The testing of welded bridges and structures

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The Testing of Welded Bridges and Structures.

Prüfung der geschweißten Brücken und Hochbauten.

Contrôle des ponts et charpentes soudés.

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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 stéel 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 (180^0), 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.)