Experience obtained with structures executed in Sweden

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Experience obtained with Structures Executed in Sweden.

Erfahrungen bei ausgeführten Bauwerken in Schweden.

Observations sur les ouvrages exécutés en Suède.

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Introduction.

One of the greatest of recent advances in Structural Steel Engineering has been the application of welding, particularly in bridge and structural engineering work. Until the time that mild steel and ingot iron was used for these purposes, and welding became a practical proposition, rivetted and bolted joints were being employed everywhere almost exclusively. Welding engineering brought about a radical change in this connection, comparable in importance only to the replacement of cast iron by mild steel, and the use of concrete as a competitor to steel.

Spread of the Welding Method.

The first practical experiments with welding as applied to steel structures were made in Sweden about 1930. The skeleton of a Mental Asylum was erected at Lund by welding methods, and in the same year the Harbour Board at Stockholm applied welding to the strengthening of two smaller bridges.

In the steel superstructure of the *West Bridge* in Stockholm, supplied in 1932—34 (Fig. 1)*, welding was used to a certain extent in the construction of the roadway, the upper horizontal bracing and the roadway columns, representing a total weight of roughly 2000 tons.

At about the same time as the steel superstructure of the West Bridge was being erected, the roadway girders (including bracing) of the *Tranebergs Bridge* (Fig. 2), which was otherwise constructed in reinforced concrete throughout, was being constructed as a welded steel structure. The total weight of the roadway framing amounts to about 1300 tons.

At a still slightly later date was built the *Pålsund Bridge* (Fig. 3)* which, together with the West Bridge, affords road facilities between the west and south parts of Stockholm. The steel superstructure of this bridge was almost entirely welded. A noteworthy feature is the construction of the transverse

* See theme VII a.

girders and arches. The latter were welded almost exclusively on the site. The total weight involved was roughly 1100 tons.

In 1935, the construction and erection of the new, fully welded superstructure of the (reconstructed) *St. Eriks Bridge* in Stockholm (Fig. 4) was begun. The total weight of the steel structure is about 1125 tons.

Finally, during the period from 1931 to 1935, about 3000 tons of welded steel structures of various types and smaller dimensions, including a few highway bridges, and also about 30,000 tons of welded steel electrical transmission masts were constructed. To these must be added a large number of other welded steel structures for the total weight of which no data are available.

The constantly increasing consumption of welding electrodes is a reliable indication of the increasing adoption of welding to steel structural work. The

Fig. 2.
Tranebergs Bridge.

annual consumption of electrodes in Sweden has risen from about 200 tons in 1925—30 to 1300 tons at present. Taking the average consumption of electrodes at 3 p. c. of the finished welded structures, this figure represents no less than 40,000 tons of welded steel structural work per annum.

Experience gained with Actual Welded Structures.

The welding process has developed to such an extent that welded structures can now be carried out with at least the same degree of safety as regards strength and resisting capacity, as rivetted structures. Welding also enables the designer to adopt simpler and more rational designs than are possible with rivetted structures, especially in conjunction with the shaping of the material by cutting.

Generally speaking, welding saves 17—25 p. c. on material and 12—15 p. c. on cost as compared with rivetted structures.

Nearly all bridge and structural engineering jobs can now be carried out by welding, and this with advantage and without any risk. Until recently, frame or latticework structures formed an exception, due to the shrinkage stresses set up, during cooling, in the various parts of the geometrically invariable latticework (framework) system. Recent experience shows, however, that even lattice structures can now be satisfactorily welded, provided suitable precautions are taken.

The conditions necessary for obtaining good strength properties in welded parts are (1) the employment of skilled and experienced welders, and (2), the selection of a weldable base metal, (3) electrodes suited to the material and the method of welding, and (4) suitable mechanical equipment. These conditions can now be satisfactorily met without special difficulties, but particular emphasis must be laid on the necessity of having a material that can be satisfactorily welded.

The dimensions of the welds are calculated in terms of a permissible stress which bears a certain relation — ascertained by experiment — to the permissible stresses of the base metal. The more homogeneous and perfect the weld, the

Fig. 4.
St. Erik's Bridge.

more closely will the permissible stress of the weld approximate to the corresponding stress of the base metal.

In many cases, a full 100 p. c. can be allowed without objection at present for certain welded joints under compressive stresses, and it is even possible that the limits for the 100 p. c. utilisation factor can be extended. As regards the stresses at present permitted in Sweden when fixing the dimensions of welds under existing specifications, it is pretty safe to say that there is a surplus of safety.

As regards the inspection of finished welds and the means for ensuring a satisfactory check, there is still much to be done before perfectly satisfactory methods of control can be achieved. Engineers in Sweden have hitherto been satisfied with inspection and various types of random tests, such as drilling, chiselling the weld at suspected points, cutting out test pieces with a pointed flame and also, where possible, by applying test loads. The X-ray method of examination has also been utilized, but this method is very expensive to use and requires considerable experience for properly assessing the results. Experiments with apparatus based on the use of a magnetic field have not yet led to any results capable of practical application. What welding engineering urgently requires is a simple, cheap and handy arrangement with which the finished weld can be thoroughly and reliably tested. It is impossible to overestimate the importance of such an arrangement, both from the practical point of view, and (morally) from the welders' standpoint.

Although very valuable practical experience has been gained in the practice of welding, there is still a great deal to be done before all the difficulties associated with welding are overcome.

It has been found, for instance, that the butt weld (single or double vee butt joint) is generally preferable to the fillet weld in the case of joints or connections where the transmission of a force involves the whole material of the weld. Straps should be avoided where possible, but if they cannot, they should be arranged so that no stress peaks can arise, and so that the power is satisfactorily transmitted by the welds. Further, when welded structures are being designed, care should be taken to avoid any arrangement capable of setting up stress peaks, or what are termed notch effects, as, for example, when gussets, plate stiffeners or similar parts are welded, at right angles to the direction of the force, to structural parts under tensile stress. If this cannot be avoided, the arrangement should be designed so as to reduce the notch effect to a minimum. At any rate, this particular problem calls for further investigation.

The above remarks apply primarily to structural parts subject to alternating stresses.

One of the most difficult problems calling for research and solution is the influence of heat and the means of eliminating or mitigating it. Warping and other deformations which occur due to the unequally distributed shrinkage stresses whilst the weld is cooling, often cause considerable difficulties in the production of welded structures, especially where these are complicated and of small dimensions. By adopting a suitable sequence in the welding operations, and by other precautions, the influence of the heat effect can in many cases be wholly or partly eliminated or neutralized. To find a suitable basis for assessing suitable methods of solving the deformation problem, however, calls first of all for a systematic investigation into the extent and distribution of shrinkage stresses, and the joint effect of the latter and the static stresses due to the weight of the structure itself, the traffic load, etc.

The officially regulations usually specify that welding on the site should be avoided where possible. There seems to be no valid reason for prohibiting erection-welding, provided the work is properly supervised and where vertical and overhead welds can be made as successfully as horizontal welds. Fundamentally, there is no difference between shop welding and welding *in situ*. Experience in the construction of the Pålsund Bridge in Stockholm (see p. 2) has shown that a temporary welding plant can be arranged on the job without special difficulties and with financial advantage.

By adopting automatic welding for the production of plate girders and the like, and by simplifying and improving upon old methods of welding, still further savings may be effected under certain conditions.

In order that welding may be utilized to the fullest possible advantage, the structure or its parts must absolutely be designed so as to allow of welding, but it will take some time before this aim is fully achieved, owing to the influence of the traditional method of rivetting.

The manufacture of new rolled sections more suitable for welding, together with standardisation sensibly applied, would doubtless contribute to the further development of welding as applied to structural engineering.

It would also appear desirable that the endeavours now being made in the different countries to promote welding technique and to put it on the right lines, should be directed towards ensuring that the standards for welded structures were, as far as practicable, made uniform and international in character.