Control of weld quality and inspection

No. 6.01

Scope

This Guidance Note gives general information about controlling the quality and inspection of welds in structural steelwork for bridges. The intention is to provide an appreciation of the factors that can influence weld quality, and the inspection practices currently used before and during welding for the fabrication and erection of bridge steelwork.

Welding quality requirements

The execution standard for steel structures EN 1090-2 (Ref.1) gives technical requirements for welding and these are supplemented by other documents necessary to specify fully the work to be carried out for the particular project. Generally the drawings provide the detailed requirements, supported by the project specification.

For highway infrastructure projects, the project specification comprises the Specification for Highway Works Series 1800 (Ref.2), supplemented as necessary by an 'Appendix 18/1' (which covers project-specific requirements). The SHW interprets and implements recommendations in PD 6705-2 (Ref.3), which introduces the concept of Quantified Service Categories (QSC). The QSC characterizes a component or structure (or part thereof) in terms of the circumstances of its use within specified limits of static or cyclic stressing. Six levels of QSC are designated, depending on stress level. See GN 2.12 for guidance on specification of QSC.

The QSC determines the method, frequency of testing and acceptance levels, which are different from those in EN 1090-2.

Generally, EN 1090-2 requires that fusion welding shall be undertaken in accordance with the requirements of the relevant part of EN ISO 3834.

EN ISO 3834 comprises a number of parts that describe the requirements necessary to ensure that quality is achieved by control of manufacture: it is recognized that quality cannot be added after manufacture by an inspection procedure. The document deals with all aspects of welding, from a technical review of the requirements through planning and process control to inspection and testing and control of records.

For bridgework, EN ISO 3834-2 (Ref.4) is relevant and this specifies comprehensive requirements for controlling weld quality. There are many essential tasks to consider in welding, some practical influences are:

- Materials
- Preparation and fit-up conditions
- Welding procedures
- Welder approval
- Control of parameters before and during welding
- Inspection and testing after welding
- Acceptance criteria

Materials

Consideration must be given to the type and grade of material to be welded, particularly where additional properties such as toughness are specified. For carbon manganese steel, the carbon equivalent (CE) value is a measure of weldability. The CE, together with the combined thickness of the parent metal, heat input and the hydrogen content of the consumable, determines the preheat requirements for the weld necessary to avoid hydrogen cracking, although there are significant other considerations to take into account when assessing the overall risk. EN 1011-2 (Ref.5) Annexes C and D provide detailed guidance on avoiding hydrogen cracking and on heat affected zone toughness and hardness.

Inspection certificates for steel must be authenticated to verify the applicable standard and relevant material grade. All principal steelwork including flanges, webs, stiffeners, diaphragm plates, bracing members, cover plates, etc. should be traceable to material inspection certificates throughout the fabrication process. A practical approach to piece, type or stock traceability is as follows:

- For flanges, webs and diaphragms in main girders, the records should be maintained for each individual piece. A unique item mark should be made on each piece.
- For stiffeners, splice plates, bracing members and fasteners, the records should be maintained for each item type, of which there can be many individual pieces. Products of one type may come from more than one source and be installed in more than on location.

- For welding consumables and shear connectors, the records should be maintained according to stock certification, which should show that the stock material meets the project requirements.

Preparation and fit-up conditions
The successful deposition of a satisfactory weld is dependent on the preparation and fit-up conditions. A correctly prepared and assembled joint should enable the welding operative to deposit a satisfactory weld.

Normally, weld preparation and fit-up conditions for both butt and fillet welds should be in accordance with the Welding Procedure Specification (WPS), although additional tolerances, such as those given in the applicable welding application standard (usually EN 1011), may apply. Examples of preparation and fit-up conditions for a typical flange to web fillet weld joint are shown in Figure 1 and for a typical asymmetric double V flange plate butt joint welded from both sides in Figure 2. Note that for fillet welds, any increase in the root gap requires a proportionate increase in leg length of the fillet weld in order to maintain the effective design throat thickness of the fillet weld. See GN 5.01 for more information on joint preparation and fit up considerations.

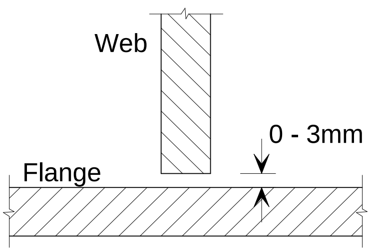

Figure 1 *Typical flange to web fillet weld joint*

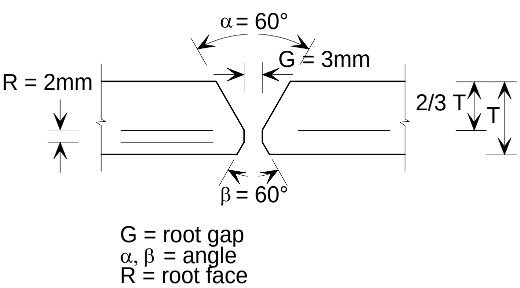

Figure 2 *Typical asymmetric double V flange plate butt weld joint*

Weld preparations should be examined visually and checked dimensionally using a suitable gauge capable of measuring bevel angle, root face and root gap. Preparations range from simple flange-to-web fillet welded joints as in Figure 1 and in-line butt welds in plated girders as in Figure 2, to more complex cruciform joints and corner connections in box girders.

Whilst inspection of the fit-up conditions and weld preparations on most connections is usually examined on a random basis, it is prudent to inspect the assembly of all critical joints such as tension flange butt welds, fitted bearing stiffeners etc. Weld preparations and fit-up conditions that do not comply with the relevant WPS or the tolerances given in the application standard must be rectified.

Welding procedures
Welds can be deposited using a variety of processes including:

- submerged arc welding (SAW)
- gas-shielded metal arc welding (MAG or FCAW)
- manual metal arc welding (MMA)

Of these, SAW and MAG are the most commonly used in the fabrication of steelwork for bridges. Cored wires are increasingly being used, particularly because of the higher deposition rates, positional versatility and the ability of the flux to influence the weld chemistry. More reliable, compact power sources and wire feed units have enabled site constructors to utilize gas-shielded processes on site to take advantage of high deposition rates and improved weld integrity. Good draught-proof shelters are essential to achieve the benefits of these processes under site conditions. MMA welding remains the preferred site process where access is difficult or the economics of more complex equipment requirements are just not viable. For more information on site welding see GN 7.01. Examples of site joints are shown in Figure 3. Summary descriptions of the processes are given in GN 3.04.

In order to ensure that the quality of the deposited weld metal is to an acceptable standard, welding must be carried out in accordance with a suitably approved WPS drafted in accordance with EN 15609-1 (Ref 6). Such a specification is normally based on a scheme specific or prequalified

Welding Procedure Qualification Record (WPQR) in accordance with EN 15614-1 (Ref.7). Procedures approved in accordance with former standards or specifications, e.g. EN 288-3, are not invalidated by the issue of this standard, provided that technical requirements are equivalent. GN 4.02 describes in more detail welding procedure testing and the formulation of WPS based upon the ranges of qualification.

During production welding, parameters should be set within the ranges established during qualification of the welding procedure, taking account of welding position, preparation and fit-up conditions.

Welder approval

Another important aspect of welding is to monitor the competence of individual welders or machine operators. The requirement for qualification or approval testing is prescribed in specifications and standards but the success of all welding projects relies heavily on the workforce having appropriate training.

Qualification testing for bridgework in the UK is normally carried out in accordance with the requirements of EN ISO 9606-1 (Ref.8). The standard prescribes tests to be conducted to approve welders for process, type of joint, position, filler material and material thickness. Welder qualification tests carried out in accordance with “current, superseded” standard EN 287-1 are still valid during the transition to the more recent standard.

Control before and during welding

Maintaining control before and during welding is essential to achieve a successful result. EN ISO 3834-2 defines the in-process inspections and tests necessary.

Prior to welding it is important that welding consumables are as stated on the WPS and that they have been stored in accordance with the manufacturer’s recommendations. In addition, any other requirements of the WPS must be implemented, for example, application of preheat and any distortion control measures.

To ensure that parameters are controlled satisfactorily during welding, it is essential that welding plant is serviced and calibrated, so that the equipment settings can be adjusted accurately. Periodic checks should be made during production welding using calibrated meters to confirm that the essential parameters stated in the WPS, including current, voltage, travel speed etc. are adhered to and welding consumables are correctly used and handled. Preheat should be maintained throughout the welding processes and where appropriate interpass temperature monitored. Attention should be paid to the welding sequence, the cleaning and shape of runs and layers, the profile and integrity of back-gouged butt welds. Intermediate checking of dimensions may justify a change of strategy and it is sometimes prudent to modify the welding sequence to balance weld shrinkage and control distortion. Additional precautions may be necessary because of environmental conditions, for example during site welding operations.

Inspection and testing after welding

Welding is not perfect: following deposition, a weld may contain imperfections or discontinuities. Unacceptable imperfections (defects) prevent the weld from developing the strength or fatigue life intended by the designer. Imperfections may be visible on the surface of the weld, or they may be sub-surface, embedded within an otherwise visually satisfactory weld. The detection and sizing of imperfections are dependent on the inspection methods and the extent of testing specified in the application standard or contract. It should be appreciated that with non-destructive examination it is not possible to detect, characterize and size all the imperfections that may be present in the weld.

What is important is whether any imperfections that exist in the welded components are likely to affect the satisfactory performance of the structure, i.e. to affect its ‘fitness-for-purpose’. If they do, they should be considered to be defects and repaired accordingly.

In practice, quite large imperfections (either a few large isolated ones or numerous small ones) can exist without compromising the static ultimate strength of the element or structure. However, imperfections can have a greater effect on fatigue strength, since they can grow as a result of cyclic loading. The level of imperfection that can be tolerated in a welded detail therefore depends on the fatigue loading that the welded detail is required to endure. An effective testing regime and quality acceptance specification will seek to determine what level of imperfection exists, and then judge whether these will impair the fitness-for-purpose of the structure. To call for the repair of imperfections that do not reduce fitness-for-purpose is not only an unnecessary waste of time and resources, but introduces other imperfections, often large enough to be defects, in the course of repair.

Various inspection and test methods are used to ensure the integrity of completed welds and are described in other Guidance Notes. The visual inspection of welds is described in GN 6.06. Non-destructive testing techniques such as the surface inspection of welds using magnetic particle testing (MT or MPI) and penetrant testing (PT), and the sub surface inspection of welds using ultrasonic testing and radiography, are the subjects of GN 6.02 and GN 6.03 respectively.

Acceptance criteria

Generally, workmanship standards for all aspects of the execution of steelwork are given in EN 1090-2 in relation to the 'execution class'. Four classes are defined and class EXC3 is appropriate for most bridge steelwork.

The quality of production welds is specified in terms of weld acceptance levels. For each form of imperfection these will place limits on the occurrence or maximum dimension of the imperfection. For EXC3 welding quality is specified as Quality Level B to EN ISO 5817 (Ref.9). Any additional requirements for weld geometry and profile need to be specified.

For highway works, the SHW provides full acceptance criteria depending upon the Quantified Service Category (QSC) for each joint. If a higher quality level is required, for example where joints are required to have an enhanced design fatigue strength, the QSC should be specified for each relevant joint detail and the extent and method of testing can be determined to detect imperfections and to characterize them. Clearly the simpler that this is stated in the project documentation the easier it will be to implement in practice. GN 6.02 and GN 6.03 provide further information on surface and sub-surface examination of welds.

The results from inspections should be recorded formally in a report giving details of the items examined, weld identification, acceptance criteria, reference to the procedure used, together with the results of any visual inspection carried out.

Welding coordination and inspection personnel

EN ISO 3834-2 requires that welding coordination personnel shall be responsible for the quality activities associated with welding and such persons shall have sufficient authority to enable any necessary action. For the grade and thickness of materials used in bridges welding coordination personnel should have a comprehensive knowledge of welding as defined in EN ISO 14731 (Ref.10).

All inspection to ensure the quality of the completed welding shall be carried out by appropriately qualified and experienced personnel as required by EN 3834-2. Non-destructive testing, such as ultrasonic testing or magnetic particle testing should be performed by personnel qualified in accordance with EN ISO 9712 (Ref.11).

In many cases, the services of an independent testing organization will be engaged, in addition to the inspection carried out by the fabricator. This independent organization will normally place an inspector at the works on a full- or part-time basis to monitor the inspection carried out by the fabricator as part of the production process, and also to carry out verification testing in parallel.

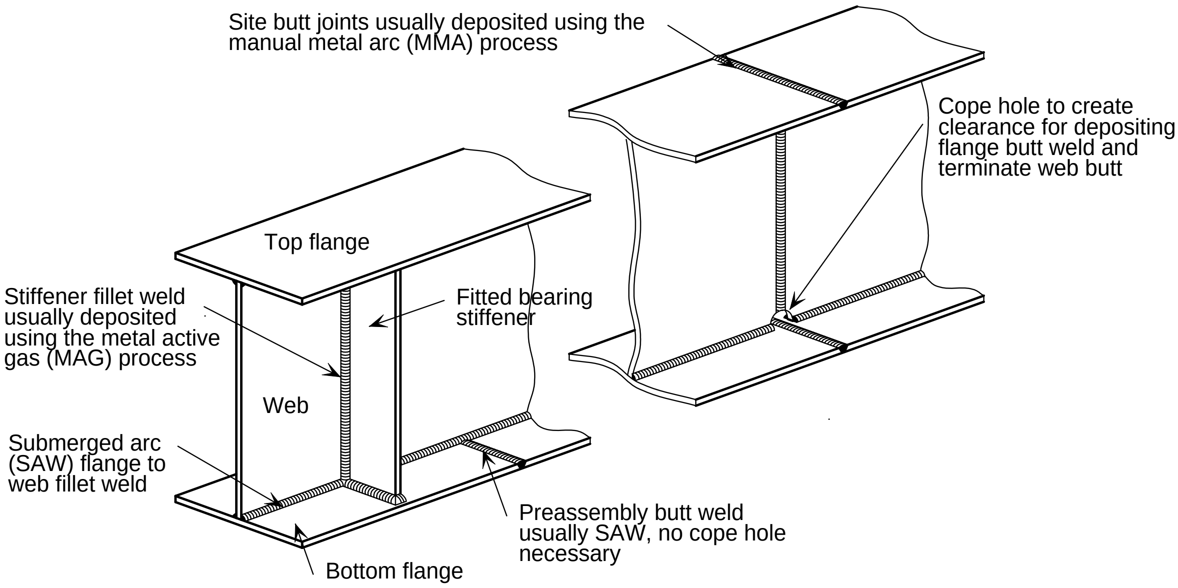

Figure 3 *Use of SAW, gas-shielded processes and MMA in bridge steelwork*

References

1. EN 1090-2:2008+A1:2011 Execution of steel structures and aluminium structures. Technical requirements for steel structures.
2. Manual of Contract Documents for Highway Works. Volume 1 Specification for Highway Works. Series 1800 Structural steelwork. Amendment – August 2014, TSO.
3. PD 6705-2:2010+A1:2013 Structural use of steel and aluminium. Part 2: Recommendations for the execution of steel bridges to BS EN 1090-2.
4. EN ISO 3834-2: 2005 Quality requirements for fusion welding of metallic materials – Part 2: Comprehensive quality requirements.
5. EN 1011, Welding. Recommendations for welding of metallic materials.
   Part 1: 1998, General guidance for arc welding
   Part 2: 2001, Arc welding of ferritic steels.
6. EN ISO 15609-1: 2004, Specification and qualification of welding procedures for metallic materials. Welding procedure specification. Arc welding.
7. EN ISO 15614-1: 2004, Specification and qualification of welding procedures for metallic materials. Welding procedure test. Arc and gas welding of steels and arc welding of nickel and nickel alloys.
8. EN ISO 9606-1:2013 Qualification of welders. Fusion welding. Steels.
9. EN ISO 5817: 2014, Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections.
10. EN ISO 14731: 2006 Welding coordination – Tasks and responsibilities.
11. EN ISO 9712:2012 Non-destructive testing – Qualification and certification of NDT personnel.