Site welding

No. 7.01

Scope
This Guidance Note focuses on the practical management and control necessary to achieve satisfactory performance of site welding operations.

General
Technically, there is very little difference between undertaking bridge welding operations at site and in the workshop. The principal differences relate to issues of accessibility and the varying environmental conditions encountered, but with careful control, a range of welding techniques and practices can be as effective in the site environment as in the shop.

Inevitably, there are costs associated with managing any site operation, and economics will dictate whether welding is more cost effective than bolted joints. Handling and lifting activities and the provision of resources in terms of equipment and labour all contribute to the decision-making process. There are, of course, many other considerations and each project has to be assessed on individual merits. For a comprehensive review and a tabular comparison between welded and bolted splices, see GN 1.09.

Characteristics of site welded joints
The location of site joints is normally determined at the design stage. Designers locate joints at points of contraflexure and/or where there may be intended changes of plate thickness. Ideally, the site joints should be in the thinnest materials, to minimize welding times and thus reduce costs.

Most site welds on bridgework are in-line butt welds in several positions including flat, vertical and overhead. Some fillet welds are required, for example to continue the web to flange joints or to introduce a stiffener or other member omitted in order to provide improved access for welding.

Shop trial assembly ensures reasonable fit up and alignment of joints but frequently site conditions cause variations in root gaps and misalignment of flanges and webs during construction. Some form of designed connection, either bolted brackets or welded landing cleats or a combination of both, is necessary to connect the girder sections in the temporary condition prior to welding either at ground level or in the air. These temporary connections are normally removed after joint completion to restore the clean lines of the bridge. Temporary welded attachment areas need non-destructive testing to ensure that no unacceptable imperfections remain.

Access, working platforms and shelters
Safety is always the prime consideration and all activities must be conducted in accordance with current statutory legislation.

Shelters are needed to provide protection for the operatives and to shield weld areas from wind and rain. Well-designed shelters provide an environment relatively free from draughts but running water is more difficult to protect against. To protect weld zones, more primitive methods of protection are needed, such as ‘putty dams’ to divert water flows away from the welding area.

Many or all of the joints require temporary access to be provided. Working platforms must be at a suitable height to enable welding to be undertaken in as much comfort as possible. Variable height platforms may be required on deep section girders to provide access to all parts of the joint.

It is necessary to protect the public, other trades and contractors from the risk of falling objects, grinding sparks and ultra-violet light from the welding arc. Fire risks need to be controlled and any hot metal spillage must be contained within the welding area in fire blankets or other non-flammable material. Molten metal dropping on timber boards can smoulder for many hours after work has ceased and can burst into flame when fanned by the wind.

Gas equipment needs to be regularly inspected to check for leaks and damage. Hoses carrying flammable gases for cutting and welding should be routed away from the immediate welding area and removed completely from enclosed areas, when not in use.

Inside box girder sections or other spaces where there is difficult access or poor ventilation, consideration should be given to the need for fume extraction and confined space working procedures.

Power supply
Power is normally generated at site; it is rare to be able to pick up mains power to run equipment on bridge construction projects. The site needs and location dictate the economics of how this is done. One option is to have large primary generators powering several welding sources and perhaps other pieces of equipment, such as lights and power tools, via a distribution board. Alternatively, each welder might have his own mobile generator complete with welding and auxiliary power to run grinders and other electric hand tools. The latter system provides the flexibility to work on several remote fronts and does not stop everybody working in the event of a major breakdown on primary generation plant.

Electrical equipment is subject to safety regulations; installations should be checked regularly by qualified personnel. Clearly, equipment including personal protection equipment should be kept dry and in good condition to avoid the risk of electrical shock or burns. Damage to equipment and cables should be reported and regular inspections made to ensure earth connections are making good contact.

Refurbishment projects
On refurbishment projects, site welding may include joining to or repair of existing structures and thorough site tests and investigations have to be undertaken to identify the material type and composition and to establish weldability. Clearly older materials are likely to present more welding complications than more modern materials of known history.

It should also be noted that the effects of direct high temperature flame or arc on some construction materials, such as lead-based paints and cadmium plating on bolts, produce highly toxic fumes that can create a severe hazard to health. Thorough investigation of the existing structure and risk assessment is essential before any cutting or welding operations are permitted.

Contaminants such as oil, grease and paint have to be removed prior to welding operations taking place. The use of solvents and paint strippers necessitates appropriate risk assessment and safety precautions.

Where the nature of existing material is uncertain (and thus the determination of suitable welding procedures is difficult) it may be helpful to take small samples for chemical analysis (from non-critical locations) using a Rotabroach tool. It is worth retaining any material that is removed as part of the refurbishment, so that test samples can be made.

Procedure control
All site activity has to be controlled in accordance with written and approved method statements; welding operations are no exception. Risk assessments should address all potential site hazards including those specifically associated with welding operations. The method statement needs to include safe systems of work to overcome the hazards and to protect the workforce.

Welding procedures are an integral part of the method statement. Formulating welding procedure specifications should be under the control of welding coordination personnel appropriately qualified, trained and experienced. Bridgework specifications typically require qualification testing of welding procedures in accordance with EN ISO 15614-1 +A2 (Ref 1). Procedures qualified in accordance with former national standards or specifications are not invalidated by the issue of this Standard, provided that technical requirements are equivalent.

Based upon these tests, detailed working procedures can be developed specifically for the project. Procedure development is influenced by the following factors:

Processes:
The two most important factors that affect welding costs are deposition rates and duty cycle. (‘Duty cycle’, in this context, is the ratio of actual welding (arcing) time to the total time, from setting-up before welding to final checking and cleaning of the completed weldment. It is sometimes referred to as operator efficiency.) These factors are very much process-dependent and in turn influence the choice of site welding process.

Several welding processes are viable under site conditions and it is a matter of selecting the appropriate one for the application. The following comments are made in relation to the use of common welding processes (process numbers are as defined in EN ISO 4063 (Ref 2)).

- **Manual metal arc (MMA) welding - Process 111**
  This is the most widely used process for site welding because of its versatility and relatively simple equipment. It may well be the only practicable method where access is difficult or the joint is remote from the power source. Hydrogen controlled basic electrodes are required for welding of carbon manganese and low alloy steels and stringent storage controls are necessary to preserve their low hydrogen characteristics. Deposition rates and duty cycles are relatively low. The process produces its own gas shield around the arc from the flux coating. While this is a fairly robust process, it still needs shielding from direct draughts to avoid welding defects.

- **Gas-shielded metal arc welding - Process 13**
  Metal active gas (MAG) with solid wire - Process 135
  Tubular flux cored wire (FCAW) - Process 136
  Tubular metal cored wire (MCAW) - Process 138
  All of these processes can be effective at site and provide good deposition rates. However, the requirement for a gas shield necessitates good environmental protection otherwise draughts can blow away the gas and cause porosity and possible metallurgical changes. Solid or metal-cored wire electrodes can be used successfully in the flat and horizontal positions, whilst flux-cored wires are better suited to positional welds.

  The main disadvantage of these processes is the more complex equipment required. Rectifier or inverter type power sources and shielding gas bottles are normally situated at ground level. Wire feed units generally have to be positioned close to the working area. Long interconnecting cables are required if the working area is remote. Duty cycles are higher than for MMA welding because there is no regular electrode changing and welders can sustain longer weld runs. Poor equipment management may adversely affect the duty cycle and regular maintenance is vital to prolong equipment usage.

- **Self-shielded tubular cored arc welding (Innershield) - Process 114**
  This process offers good productivity, with similar equipment to that for processes 135, 136 or 138. It has the advantage that a separate gas shield is not required and welding can be undertaken in somewhat less effective shelters. Tight procedural control is required to ensure the mechanical properties of the weld.

- **Submerged arc welding - Process 12**
  Submerged arc welding with one electrode - Process 121
  Submerged arc welding with tubular cored electrode - Process 125
  High deposition rates can be achieved with these processes but they are limited to flat plate butt or fillet welding and generally would only be economically viable in situations where long joints in thick plates or large fillets are required. The processes are normally mechanized on a tractor carriage unit and the equipment is therefore bulky and some form of guidance may be needed to follow the weld preparation. Other process variants include multiple wires or metallic powder additions but equipment becomes increasingly complex and impractical for site use.

  Most submerged arc welding fluxes are hygroscopic in nature and stringent handling procedures are necessary to condition the flux and to control weld metal hydrogen levels.

- **Drawn arc stud welding with ceramic ferrule - Process 783**
  For bridgeworks, welded shear stud connectors are required for composite construction or threaded studs are sometimes welded on for fixing formwork. These are normally shop welded to beams and girders, but occasionally, it becomes necessary to carry this out on site. Specialist subcontractors have mobile equipment capable of undertaking this operation. Pre-

production testing is required to ensure correct operation and performance of the equipment.

For situations where there are very few studs to attach at site, for example to replace damaged, missing or incorrectly positioned studs, it may be quicker and easier to manually weld on the studs. This requires the same procedural controls as previously described and appropriate design checks on weld type and size to ensure their integrity.

Welding position:
The nature of bridge construction necessitates the welding of girder sections in position either before erection on the ground or after erection from access platforms. Typical I-section girder flanges are normally filled in the flat (PA) position from the top; backgouging and welding to completion takes place in the more difficult overhead (PE) position. The web is normally welded from one side and back gouged and completed from the other side in the vertical (PF) position. Large cope holes are required in the top and bottom of the web to provide continuity in the transverse flange welds. Infill plates may require butt welding into the web to fill these holes upon joint completion and testing. Horizontal-vertical (PB) and horizontal-overhead (PD) fillet welds complete the joint. Working positions are defined in more detail in EN ISO 6947 (Ref 3)

Inclined webs of trapezoidal box girder sections and other architectural bridge designs may require intermediate positional welds and these need to be considered accordingly.

Joint set up and accuracy:
Provided that a satisfactory trial assembly is undertaken at the steelwork contractor's works, there is every chance that the site joint set up will be accurate. However, it is inevitable that site conditions necessitate small adjustments to deal with plate misalignments. Experienced contractors anticipate this possibility and provide jacking and wedging equipment to effect these adjustments. Root gaps can be adjusted by trimming or weld metal build up, under procedure control to ensure that the welding conditions are within the range of dimensional tolerances allowed by the WPS.

Many contractors use ceramic backing to support the first run of weld deposited in the root area, to improve quality. These backings are supplied in a variety of shapes and sizes to fit on or in joints. Adhesive foil tape holds the ceramic backing in place. The advantage is that a higher current than normal for root runs can be used to deposit the first run, thus minimizing the risk of fusion defects and ensuring a consistent penetration bead. The regularity of the penetration bead means that a minimum backgrind, if any, may be all that is necessary to dress the root prior to second side welding.

Sequence:
Careful sequencing of the welds is necessary to reduce the risk of distortion and to minimize the building in of residual stress. With splices in I-section girders, the flanges are normally welded first, to allow the shrinkage forces to distribute themselves without any web plate restraint. Web gaps are sometimes deliberately set wide to allow shrinkage to occur, thus leaving the intended gap prior to commencing the web weld.

Large box girders may need a stepped welding sequence to distribute shrinkage forces in a balanced way to reduce the risk of distortion. It is very important to maintain dimensional control and to adjust the sequence if necessary to counteract distortion effects. It is more difficult to correct out-of-tolerance shape after welding than to take sensible precautions before and during the process.

Preheat:
Preheating joint areas prior to welding and maintaining heat during welding is part of a strategy designed to avoid hydrogen (or cold) cracking of welds. It is an expensive operation and often difficult to control, particularly under site conditions. Temperature is dependent on factors including material thickness and composition, weld heat input and the hydrogen potential of the process used. EN 1011-2 (Ref 4) gives detailed guidance and methods for calculating preheats.

Applying preheat promotes the diffusion of hydrogen from the weld and heat affected zone and reduces thermal shock effects. In addition, it modifies the rate of cooling of the weldment to lessen the risk of forming crack susceptible microstructures in the heat affected zone.

Modern steel-making processes produce structural steels with good weldability and careful balancing of the factors affecting hydrogen cracking can reduce the preheat requirement. Conditions requiring more stringent procedures are discussed in the Standard; of particular relevance to bridgework are the comments on joint restraint. In any event, it is prudent to include in the procedure an instruction to warm the joint prior to welding to dispel any moisture present from, for example, damp weather or early morning condensation.

Methods of applying heat at site normally include using an oxygen-fuel gas lamp fitted with purpose made heating nozzles. Time needs to be allowed for heat to distribute through the thickness of the material. Temperature-indicating crayons or contact thermometers can effectively measure temperature. Larger lengths of joint in very thick materials may justify the cost of electrical resistance type heaters or portable induction heating equipment, which can be controlled using thermocouples to maintain accurate temperature.

It is important to keep a regular check on preheat temperature; the effects of cold weather and inherently large heat sinks can lower steel temperature rapidly.

Maintaining or even increasing the temperature for a period of at least 2 hours as a post heat-treatment assists the hydrogen diffusion process and can be included in the procedure. Control of post heating can only be done effectively using an electric heater system.

Consumable storage:
All welding consumable electrode products need to be stored in a clean, dry environment. Traditionally, hydrogen controlled electrodes are supplied in shrink-wrapped cardboard packaging. These need transferring to a drying oven before use to ensure that anticipated low hydrogen properties are achieved. Welders are issued with a quantity of electrodes in a heated quiver to maintain controlled storage at the work place.

Increasing use is being made of electrodes supplied in vacuum-sealed packaging, e.g. tins, foil wrap and plastic tubes. These are supplied with guaranteed low hydrogen potential and eliminate the use of on-site ovens and quivers. However, it should be emphasized that hydrogen levels are preserved only when operators adhere strictly to the manufacturer recommendations for using these products.

EN 1011-2 emphasizes the point that the most effective assurance of avoiding hydrogen cracking is to reduce the hydrogen input to the weld metal from the welding electrodes. Stringent consumable storage and handling procedures provide this assurance.

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.

Approval testing for bridgework in the UK is normally carried out in accordance with the requirements of EN ISO 9606-1 (Ref 5). The Standard prescribes tests to be conducted to approve welders for process, type of joint, position and filler material.

Inspection and testing
EN 1090-2 (Ref 6) is the Standard for the execution of steel structures and defines the inspection and testing requirements for welded joints. The execution class normally specified for bridgeworks is EXC3. Clause 12.4 of the Standard describes the welding inspection requirements. These may be supplemented or changed by project specific requirements.

For highway infrastructure projects, the requirements are given by the Specification for Highway Works (SHW) Series 1800 published in August 2014 (Ref 7) and a project-specific Appendix 18/1. The SHW interprets and implements PD 6705-2 (Ref 8) and 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 by the following symbols, F36, F56, F71, F90, F112 and F140. For comment on specifying QSC, see GN 2.12.

The QSC determines the method, frequency of testing and acceptance levels which are different from those in EN 1090-2. It should be noted that Table 18/5 of the SHW increases the frequency of testing for site welded joints.

Non-destructive testing techniques typically include visual and magnetic particle inspection for surface examination, and ultrasonic testing for sub-surface examination. An alternative non-destructive testing technique is radiography but this method is rarely used on site because of safety and practicality issues. Guidance Note 6.06 describes visual inspection after welding and Guidance Notes 6.02 and 6.03 describe in further detail the surface and sub-surface non-destructive testing of welds.

Specifications state that personnel should be appropriately trained and qualified to undertake the work.

SHW Series 1800 Clause 1812.4.3 describes the ring and bend testing required for any on-site welded shear studs. Of course, threaded studs should be load tested to confirm the weld integrity to avoid damaging the thread.

Destructive testing of production test plates may also be required where site butt welding is undertaken. The requirement is not included in EN 1090-2 and needs to be specified. SHW Table 18/11 does specify production tests depending on weld type, QSC and material grade. The Table includes details of test type and testing rate. Test specimens, such as, tensile tests, macros and Charpy impact tests need to be taken from extended run on/off plates attached to the joints. It is prudent that such plates are of sufficient size to permit the taking of extra samples in case there is a need for re-tests.

Important considerations at site again include maintaining safe access for inspection personnel until all testing is complete and satisfactory.

References

1. EN ISO 15614-1: 2004 + A2: 2012 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.
2. EN ISO 4063: 2010 Welding and allied processes. Nomenclature of processes and reference numbers.
3. EN ISO 6947: 2011 Welding and allied processes. Welding positions.
4. EN 1011-2: 2001 Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels.
5. EN ISO 9606-1: 2013 Qualification testing of welders. Fusion welding. Steels.
6. EN 1090-2: 2008+A1: 2011 Execution of steel structures and aluminium structures. Technical requirements for steel structures.
7. Manual of Contract Documents for Highway Works. Volume 1 Specification for highway works. Series 1800 Structural steelwork. Amendment – August 2014, TSO.
8. 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.