Guidance Note 2.07

Welds – how to specify

Scope

This note gives general advice on the way in which to specify welds in contract documents and provides suggestions for further reading. It is based on the assumption that all welds are arc welds.

Terminology

There are a number of terms in this Note that are used with specific meanings. Where these terms are first used in the Note they are underlined. The most useful standard giving long-accepted definitions is BS 499-1:2009, *Welding terms and symbols: Glossary for welding, brazing and thermal cutting*. It is worth studying to avoid misunderstandings about the terminology used in this Guidance Note. This standard has been updated to substantially align with European and international lists of terms and definitions. There are subtle differences so care is necessary when they are invoked or cross referenced in contract drawings or specifications.

General

Guidance Notes GN 2.01 to 2.05 give advice about detailing of steelwork. They give guidance on how a bridge girder is assembled (i.e. how it is joined together) and give advice on where to put splices in plates, stiffeners, fittings and attachments. The prepared pieces of plate and section are brought together to be connected by (welded) joints.

These joints fall into seven defined types of joints: butt, T, cruciform (a double T), lap, plug (a form of lap), corner and edge.

Most types of joint, including corner joint, can be made by one of two main types of weld: butt or fillet (or combinations of both). Where two plates lie flat together, with their edges aligned, they can be joined by a kind of butt, defined as an edge weld. Plug welds or fusion spot welds are used to make some lap joints, although they are very seldom used in bridgework.

A butt weld is most commonly used, to join two plates which are co planar, to make one plate the continuous and wholly integral extension of the other. A fillet weld is used around a lap joint and where one plate meets another at or about a right angle (a corner or T joint). Sometimes, however, because of design requirements, corner, T and cruciform joints are required to be made with butt welds.

The type of weld chosen will depend most on its function. In the simplest terms, a butt weld is specified when the joint has to transfer the whole of the design force from one side of the joint to the other side, and/ or when there is a requirement for a joint of high fatigue classification. Where there is no need to transfer the full force, the connection can be made with fillet welds, by butt welds of partial penetration or with a compound of butt and fillet welds. Such joints have an inherently lower fatigue classification than full penetration butt welds and may not be acceptable in certain locations on a structure. (Refer to BS EN 1993-1-8 clause 4 for the design of partial penetration welds.)

Execution general

A weld is a particular way of making a joint; in a number of instances there is no practical alternative to welding. A welded joint has costs in preparation, in performance and in testing and inspection. Even before commencing production work there are costs in training and qualification of welders, and in performance, testing and certification of the welding procedures to be used (see GN 4.02).

Of the various types of weld, butts are considerably more expensive to make than fillets. Butts require careful preparation of the fusion faces and root face either by thermal cutting or by machining. The two parts then have to be brought together within close tolerances of alignment in plane and in the gap between the root faces. They have to be held in that position until sufficient weld is deposited to avoid significant and uncontrolled relative movement. The volume of weld metal laid is significant, often requiring several runs. The welding sequence is important: both to avoid distortion at the joint and to achieve the specified mechanical properties of the weld metal and adjacent parent metal. Finally, after the weld is completed, the requirements for, and extent of, inspection and testing are considerably more for butts than fillets. The requirements for inspection invariably include sub-surface (sometimes called volumetric) non-destructive testing of the weld metal, the adjacent fusion zone and the parent metal to confirm the integrity of the joint. The extent of inspection should be specified in the project documents along with any additional requirement for the preparation and destructive testing of test pieces (test coupons) for a representative sample of similar joints. In previous standards for steel bridgework, typically 1 in 5 joints in tension zones were specified to be destructively tested. The ratio was 1 in 10 similar joints for connections that experience no tension in service.

Fillet welds, on the other hand, are usually made at the junction of the flat surface of a plate (which requires no preparation except reasonable cleanliness) and the sides/ends of another flat plate (which only needs to be prepared square and straight). The require-ment for reasonably close contact between the parts to be joined (the root gap) is a positive advantage. The gap cannot be too small and sufficient contact is usually achievable by pressing together the two elements, which is necessary anyway to locate the attachment in the correct place. The control of the welding sequence is usually less of a problem (many fillets can be laid in one run) but it is sometimes necessary to balance the welding on each side of a joint to avoid distortion (rotation) of the attachment. Finally, except for large fillet welds (more than 12 mm leg length), the only inspection that can be performed is visual (although this does include checking the weld size) and non destructive testing for surface breaking imperfections.

Even with large fillet welds, where sub-surface, non-destructive, inspection is required e.g. ultrasonic examination, the results need very careful evaluation by an experienced NDT engineer to avoid unnecessary rejection due to spurious responses from the root and toes.

Design

The standard for the design of steel structures is BS EN 1993: Eurocode 3 - *Design of steel structures*. Part 1-1 covers general rules; Part 1-5 deals with plated structures; Part 1-8 deals with the design of joints; Part 1-9 deals with fatigue and Part 1-10 deals with with material toughness and through-thickness properties. BS EN 1993-2: *Steel Bridges* provides additional rules for the design of steel bridges.These Parts give guidance, among other things, as to where different types of weld may and may not be used.

Execution - specific

It is the designer's responsibility to determine the type of joint and type of weld at each location in the assembly. If a partial penetration butt weld is permitted, the designer is required to specify the extent of penetration and, for fillet welds, the required size. However, the fabricator chooses how to perform the work, the sequence of assembly, the order and orientation of the joints for welding and the welding process(es) / welding sequence to be employed. These choices rely on the experience and competence of the fabricator and are based on enabling the work to be performed in the most economical manner whilst achieving the specified requirements. This typically involves selecting the shape of the weld preparation, the root face, root gap and included angle which can be different for the same type of weld when performed a different way and/or with a different process.

BS EN ISO 9692 is published in **multiple** parts and recommends weld preparations for manual welding processes in Part 1 and for submerged arc welding in Part 2. Butt and fillet weld joint preparations in various configurations are tabulated and shown in some detail with an illustration and with fully dimensioned cross-sections for each referenced (numbered) weld. However, the Introduction does make it clear that the requirements given in the Standard have been compiled on the basis of experience, and contain dimensions for types of weld preparation that are generally found to provide suitable welding conditions. It recognises that the extended field of application makes it necessary to give a range of dimensions, representing design limits as stated above, and that these are not tolerances for manufacturing purposes. Hence, the examples given cannot be regarded as the only solution for the selection of a joint type.

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Designer: limit specification to the provision of information on the location, dimensions and types of all welded connections. This information should be put on the contract drawings in accordance with BS EN ISO 2553. For butt welds, specify whether these are full or partial penetration. If partial specify the degree of penetration and the minimum design throat thickness rather than giving a percentage. If there is a particular concern about fatigue strength, specify the requirements for the surface finish of the weld profile. Any welded joints requiring specific welder approval and/or pre-production welding trials should be identified in the contract documentation, on the drawings and in the project specification: see also GN 4.02.

Fabricator: provide information on the dimensions and details of the weld preparations that are intended to be used. Where no application standard is invoked by the project specification these should be in accordance with the examples given in BS EN ISO 9692. (The designer should check this.) If the proposals are not in accordance with the recommendations of the standard, the fabricator should be able to provide acceptable reasons to the designer for going outside the ranges, but may still be required to demonstrate acceptable performance by carrying out appropriate tests. See GN 4.02.

Both designer and fabricator: use a consistent system of welding terms and symbols, for example those given in BS 499-1 and BS EN ISO 2553.

Other considerations

This note deals with the specification of welds. It does not cover rectifying defects that may arise during the execution of the welding. In effect, the act of specification assumes that the weld will be executed without significant departure from the requirements with regard to size, shape, penetration (or otherwise), surface finish, reinforcement, etc. Clearly, however, in a complete fabrication there will be departures from intent during execution of the work. BS EN ISO 5817 gives guidance on quality levels for imperfections. However, Guidance Note 6.01 has been prepared to provide additional advice on the subject and should be taken into consideration by the designer when setting acceptance criteria for weld imperfections which are different or additional to those in the application standards. The designer should also consider the project specific documentation.

Reference standards

[1] BS 499-1: 2009, Welding terms and symbols. Glossary for welding brazing and thermal cutting.

[2] BS EN 1993, Eurocode 3: Design of steel structures (in many Parts)

[3] BS EN ISO 5817: 2023, Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections.

[4] BS EN ISO 2553:2019, Welding and allied processes. Symbolic representation on drawings. Welded joints.

[5] BS EN ISO 9692: Welding and allied processes- Types of joint preparation.
Part 1:2013 Manual metal-arc welding, gas-shielded metal-arc welding, gas welding, TIG welding and beam welding of steels.
Part 2:1998 Submerged arc welding of steels.

Other references

For those who are interested in actually designing welds the following is a useful simple guide:

A guide to designing welds, Hicks J, Abington Publishing, 1989.

Note: The reference by Hicks is dated albeit it still provides much relevant information.