if they were mass produced, which is not probable within the foreseeable future. Round or square tubes and other hollow bars have been considered as promising and have actually been employed, sometimes in spectacular structures. They are available in large quantities, but are equally expensive whether they are produced by rolling or by welding. Their connections require rather complicated workmanship. Their mechanical properties are realised by equivalent H-bars. In most building steel structures, it will always be possible to evolve a suitable design with bars of existing sections. If the usual dimensions are exceeded, for large or high building structures, H-joists may be produced by welding, if necessary with the use of ribbed flanges. Some research has already been done, and still remains useful, on the strength and behaviour of such joists. They have at least one disadvantage with regard to economy and safety, that is the large amount of welding involved. On the other hand, large rolled joists may suffer from large internal stresses from the rolling : this also is a matter for research.

STRESS REDISTRIBUTION—In research, economy is coupled with safety, because if economy is the aim, the limit is safety. On the other hand, research on safety in the engineering sense generally implies economy. It is, in fact, on the subject of safety that research is essential. This aspect is already involved in the above-mentioned research on continuity, connections and welded joists. With regard to strength, there is no very difficult problem in the elastic range, but the behaviour of welded structures in the plastic range is greatly complicated by the difference in plasticity between the steel and the weld. The theories of elasticity and of plastic stress-redistribution are not reliable in welds and in their neighbourhood. If some kind of stress-redistribution is required, special features without welds should be provided. The author has no special knowledge of such features, and their use would have to be preceded by suitable research.

SHRINKAGE OF WELDS—A quite common subject of research in welded structures is shrinkage of welds, free or restrained, and welding stresses, local or general (in the case of restraint). There is a good deal of literature on these subjects, but not very much real and systematic research in a statistical sense. They are indeed of great importance, not only because the resulting distortions often produce serious difficulties, or the stresses give rise to cracks, but also from the point of view of design and safety. Research has shown that shrinkage is not only dependent on the section of the weld, but increases considerably with the thickness of the welded plates and also with the length of the weld (according to a logarithmic law.) It is already possible for the designer to make an accurate assessment of shrinkage, on a basis of dimensions and clearances. Stresses due to welding can also be predicted, with some degree of approximation in cases of restraint. They often reach the elastic limit (or exceed it as a result of cold-working). Stress relief by heat treatments is not very likely to be applicable in welded steel building structures. In order to minimise shrinkage, distortion and stresses, welds should be as small as possible, both in length and thickness. Fillet welds are generally more favourable in this respect than butt welds, and are reliable if fatigue has not to be considered. It is a question of design to avoid restraint as much as possible, at least over small lengths.

With reliable data regarding shrinkage and thermal expansion it is possible to make good use of the prestress due to welding, instead of being subjected to the generally undesirable effects of this consequence of welding. The author would like to quote from his own experience the case of a welded travelling crane of 13 m. span, for heavy dynamic duty of 15 tons maximum load, which has been working without any trouble since 1937. The girders consist of a straight joist sustained by a parabolic lower bow, in which prestress was introduced by heating prior to the execution of a butt weld. The rather large weld in question was satisfactory in all respects. The control of such operations requires sound knowledge based on research.

BRITTLE FRACTURES—Brittle fractures have been a subject of research on welding in recent years. As already mentioned, they have little to do with welded steel building structures. Critical temperature, triaxial stresses and fatigue are not generally involved. Incidentally, it may be observed that the above-mentioned welded steel structure in normal Thomas steel (non-killed), of 58-65(kg./mm.^{2}) strength, was erected and welded on the site during the cold winter of 1932-33 in the open air without any difficulty. The author considers that there is no point in increasing the cost of welded steel structures, by using highly weldable steels merely in order to avoid the consequences of possible major defects in the design or in its execution. It seems to the author to be more rational, both technically and economically, to employ steel of good normal quality and at normal cost and to avoid mistakes and defects as far as is humanly possible. Practice confirms these opinions. For other structures, such as bridges, ships and pressure vessels, similar principles will apply.

Conclusion

It is probable that the accumulated results of research will eventually provide a more generally reliable basis of knowledge for the design and erection of welded steel structures ; and the continuance of the competition between steel and reinforced or prestressed concrete will in the end ensure the final success of this new technique, economy and safety being reached by a progressive adaptation rather than by any kind of revolution. Such a result will be the outcome of research, however, rather than of inherent differences in the economy of these forms of construction.