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PUBLISHED DOCUMENT

Structural use of steel and aluminium

Part 2: Recommendations for the execution
of steel bridges to BS EN 1090-2

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Contents

Foreword *iii*

1	Scope	1
2	Normative references	1
3	Terms and definitions	3
4	General	3
5	Basis for the recommended selections of choice permitted by BS EN 1090-2:2008+A1:2011	3
6	Specifications and documentation (see BS EN 1090-2:2008+A1:2011, Clause 4)	6
7	Constituent steel products (see BS EN 1090-2:2008+A1:2011, 5)	6
8	Preparation and assembly (see BS EN 1090-2: 2008+A1:2011, Clause 6)	9
9	Welding (BS EN 1090-2:2008+A1:2011, Clause 7)	12
10	Use of bolt assemblies (see BS EN 1090-2:2008+A1:2011, Clause 8)	15
11	Erection (see BS EN 1090-2:2008+A1:2011, Clause 9)	17
12	Surface treatment (see BS EN 1090-2:2008+A1:2011, Clause 10)	18
13	Geometrical tolerances (see BS EN 1090-2:2008+A1:2011, Clause 11)	18
14	Inspection, testing and correction (see BS EN 1090-2:2008+A1:2011, 7.6 and Clause 12)	19

Annexes

Annex A (informative)	Background to the development of European and International execution standards and their relationship to previous British execution standards	32
Annex B (informative)	Method of determination quantified service category and guidance for use in drafting specifications	36
Annex C (informative)	Explanatory notes on selected recommendations	39

Bibliography **49**

List of figures

Figure B.1 – Method of designation of quantified service categories on drawings F71 to F140	39
Figure C.1 – Definition of plain edge and stress raising zones for machine plasma cut edge surfaces	42

List of tables

Table 1 – Method for slotted holes	11
Table 2 – Torque values for the part turn method – step one	17
Table 3 – Rotation values for the part turn method – step two	17
Table 4 – Minimum extent of supplementary NDT of shop welds in steel grades up to and including S355 and quantified service category F56	24
Table 5 – Adjustments in proportions of supplementary NDT for conditions other than those covered by Table 4 and Table 6	24
Table 6 – Minimum extent of supplementary NDT of shop welds in steel grades up to and including S355 and quantified service categories F71 to F140	25
Table 7 – Weld acceptance criteria for visual inspection	26
Table 8 – Weld acceptance criteria for visual inspection for quantified service categories F71 to F140 where limits differ from those for F56 in Table 7	28
Table 9 – Weld acceptance criteria for magnetic particle and penetrant testing	29

Table 10 – Weld acceptance criteria for ultrasonic testing with limited optional radiographic testing 30

Table 11 – Production tests on run off coupon plates 31

Table B.1 – Definition of quantified service categories 36

Table B.2 – Typical examples of likely maximum quantified service categories in different types of bridge elements 38

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 50, an inside back cover and a back cover.

Foreword

Publishing information

This part of PD 6705 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 December 2010. It was prepared by Subcommittee B/525/10, *Bridges*, under the authority of Technical Committee B/525, *Building and civil engineering structures*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

PD 6705-2:2010+A1:2013 supersedes PD 6705:2010, which is withdrawn. The start and finish of text introduced or altered by Amendment No. 1 is indicated in the text by tags $\boxed{A_1}$ and $\boxed{A_1}$. Minor editorial changes are not tagged.

Relationship with other publications

This Published Document gives guidance on the use of BS EN 1090-2:2008+A1:2011 for the execution of steel bridges in the UK.

Information about this document

BS EN 1090-2 superseded BS 5400-6 in March 2010 following a period of coexistence. The replacement of BS 5400-6 with BS EN 1090-2 represents a substantial change in construction practice in the UK. The purpose of this Published Document is to ensure that steel bridges are executed with the same level of assurance of reliability as that implicit in BS 5400-6.

BS EN 1993, *Design of steel structures*, calls up BS EN 1090 as the key reference standard for execution and erection which is necessary for the design assumptions in BS EN 1993 to be valid.

The guidance given in this Published Document consists of non-contradictory complementary information (NCCI) to enable the user to apply BS EN 1090-2:2008+A1:2011 in a safe and cost-effective manner, with particular reference to the following:

- selection of options where they are defined in BS EN 1090-2:2008+A1:2011;
- selection of service categories in terms of quantified performance requirements, for use in choosing execution requirements, where applicable;
- alternative information where permitted in BS EN 1090-2:2008+A1:2011.

Explanatory notes are provided in Annex C, giving the background to selected recommendations for additional specification material, selection of options and choice of execution class, where the issues involved are of a specialist nature.

The main differences in the scope and technical bases of BS 5400-6 compared to BS EN 1090-2:2008+A1:2011 are identified in Annex A, to assist the user in adapting to the changes in practice necessary when using BS EN 1090-2:2008+A1:2011.

The amendment A1:2013 updates this Published Document to take account of Amendment A1:2011 of BS EN 1090-2:2008. It also takes account of comments arising from the application of this Published Document in the drafting and use of specifications based on BS EN 1090-2:2008+A1:2011.

Presentational conventions

The provisions in this Published Document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document cannot confer immunity from legal obligations.

1 Scope

This part of PD 6705 gives guidance on the use of BS EN 1090-2:2008+A1:2011 for the execution of all types of steel bridges designed to BS EN 1993.

It is applicable to the same scope of application as BS EN 1090-2:2008+A1:2011 with the following exceptions:

- stainless steels;
- sheeting;
- resistance welding;
- riveting; and
- matters not related to structural integrity, e.g. visual appearance.

The recommendations given in this Published Document are only applicable when the design requirements and recommendations in the following documents have been adopted, where relevant:

- BS EN 1990, Eurocode – Basis of structural design;
- BS EN 1991, Eurocode 1: Actions on structures;
- BS EN 1993-2, Eurocode 3: Design of steel structures – Part 2: Steel bridges;
- BS EN 1994-2, Eurocode 4: Design of composite steel and concrete structures – Part 2: General rules and rules for bridges;
- any UK National Annexes and Published Documents referenced normatively or informatively in the above standards.

This Published Document is prepared for personnel involved in the regulation, design, procurement, fabrication, erection and certification of steel bridges when BS EN 1090-2:2008+A1:2011 is used as the basis for specifying the execution.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 1090-2:2008+A1:2011, *Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures*

BS EN 1435, *Non-destructive examination of welds – Radiographic examination of welded joints*

BS EN 1593, *Non-destructive testing – Leak testing – Bubble emission techniques*

BS EN 1714, *Non destructive testing of welded joints – Ultrasonic testing of welded joints*

BS EN 1990, *Eurocode – Basis of structural design*

BS EN 1991, *Eurocode 1: Actions on structures*

BS EN 1993-1-9, *Eurocode 3: Design of steel structures – Part 1-9: Fatigue*

BS EN 1993-2, *Eurocode 3: Design of steel structures – Part 2: Steel bridges*

BS EN 1994-2, *Eurocode 4: Design of composite steel and concrete structures – Part 2: General rules and rules for bridges*

BS EN 10025-1:2004, *Hot rolled products of structural steels – Part 1: General technical delivery conditions*

BS EN 10025-5, *Hot rolled products of structural steels – Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance*

BS EN 10025-6, *Hot rolled products of structural steels – Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition*

BS EN 10088-1, *Stainless Steels – Part 1: List of stainless steels*

BS EN 10160, *Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)*

BS EN 10163-2, *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections – Part 2: Plate and wide flats*

BS EN 10163-3, *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections – Part 3: Sections*

BS EN 14399, *High-strength structural bolting assemblies for preloading*

BS EN 14399-3, *High-strength structural bolting assemblies for preloading – Part 3: System HR – Hexagon bolt and nut assemblies*

BS EN ISO 3834-2, *Quality requirements for fusion welding of metallic materials – Part 2: Comprehensive quality requirements*

BS EN ISO 5817:2007, *Welding – Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections*

BS EN ISO 6520-1, *Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding*

BS EN ISO 14555:2006, *Welding – Arc stud welding of metallic materials*

BS EN ISO 15613, *Specification and qualification of welding procedures for metallic materials – Qualification based on pre-production welding test*

BS EN ISO 15614-1, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

BS EN ISO 23277, *Non-destructive testing of welds – Penetrant testing of welds – Acceptance levels*

BS EN ISO 23278, *Non-destructive testing of welds – Magnetic particle testing of welds – Acceptance levels*

PD 6695-1-9, *Recommendations for the design of structures to BS EN 1993-1-9*

PD 6695-1-10, *Recommendations for the design of structures to BS EN 1993-1-10*

3 Terms and definitions

For the purposes of this part of PD 6705, the terms and definitions given in BS EN 1090-2:2008+A1:2011 and the following applies.

3.1 quantified service category

category that characterizes a component or structure (or part thereof), in terms of the circumstances of its use within specified limits of static and cyclic stressing

NOTE See Annex B.

4 General

BS EN 1090-2:2008+A1:2011 represents a major change in practice for specifying the execution of steelwork applied to bridges compared to its predecessor BS 5400-6. The background to the main developments in its preparation and a comparison of the main features of the two standards are given in Annex A.

As BS EN 1090-2:2008+A1:2011 has a wider scope covering all structural steelwork, it contains many clauses where the user either has to make a selection between options or has to provide additional information. Around a third of these clauses have been identified as having a significant influence on the level of design resistance realized in the executed structure.

BS EN 1090-2:2008+A1:2011 enables persons responsible for preparing the execution specification for steel bridges to incorporate appropriate requirements relating to those clauses in order to conform to BS EN 1993-2. This applies whether the specification is intended to cover steel bridges in general, particular types of steel bridge, parts of a steel bridge, or a bridge for an individual project.

The recommendations given in this Published Document represent the minimum requirements needed to ensure that the design conforms to BS EN 1993-2. Compliance with additional requirements does not invalidate this, although there might be a cost penalty. Not all recommendations given in this Published Document are relevant if the scope of the execution specification is limited. The recommendations do not preclude the addition of further requirements in an execution specification, provided they do not lower the level of a recommended minimum requirement.

5 Basis for the recommended selections of choice permitted by BS EN 1090-2:2008+A1:2011

5.1 Objectives

The prime objective of the recommendations given in this Published Document is to ensure that, when using BS EN 1090-2:2008+A1:2011 for specifying the execution of steelwork in bridges, the design resistance values assumed in BS EN 1993 and its associated documents are realized in the final bridge construction to the level of reliability implicit in BS EN 1990 and BS EN 1993. This is achieved by specifying appropriate controls on management systems, procedure approval, personnel qualification, process selection, quality of materials and workmanship, inspection, testing and recording.

BS EN 1090-2:2008+A1:2011 contains multiple options and requirements for further information. Many of these involve decisions on specialist technical matters which users might not feel qualified to make. Use of this Published Document should ensure that technically sound choices are made, resulting in bridges being $\boxed{A_1}$ executed $\boxed{A_1}$ as economically as possible, whilst maintaining the level of reliability defined above.

5.2 Reliability level

The partial factors for actions and material properties chosen by the UK and specified in the National Annexes (NA) to BS EN 1990 and BS EN 1993-2 are based on achieving the same notional safety margins used for general structural applications.

NOTE In BS EN 1990 this generally aligns with reliability class (RC) 2 which is consistent with the basis of the safety factors used for most British Standard limit state structural design codes. BS EN 1990, Annex B recommends that RC2 may be associated with consequence class (CC) 2.

The partial factor γ_M is necessary to allow for inherent deviations in chemical, mechanical and geometrical properties of the members and joints in the final structure, including $\boxed{A_1}$ execution $\boxed{A_1}$ induced stresses and notch-like imperfections. The recommendations in this Published Document control these deviations so that the values of γ_M assumed by the UK are valid for all steel bridge applications.

In cases where a higher level of reliability is deemed to be necessary (e.g. class RC3 in BS EN 1990, Annex B), it might be appropriate to increase the scope of testing and inspection to levels above that recommended in this Published Document.

5.3 Types of choice in BS EN 1090-2:2008+A1:2011

There are three types of choice available to the user of BS EN 1090-2:2008+A1:2011.

- Execution class: BS EN 1090-2:2008+A1:2011, **A.3** lists 36 technical requirements where choices can be made by selection of execution class. Twenty-one of these are related to assurance matters, e.g. extent of inspection and testing, qualification of personnel and procedures, traceability, documentation. The remaining fifteen relate to the physical quality required for the structure and its components and joints, e.g. geometrical tolerances, surface finish, attachments, weld acceptance criteria.
- Options: BS EN 1090-2:2008+A1:2011, **A.2** lists over ninety requirements which can be subject to variation by the specifier.
- Additional information: BS EN 1090-2:2008+A1:2011, **A.1** lists around seventy requirements which, if relevant to the structure, require further information to be provided by the specifier.

5.4 Selection of execution class (EXC)

The guidelines for selection of execution class given in BS EN 1090-2:2008+A1:2011, Annex B are not recommended for the following reasons.

- Execution class is dependent on the choice between service category 1 (SC1) and service category 2 (SC2), which are not defined in quantitative terms.
- The main unresolved issue resulting in the UK's negative vote on prEN 1090-2 was the technical basis of the guidelines and

their perceived incompatibility with BS EN 1990. This particularly applied to the quality related items, as opposed to the assurance related items (see 5.3), which in BS EN 1090-2:2008+A1:2011 are still allied directly to the reliability level instead of quantitatively defined service categories. The UK was able to implement BS EN 1090-2:2008+A1:2011 due to the flexibility allowed in BS EN 1090-2:2008+A1:2011, 4.1.2 and the fact that Annex B is informative.

In BS EN 1090-2:2008+A1:2011, where there is a choice of execution class in a particular clause, this Published Document considers each case separately. In certain clauses the requirements can be the same for more than one execution class. In these cases, the recommendation is given by the execution class number(s). For example, if the preferred option is the same for execution class 2, 3 and 4, the choice is indicated as EXC2/3/4.

The recommendation for selecting a particular execution class (or classes) does not imply any change in reliability level (see 5.2). For this reason the recommendations in this Published Document might not accord with those given in BS EN 1090-2:2008+A1:2011, Annex B.

NOTE Where the execution class has been used to differentiate a quality requirement, there might be more than one recommendation, the distinction being made on the basis of a quantified service category (see 5.5).

5.5 Quantification of service category

The fatigue design rules specified in BS EN 1993-1-9 permit high levels of cyclic stressing for certain categories of detail. These levels are acceptable provided a high quality of **A₁** execution **A₁** can be assured, free from all but very small notches. This demands a high degree of control of **A₁** execution **A₁**, particularly for welding, and careful inspection procedures for detection and assessment. Such stress levels are usually only found in limited parts of certain bridges. However, when they do occur, extra controls should be applied to achieve the correct level of reliability.

BS 5400, ISO 10721, BS 8118, PD 6702-1 and PD 6705-3 provide a simple means of identifying the higher risk areas. Annex B provides means of calculating and designating the various levels of fatigue stressing and static stressing. These are compatible with the design rules in BS EN 1993-1-9 and BS EN 1993-1-10 including their National Annexes, PD 6695-1-9 and PD 6695-1-10. For this purpose, six levels of quantified service category are defined, designated F36, F56, F71, F90, F112 and F140 in increasing severity of quality requirement. Annex B gives guidance on how these can be used in the drafting of an execution specification.

5.6 Options

Guidance on selection of any BS EN 1090-2:2008+A1:2011, **A.2** options which could affect the structural reliability level in a bridge are given in Clause 6 to Clause 14, where relevant. If no guidance is given, the stated requirement should be assumed to be acceptable for UK bridges.

5.7 Additional information

Guidance on any BS EN 1090-2:2008+A1:2011, **A.1** items of required additional information considered necessary to control the structural reliability level of a bridge are given in Clause 6 to Clause 14, where relevant.

6 Specifications and documentation (see BS EN 1090-2:2008+A1:2011, Clause 4)

6.1 Execution class and service category (see BS EN 1090-2:2008+A1:2011, 4.1.2 and Annex B)

Execution class is used in Clause 6 to Clause 14 of this Published Document for the purposes of recommending the appropriate requirement where options based on this parameter are given in BS EN 1090-2:2008+A1:2011 (see 5.4). In some cases, the applicable recommended requirement might depend on the quantified service category (see 5.5).

NOTE Where more than one execution class applies to the same requirement, any one of the recommended classes may be used to select the requirement.

6.2 Quality documentation (BS EN 1090-2:2008+A1:2011, 4.2.1)

Quality documentation should conform to the requirements for EXC2/3/4.

6.3 Quality plan (see BS EN 1090-2:2008+A1:2011, 4.2.2 and Annex C)

A quality plan for execution of the works should be provided and should include the items recommended in BS EN 1090-2:2008+A1:2011, Annex C, if applicable.

7 Constituent steel products (see BS EN 1090-2:2008+A1:2011, 5)

7.1 Identification, inspection documents and traceability (see BS EN 1090-2:2008+A1:2011, 5.2)

7.1.1 Inspection documents for steel grades S355 JR and J0 (BS EN 1090-2:2008+A1:2011, Table 1, note a)

Inspection documents for steel grades S355 JR and J0 should conform to the requirements for EXC2/3/4.

7.1.2 Stages of traceability (BS EN 1090-2:2008+A1:2011, 5.2)

Stages of traceability should conform to the requirements for EXC3/4.

7.1.3 Unique traceability of products (BS EN 1090-2:2008+A1:2011, 5.2)

Specialist proprietary and/or bespoke products incorporating non-standardised features, components or methods of manufacture, e.g. castings, forgings, cables and their terminations, energy absorbing devices, mechanical components such as movement joints and major bearings should be uniquely traceable.

7.1.4 Marking of different grades and/or qualities (BS EN 1090-2:2008+A1:2011, 5.2)

The identification of different grades and/or qualities $\boxed{A_1}$ of constituent products $\boxed{A_1}$ should conform to the requirements for EXC2/3/4.

7.2 Structural steel products (see BS EN 1090-2:2008+A1:2011, 5.3)

7.2.1 Options (see BS EN 1090-2:2008+A1:2011, 5.3.1)

Wrought steel product forms covered by BS EN 1090-2:2008+A1:2011, Table 2, Table 3 and Table 4 should be specified in accordance with the product standards listed in these tables.

The only options usually needed are those covered by 7.2.2 to 7.2.5, below. In particular, caution should be exercised in the use of optional variations to chemical composition. The reason for specifying such an option should be given and it should be verified that no adverse effect on mechanical properties, weldability or other property could result.

Option 3 in BS EN 10025-1:2004, 7.3.2.2 allowing Charpy quality to be verified at a temperature above the lowest test temperature should not be adopted.

7.2.2 Thickness tolerances (see BS EN 1090-2:2008+A1:2011, 5.3.2)

For thickness tolerance, thickness tolerance class A should be used.

NOTE See explanatory note C.1.

7.2.3 Surface conditions (see BS EN 1090-2:2008+A1:2011, 5.3.3)

For plates $\boxed{A_1}$ and wide flats $\boxed{A_1}$, EXC3/4 should apply and more stringent surface conditions should be required as follows. Class A3 and class B3 to BS EN 10163-2 may be applied in all circumstances. Class A2 and class B2 may be applied where:

- steels are not specified to BS EN 10025-6;
- the quantified service category is F90 or less;
- reports on weld repairs are submitted;
- UT and MPI are used for inspection of weld repairs; and
- weld repairs are rechecked on delivery for quantified service categories F71 and above.

For sections, the special restrictions on surface imperfections and repair should conform to BS EN 10163-3 as follows:

- cracks, shells and seams in sections should be repaired in all circumstances;
- class C3 and class D3 require no special restrictions;
- class C2 and class D2 should have the same restrictions in use as for plates to class A2 and class B2, above;
- class C1 and class D1 should be restricted to quantified service category F36.

NOTE 1 There could be cost penalties or availability restrictions for class B and class D.

NOTE 2 See explanatory note C.2.

7.2.4 Special properties (see BS EN 1090-2:2008+A1:2011, 5.3.4)

7.2.4.1 Cross plates in welded cruciform and welded tee joints – transmitting primary stresses through the plate thickness

For quantified service category F56, the internal discontinuity quality class should conform to the requirements for EXC3/4.

For quantified service category F71 and above, BS EN 10160 internal discontinuity quality class S_2 should apply.

NOTE See explanatory note C.3.

7.2.4.2 Flange or web plates close to bearing diaphragms and/or single-sided bearing stiffeners

Flange or web plates close to bearing diaphragms and/or single sided bearing stiffeners, where attached by welding, should be checked for conformance to BS EN 10160 internal discontinuity quality class S_1 in the areas defined in BS EN 1090-2:2008+A1:2011, 5.3.4.

NOTE See explanatory note C.3.

7.2.5 Improved deformation properties (Z testing) perpendicular to the surface (see BS EN 1090-2:2008+A1:2011, 5.3.4)

The precautions necessary to avoid lamellar tearing in tee, cruciform and corner joints should be decided by the A_1 constructor (A_1), whether or not improved deformation properties have been specified for the through plates.

NOTE See explanatory note C.4.

7.3 Steel castings (BS EN 1090-2:2008+A1:2011, 5.4)

The specification of grades and qualities and selection of options permitted by the product standard is beyond the scope of this Published Document and expert advice should be sought.

NOTE See explanatory note C.5.

7.4 Welding consumables for weathering steels (see BS EN 1090-2:2008+A1:2011, Table 6 and 7.5.10)

Options 1, 2 and 3 in BS EN 1090-2:2008+A1:2011, Table 6 are suitable for the purposes of weather resistance. Options 2 and 3 are preferable to option 1 in terms of weldability.

C-Mn consumables may be used, but only for:

- single run fillet welds not exceeding 8 mm leg length using processes 135 and 121;
- butt welds using one run only per side;
- the body of multi-pass butt welds except for the outer 3 mm thick surface zones of the cap, root and ends (excluding any overfill).
The surface zones should be deposited using consumables conforming to options 1, 2 or 3.

NOTE See explanatory note C.6.

7.5 Bolt assemblies (see BS EN 1090-2:2008+A1:2011, 5.6)

7.5.1 Preloaded bolting assemblies (see BS EN 1090-2:2008+A1:2011, 5.6.4)

The following products should be used for preloaded bolt assemblies using all tightening methods, except the HRC method:

- bolt assemblies conforming to BS EN 14399-3 (HR type);
- nuts lubricated by the manufacturer after the nuts have been tapped (and, if relevant, after any coating passivation process has been completed).

A1 Bolts of property class 10.9 should not be used for assemblies tightened by the part turn method. See 10.2.6. **A1**

Electroplated **A1** property class **A1** 10.9 bolt assemblies should not be used.

Cleaning of **A1** property class **A1** 10.9 bolts prior to hot dip galvanising should be by blast cleaning and not by pickling.

Nuts of property class 10 may be used with bolts of property class 8.8.

NOTE See explanatory note C.7.

7.5.2 Foundation bolts (see BS EN 1090-2:2008+A1:2011, 5.6.7)

Reinforcing steels should not be used for foundation bolts carrying applied tension forces.

7.5.3 Locking devices (see BS EN 1090-2:2008+A1:2011, 5.6.8 and 8.2.1)

Prevailing torque type nuts should not be used as a substitute for nuts conforming to BS EN 14399 when used with bolts conforming to BS EN 14399 in pre-loaded joints.

NOTE Preloaded assemblies installed and tightened in accordance with BS EN 1090-2:2008+A1:2011 are resistant to loosening.

8 Preparation and assembly (see BS EN 1090-2: 2008+A1:2011, Clause 6)

8.1 Identification of components (BS EN 1090-2:2008+A1:2011, 6.2)

Identification of components should conform to the requirements for EXC3/4.

8.2 Marking methods (see BS EN 1090-2:2008+A1:2011, 6.2)

Hard stamps, punched or drilled marks **A1** may only **A1** be used for zones with a quantified service category of **A1** F56 and below **A1**.

A1 Soft or low stress stamps may be used for zones with a quantified service category of F90 and below. **A1**

No type of **A1** marking process involving deformation of or removal of metal from the surface **A1** should be used for zones with a quantified service category of F112 and above.

8.3 Quality of thermally cut surfaces (BS EN 1090-2:2008+A1:2011, 6.4.3)

The quality of cut surfaces should conform to the requirements for EXC2/3.

8.4 Hardness of free edge surfaces (see BS EN 1090-2:2008+A1:2011, 6.4.4)

Free edge surfaces with hardnesses exceeding 380HV10 values should be ground, finished or machined until sufficient material has been removed such that the 380HV10 limit is not exceeded, subject to the following exceptions.

The above hardness limit need not apply to machine plasma cut edges where:

- a) the steel grade does not exceed S420;
- b) plain edge surfaces are not subject to a quantified service category exceeding F71 [subject to c)];
- c) edge surfaces within 25 mm of stress raising features such as re-entrant corners, openings, weld terminations on the edge that are not subject to a quantified service category exceeding F36; and
- d) edge surfaces are not subject to subsequent cold forming (unless fully fused over the full length and width by subsequent welding).

NOTE See explanatory note C.8.

8.5 Flame straightening (see BS EN 1090-2:2008+A1:2011, 6.5.3)

A suitable procedure should be developed in accordance with the requirements for EXC3/4 and should include the following recommendations:

- the materials being used for procedure approval purposes should be of a higher grade and subgrade than that used in the component being straightened;
- for destructive tests, any reduction in tensile strength should not exceed 5% of the original value and any reduction in Charpy energy should not exceed 10% of the original value at the same test temperature.

8.6 Execution of holing (see BS EN 1090-2:2008+A1:2011, 6.6.3)

8.6.1 Round holes for fasteners or pins

[A1] For material 3 mm thick or less with a quantified service category of less than F71, round holes for fasteners or pins may be formed by punching without reaming as permitted for EXC1/2. For material 3 mm thick or less with a quantified service category of F71 and above, round holes for fasteners or pins should be drilled or be punched at least 2 mm undersize in diameter, and reamed after punching. **[A1]**

For A_1 materials thicker than 3 mm A_1 , round holes should be drilled or be punched at least 2 mm undersize in diameter and reamed after punching in accordance with the requirements for EXC3/4.

NOTE See explanatory note C.9.

8.6.2 Slotted holes

The methods given in Table 1 may be used up to the maximum quantified service categories and thicknesses given in Table 1.

Table 1 Method for slotted holes

Method	Maximum quantified service category	Maximum thickness, mm
Punching and hand thermal cutting	F36	—
Punching in a single operation	F56	15
Thermal cutting by machine		
Drilling and/or milling	F112	—

8.7 Cut outs (see BS EN 1090-2:2008+A1:2011, 6.7)

8.7.1 Minimum radii

The minimum radius for re-entrant corners and notches should conform to the requirements for EXC2/3, except for quantified service category F71 or above when the requirement for EXC4 should apply A_1 (when the stress direction is in the plane of the radius) A_1 , subject to a smaller radius not being specified. A_1 If Form B in BS EN 1090-2:2008+A1:2011, 6.7 is to be used, the design should be checked for the loss of section. A_1

8.7.2 Punch cut outs

The restriction on use of punched cut outs required for EXC4 should apply where:

- quantified service categories F56 and above are required;
- materials conforming to BS EN 10025-6 are used.

8.8 Assembly (see BS EN 1090-2:2008+A1:2011, 6.9)

8.8.1 Elongation of holes by drifting

The tolerance class for EXC1/2 should be applied to non-preloaded connected parts. The tolerance class for EXC3/4 should be applied to preloaded connected parts.

NOTE See explanatory note C.10.

8.8.2 Connections for temporary assembly components

A_1 Connections for temporary components A_1 which can affect the works in service, including the reinstatement or sealing of holes and the removal or otherwise of welded attachments, should be agreed with the designer before A_1 execution A_1 starts (see 9.4.3).

8.9 Trial assembly (see BS EN 1090-2:2008+A1:2011, 6.10)

A1 A full or staged trial assembly should be required, where it is necessary to prove fit up between components and critical dimensions especially where tolerances on overall geometry or joint fit-up are small. This applies particularly to bolted joints with butting faces. **A1**

A full or staged trial assembly of the superstructure should be undertaken where:

- A1** a) erection operations are to be undertaken within restricted possession times; and/or **A1**
- b) the vertical camber is critical to the correct dead weight stress distribution in continuous main girders, particularly in cable stayed or suspension bridges; and/or
- c) fit-up tolerances are small in latticed structures which contain heavy members and rigid joints.

The correction of hole alignment by reaming of bolted splices, selection of pack thicknesses, correction of weld preparation fit-up and correct positioning of temporary alignment cleats can be carried out during trial assembly.

The following factors should be taken into account:

- 1) support of the assembly parts to minimize dead weight deflections;
- 2) correct re-establishment of the alignment of assembly parts in staged trial assembly;
- 3) control of, or allowance for, differential temperature distributions throughout the steelwork if exposed to direct sunlight when surveys are made;
- 4) unique marking for identification and orientation of individual members.

The above measures ensure that long range locked-in forces, beyond those allowed for in the design, are controlled within acceptable limits, e.g. incorrect dead load bending moment distribution in continuous girders.

9 Welding (BS EN 1090-2:2008+A1:2011, Clause 7)

9.1 Quality management (see BS EN 1090-2:2008+A1:2011, 7.1)

The BS EN ISO 3834 quality requirements should conform to the requirements for EXC3/4, except where the quality requirements for EXC2 might be suitable for simple bridges of limited span using steel grades of S355 or below and those requiring a quantified service category of no more than F56. The BS EN ISO 3834 quality requirements for EXC1 should not be applied to bridges.

The **A1** constructor **A1** should always ensure that the range of bridge types for which their welding management systems have been approved are clearly defined on a schedule. The schedule should support any certification in terms of type and size of construction, material grades, product forms and thicknesses, **A1** execution **A1** processes and quantified service categories.

NOTE See explanatory note C.11.

9.2 Qualification of welding procedures (see BS EN 1090-2:2008+A1:2011, 7.4.1)

9.2.1 Tack welds (see BS EN 1090-2:2008+A1:2011, 7.4.1.1 ^{A1} and 7.5.7 ^{A1})

^{A1} Qualification of procedures for tack welds should conform to the requirements for EXC2/3/4. ^{A1}

Where tack welds are used in the root of a preparation, a weld procedure specification (WPS) should be produced for this specific condition. The tolerances on size and length of the tack weld and any subsequent profiling requirements should be specified in the WPS. The WPS should state whether the tack weld is intended to be fully re-melted by the root run or not.

If the tack weld is to be removed prior to welding of the joint, the minimum permitted size ^{A1} of tack weld ^{A1} should be subject to a welding procedure test in accordance with BS EN ISO 15614-1.

If the tack weld is to be left in the joint, the maximum cross section of tack weld should be used and the root and subsequent passes should be deposited until such time as the root pass is fully covered. The full length of the tack weld location should be subjected to a welding procedure test in accordance with BS EN ISO 15614-1 [see Table 11, ^{A1}].

In both cases the weld should be assumed to be a fillet weld for the purposes of qualification.

NOTE See explanatory note C.12.

9.2.2 Methods of qualification (see BS EN 1090-2:2008+A1:2011, 7.4.1.2)

Methods of qualification should be in accordance with those permitted for EXC3/4 in BS EN 1090-2:2008+A1:2011, Table 12.

The weld procedure qualification acceptance levels in BS EN ISO 15614-1 are less stringent in some respects than those required for factory production control (FPC) for EXC3/4 (see BS EN 1090-2:2008+A1:2011, 7.6). Also, for the highest quantified service categories, the ^{A1} acceptance ^{A1} limits for certain imperfection types are more stringent than for EXC4 (see 14.3.3). If either of these criteria are being used for FPC, the relevant weld procedure qualification acceptance levels should be amended. Existing procedures qualified to BS EN ISO 15614-1 should be re-qualified accordingly by reference to the original test results, if possible. If this cannot be done, or the original results do not conform to the more stringent requirements, the relevant qualification tests for evaluation of imperfections should be repeated.

NOTE See explanatory note C.13.

9.3 Welding co-ordination (see BS EN 1090-2:2008+A1:2011, 7.4.3)

Welding co-ordination should conform to the requirements for EXC2/3/4. This Published Document gives no specific guidance on selection of execution class from BS EN 1090-2:2008+A1:2011, Table 14 as the level of technical knowledge of welding co-ordination personnel is decided by the certification body responsible for determining the conditions of certification of the ^{A1} constructor ^{A1} in accordance with BS EN ISO 3834 (see 9.1).

NOTE See explanatory note C.14.

9.4 Preparation and execution of welding (see BS EN 1090-2:2008+A1:2011, 7.5)

9.4.1 Prefabrication primers – weld procedure tests (BS EN 1090-2:2008+A1:2011, 7.5.1.1)

Where prefabrication primers are to be left on fusion faces, the weld procedures should be tested in accordance with the requirements for EXC3/4.

9.4.2 Welded joints in hollow sections (see BS EN 1090-2:2008+A1:2011, 7.5.4, 7.5.11 and Annex E)

The guidance on preparation, assembly and welding given in BS EN 1090-2:2008+A1:2011, Annex E should be applied. Regarding the assembly of hollow sections, particular attention should be paid to the following.

Adequate access for penetration to the root in the case of full penetration butt welds. A_1 Where access is restricted A_1 it is recommended that a pre-production welding test conforming to BS EN ISO 15613 is conducted.

Compensation for loss of throat and leg length in the case of fillet welded joints with root gaps (see also BS EN 1090-2:2008+A1:2011, 7.5.8.1).

9.4.3 Temporary attachments – use and removal (see BS EN 1090-2:2008+A1:2011, 7.5.6)

The use of temporary attachments should conform to the requirements for EXC3/4.

Temporary welded attachments should not be used in zones of quantified service categories F112 and A_1 above A_1 .

A_1 Restrictions on the removal of temporary welded attachments should be in accordance with the requirements for EXC3/4 for thermal cutting and chipping, except that thermal cutting may be used provided that the finished cut surface of the remainder of the attachment is at least 3 mm from the permanent member surface prior to grinding smooth. A_1 Remnants of temporary materials proud of the original member surface should be removed by grinding parallel to the member axis A_1 and the ground surface checked for freedom from cracking using magnetic particle testing. A_1

NOTE See explanatory note C.15.

9.4.4 Butt weld run-on/run-off pieces (see BS EN 1090-2:2008+A1:2011, 7.5.9.1)

Run-on and run-off pieces should be used on all butt welds and should conform to the requirements for EXC3/4, where access allows.

9.4.5 Permanent steel backing (see BS EN 1090-2:2008+A1:2011, 7.5.9.2)

Permanent steel backing should only be used if specified by the designer or if approved by the designer in advance of A_1 execution A_1 . The continuity of permanent steel backing should conform to the

requirements for EXC3/4. The execution of the continuity weld should depend upon the quantified service category related to stresses parallel to the axis of the backing component, as follows:

- F36: no additional recommendations;
- F56 to F90: make continuous by full penetration butt weld at any stage, followed by surface crack detection;
- F112 to F140: make continuous by full penetration butt weld, followed by flush grinding and surface crack detection before assembly.

NOTE See explanatory note C.16.

A1 9.4.6 Stud welding (see BS EN 1090-2:2008+A1:2011, 7.5.12)

With reference to BS EN ISO 14555:2006, Table B.1, the comprehensive quality requirements in accordance with BS EN ISO 3834-2 should be adopted. **A1**

10 Use of bolt assemblies (see BS EN 1090-2:2008+A1:2011, Clause 8)

10.1 Welding of bolted components (see BS EN 1090-2:2008+A1:2011, 8.2.1)

Welding of nuts, bolts or washers should not be used on bolt assemblies above property class 4.6. Written approval from the designer should be obtained prior to the welding of property class 4.6 nuts, bolts and washers **A1** text deleted **A1**, and should be subject to the recommendations in Clause 9, 14.3, and BS EN 1090-2:2008+A1:2011, 7.

NOTE See explanatory note C.17.

10.2 Tightening of preloaded bolts

10.2.1 Joint fit-up (see BS EN 1090-2:2008+A1:2011, 8.5.1)

10.2.1.1 Slip resistant connections

At the snug tight stage, the exposed surfaces of the components being connected should be aligned within 1 mm where they emerge from beneath the cover plate(s) at the joint plane. This is subject to the tolerances of thickness difference between the two components (including any packing plates) in BS EN 1090-2:2008+A1:2011, 8.1 also being met. If this is exceeded, steel packing plates should be used. To achieve adequate contact between the friction surfaces, the out-of-plane bending stiffness of cover plates should be limited. This can be achieved by using two plates of half the thickness each when the thickness of the original cover plate exceeds the bolt size.

NOTE See explanatory note C.18.

10.2.1.2 Connections subject to applied tension

Where a connection is designed to transfer applied tensile forces through a flanged and bolted end plate, as a minimum, the area of the mating surfaces in direct line with the tension member cross

section should be in contact when all bolts are snug-tight. Any remaining gaps in this zone should be filled by steel shims prior to the application of the remaining pre-load. If necessary, bolts can be partially slackened to enable shims to be inserted. The shims should not be loose at the final snug tight stage. In the event of a tapering gap $\square_{A_1}$ a purpose machined tapered steel shim may be used. As an alternative, flat (parallel) steel shims of not less than 0.1mm and of not more than $\square_{A_1}$ 0.2 mm thick should be inserted to refusal, in steps until the gap in the contact zone is filled, followed by retightening to the snug tight stage. If sealing of the joint is required, the remaining gaps should be filled with a corrosion $\square_{A_1}$ protection $\square_{A_1}$ medium $\square_{A_1}$ compatible with the corrosion protection to be applied to the joint $\square_{A_1}$ after final tightening of the bolt assembly.

NOTE See explanatory note C.18.

10.2.2 Minimum preloading force (see BS EN 1090-2:2008+A1:2011, 8.5.1)

The values of the nominal minimum preloading force of $F_{p,C}$ should be in accordance with BS EN 1090-2:2008+A1:2011, Table 19 for all tightening methods.

NOTE See explanatory note C.19.

10.2.3 Torque method (see BS EN 1090-2:2008+A1:2011, 8.5.3)

The torque method is not recommended for the tightening of preloaded bolts, except where joints are required to be disassembled in service and fastener assemblies reused.

NOTE See explanatory note C.20.

10.2.4 Combined method (see BS EN 1090-2:2008+A1:2011, 8.5.4)

For $\square_{A_1}$ property classes $\square_{A_1}$ 8.8 and 10.9 bolt assemblies to BS EN 14399-3 (see 7.5.1), the further rotation values in BS EN 1090-2:2008+A1:2011, Table 21 should be as follows for the same thickness ranges:

- replace 60° by 90° (¼ turn);
- replace 90° by 120° (⅓ turn);
- replace 120° by 180° (½ turn).

The k value should be checked daily with the torque wrenches in accordance with BS EN 1090-2:2008+A1:2011, Annex H and the torque for the first tightening step adjusted accordingly. Any batches that fail to conform to this test should be discarded.

NOTE See explanatory note C.21.

$\square_{A_1}$ The simplified value of $M_{r,1} = 0.13dF_{p,C}$ should not be used. $\square_{A_1}$

10.2.5 HRC bolt tensioning method (see BS EN 1090-2:2008+A1:2011, 8.5.5)

The preload should be checked with a calibrated load cell on sample assemblies from each new batch within seven days $\square_{A_1}$ prior to $\square_{A_1}$ use. Any batches showing values of preload below the minimum specified value should be discarded.

The pre-tightening step should be repeated until the shear wrench outer socket has stopped turning on all assemblies.

10.2.6 Other tightening methods
(see BS EN 1090-2:2008+A1:2011, 8.5.1)

The part turn method may be used for tightening preloaded bolts if:

- the bolts are property class 8.8 and A_1 assemblies A_1 conform to 7.5.1;
- the A_1 required nominal A_1 minimum preloading force is not in excess of the values specified in BS EN 1090-2:2008+A1:2011, Table 19; and
- the joint fit-up conforms to 10.2.1.

The part turn method is the same as the combined method in BS EN 1090-2:2008+A1:2011, 8.5.4, except that:

- K_o bolt assemblies may be used;
- in the first tightening step the nut should be tightened to a specified torque, as given in Table 2;
- in the second tightening step the nut should be tightened to a specified turn as given in Table 3.

Table 2 Torque values for the part turn method – step one

Bolt diameter d, mm	16	20	22	24	27	30
Torque value M, Nm	80	160	210	270	340	460

Table 3 Rotation values for the part turn method – step two

Bolt diameters, mm	Grip length A_1 , mm	Rotation, °
16 to 22	$t \leq 115$	180 (½ turn)
	$115 < t \leq 275$	270 (¾ turn)
24 to 30	$t \leq 160$	180 (½ turn)
	$160 < t \leq 350$	270 (¾ turn)

A_1 Equal to nominal thickness, t , in BS EN 1090-2:2008+A1:2011, Table 21.

NOTE See explanatory note C.22.

11 Erection (see BS EN 1090-2:2008+A1:2011, Clause 9)

11.1 Reference temperature for setting out
(see BS EN 1090-2:2008+A1:2011, 9.4.1)

The reference temperature should be agreed with the designer in writing before A_1 execution A_1 commences and recorded in the quality plan.

11.2 Use of levelling nuts on foundation bolts
(see BS EN 1090-2:2008+A1:2011, 9.5.4)

Levelling nuts should be slackened off before final tensioning of foundation bolts where a post-tensioning force is specified, to allow the post-tensioning force to be transferred to the foundations.

11.3 Use of shims for fit-up and alignment (see BS EN 1090-2:2008+A1:2011, 9.6.5.3 $\square_{A1}$ and 11.2.3.5 $\square_{A1}$)

The use of shims should be avoided where possible by suitable controls on preparation, assembly and weld distortion and, if necessary, by machining.

If welding is required for securing purposes, it should be carried out in accordance with BS EN 1090-2:2008+A1:2011, 7 as required for EXC3/4 in BS EN 1090-2:2008+A1:2011, 9.6.5.3. The recommendations in Clause 9 and 14.3 should apply in this context.

Where steel shims are needed to correct the fit between members, particularly in preloaded tension joints (see 10.2.1), and where gaps are variable across the interface, $\square_{A1}$ flat (parallel) $\square_{A1}$ steel shims may be used as an alternative to a purpose machined tapered $\square_{A1}$ steel $\square_{A1}$ shim. The gap should be filled by insertion of shims of not less than 0.1 mm and not more than 0.2 mm thick from the widest gap position until refusal. The excess material should be cut off on completion.

12 Surface treatment (see BS EN 1090-2:2008+A1:2011, Clause 10)

12.1 Sealing of enclosed spaces (see BS EN 1090-2:2008+A1:2011, 10.6)

All internal spaces which have been identified as being hermetically sealed should have all joints, whether welded, mechanically fastened or bonded, leak tested prior to application of the external protective coating (see BS EN 1779). The bubble emission technique in accordance with BS EN 1593 should be used.

12.2 Repairs after cutting and welding (see BS EN 1090-2:2008+A1:2011, 10.9)

Protective treatment on edges and adjacent surfaces which have been damaged by cutting should be restored in accordance with the original specification.

Coatings on pre-coated constituent products that have been damaged by welding should be restored in accordance with the original specification or, if not practicable, by an alternative treatment approved by the designer.

13 Geometrical tolerances (see BS EN 1090-2:2008+A1:2011, Clause 11)

13.1 Special tolerances (see BS EN 1090-2:2008+A1:2011, 11.1 and Annex D)

Where full contact end bearing is specified (see BS EN 1090-2:2008+A1:2011, D.1.13), the maximum gap between the two surfaces should be limited to 0.5 mm. In the case of fitted web

stiffeners, the gap should also be limited to a maximum of 0.25 mm over 60% of the fitted area.

13.2 Functional tolerance class (see BS EN 1090-2:2008+A1:2011, 11.3.2 and D.2)

Functional tolerance class 1 should be adopted, except in the following cases from BS EN 1090-2:2008+A1:2011 where class 2 should be adopted:

- D.2.1 (1 to 6) at bearing and bearing stiffener locations;
NOTE Certain bearing designs might require machined surfaces.
- D.2.3 (3);
- D.2.7 (3 and 4).

13.3 Alternative criteria (see BS EN 1090-2:2008+A1:2011, 11.3.3 and Annex D)

The alternative criteria specified in BS EN 1090-2:2008+A1:2011, 11.3.3 should only be used if there are particular reasons why those in BS EN 1090-2:2008+A1:2011, 11.3.2 and the criteria recommended in this Published Document are not appropriate.

14 Inspection, testing and correction (see BS EN 1090-2:2008+A1:2011, 7.6 and Clause 12)

14.1 Constituent products/ components – specific testing (see BS EN 1090-2:2008+A1:2011, 12.2.1 and 12.2.2)

Specific testing of proprietary products not covered by the European or International standards referenced in BS EN 1090-2:2008+A1:2011 should be specified, e.g. special fasteners, tension connectors or mechanical components required for articulation, movement or control of displacement. This should include prototype testing to provide evidence of structural performance to prove the design and establish quality criteria, and production tests to provide evidence that the quality requirements are being met in all supplied items.

14.2 Geometrical dimensions (see BS EN 1090-2:2008+A1:2011, 12.3)

14.2.1 Measurement location and frequency

The inspection plan should identify all dimensions which could be at risk of non-conformity. Checks should be made during **A1** execution **A1** and action taken to ensure that any non-conformity is corrected at the earliest opportunity. All such dimensions should be checked before the steelwork is dispatched to site. Components in the neighbourhood of site connections should be re-checked once the connections are complete.

14.2.2 Repair of dents in hollow sections

Repair by means of welded cover plates should not be undertaken without the approval of the designer.

14.3 Welding (see BS EN 1090-2:2008+A1:2011, 7.6 and 12.4)**14.3.1 Scope of specific inspection (see BS EN 1090-2:2008+A1:2011, 12.4.2.2)**

The scope of specific inspection for each joint on a bridge should be 100% visual and in accordance with the extent and methods of supplementary non destructive testing (NDT) given in Table 4, Table 5 and Table 6 of this Published Document.

NOTE 1 Table 4, Table 5 and Table 6 can be found after 14.5 for ease of reference.

Table 4 specifies the minimum proportions of welded joints subjected to supplementary NDT for shop welds in steel grades up to and including S355 and quantified service category F56, which represent the most common conditions. The percentages in Table 4 should be applied to the number of joints tested up to weld lengths of one metre in any joint. For joints with weld lengths exceeding one metre, the percentage should be applied to the proportion of weld in every joint.

Where other conditions apply, the minimum recommended proportions of welded joints should be increased (or decreased) by one or more levels in accordance with Table 5. This should be done by applying the next highest (or lowest) proportion using the following sequence of seven increasing levels of proportion: 0%, 2%, 5%, 10%, 20%, 50%, 100%.

NOTE 2 For example, if the $\boxed{A_1}$ proportion in Table 4 $\boxed{A_1}$ is 20%, an increase of one level changes the recommendation to 50% and a decrease of one level to 10%.

If adjustments are made according to more than one condition in Table 5, the net number of levels should be used, after adding and/or subtracting the number of levels given in each note.

NOTE 3 For example, if the proportion in Table 4 is 100% and the adjustments according to Table 5 are -1, -1 and +1 level respectively, the net adjustment would be -1 level, which would result in a proportion of 50%.

For quantified service category F71 and above for shop welds in steel grades up to and including $\boxed{A_1}$ S355 $\boxed{A_1}$, the minimum recommended proportions of welded joints which should be subjected to supplementary NDT are specified in Table 6. For other conditions, the proportion tested in Table 6 should be adjusted in accordance with Table 5 as described above for Table 4.

NOTE 4 See explanatory note C.23.

14.3.2 Extent of FPC inspection (see BS EN 1090-2:2008+A1:2011, 12.4.2.2)

The selection of EXC in BS EN 1090-2:2008+A1:2011, Table 24 for routine FPC inspection should be determined by the $\boxed{A_1}$ manufacturer $\boxed{A_1}$ according to the nature of the work in normal production. It should be not less than that required for EXC3 or for the specific inspection required for an individual contract, whichever is the greater.

NOTE 1 Any FPC inspections undertaken on a specific bridge which conform to Table 4, providing that the acceptance criteria in **14.3.3** are fully met, can be regarded and documented as part of the specific inspection recommended in **14.3.1**.

NOTE 2 See explanatory note **C.23**.

14.3.3 Acceptance criteria for specific inspection (BS EN 1090-2:2008+A1:2011, 7.6)

The criteria for final acceptance without the need for repair should be in accordance with the tables listed in a), b) and c) below, according to the method of inspection used:

- a) visual inspection – Table 7 and Table 8;
- b) magnetic particle and penetrant testing – Table 9;
- c) ultrasonic testing – Table 10.

NOTE 1 Table 7, Table 8, Table 9 and Table 10 can be found after Table 6 for ease of reference.

NOTE 2 See explanatory note **C.24**.

14.3.4 Acceptance criteria for FPC (see BS EN 1090-2:2008+A1:2011, 7.6)

The selection of the EXC for routine FPC should be determined by the **A1** manufacturer **A1**, according to the nature of the work in normal production.

NOTE 1 The capability of proving that some of the criteria are met can depend on the method of testing.

The criteria in BS EN 1090-2:2008+A1:2011, **7.6** might not necessarily exceed the criteria in **14.3.3**. The criteria given in **14.3.3** should apply irrespective of those used for FPC.

NOTE 2 See explanatory note **C.24**.

****A1** 14.3.5 Inspection and testing of welded shear studs for composite steel and concrete structures (see BS EN 1090-2:2008+A1:2011, 12.4.3)**

Production tests in accordance with BS EN ISO 14555:2006, **14.2**, should be performed before the beginning of welding operations and repeated after every 5 000 welds for each combination of stud diameter, parent material and type of equipment that is used.

Every stud on a production piece of steelwork should be tested by striking the side of the head of the stud with a 2 kg hammer. The weld should be considered acceptable if there is a clear ring tone due to the striking. Any stud considered to be unacceptable as a result of this test should be tested as part of the simplified production tests described as follows.

Simplified production tests should be carried out as required by BS EN ISO 14555:2006, **14.3**, and at a minimum rate of 1 test (comprising 3 studs) after every 100 welds on each piece of steelwork, with a minimum of 1 test (comprising 3 studs) per piece. The bend test should be in accordance with BS EN ISO 14555:2006, **11.3a**). Studs should not be bent back after testing. **A1**

14.3.6 Production tests (see BS EN 1090-2:2008+A1:2011, **A1** text deleted **A1** 12.4.4)

A1 Production tests conforming to the requirements for EXC3/4 should be specified. **A1**

Specific production testing should be conducted on run-off coupon plates in accordance with Table 11 **A1**, and this should apply to all parts of the structure **A1**.

NOTE Table 11 can be found after Table 10 for ease of reference.

14.4 Mechanical fastening (see BS EN 1090-2:2008+A1:2011, 12.5)

14.4.1 Pre-loaded bolted connections – inspection during and after tightening (see BS EN 1090-2:2008+A1:2011, 12.5.2.3 and 12.5.2.5)

A1 Inspection during and after tightening should conform to the requirements for EXC2/3/4. **A1**

In BS EN 1090-2:2008+A1:2011, 12.5.2.3c), the number of bolt assemblies inspected overall in a structure should conform to the requirements for EXC3/4.

The part turn method should conform to the requirements of BS EN 1090-2:2008+A1:2011, 12.5.2.3c)i.

In BS EN 1090-2:2008+A1:2011, 12.5.2.3d) the sampling plan should conform to the requirements for EXC2/3.

The bolt assembly should be checked for overtightening.

For the part turn method, the inspection and testing requirements of BS EN 1090-2:2008+A1:2011, 12.5.2.5 should apply except as follows:

- the first step should be **A1** checked **A1** as required for EXC3/4 but using the same torque conditions as given in Table 2 of this Published Document;
- for inspection after the second step, rotation angle values given for the combined method should be replaced with:
 - a) 0° (in lieu of 15°);
 - b) 60° (in lieu of 30°).

14.4.2 Torque method (see BS EN 1090-2:2008+A1:2011, 12.5.2.4)

Inspection of tightening by the torque method should conform to the requirements for EXC3/4 in BS EN 1090-2:2008+A1:2011, Table 25.

14.4.3 Combined method (see BS EN 1090-2:2008+A1:2011, 12.5.2.5)

For the combined method, **A1** checking **A1** of the first step should conform to the requirements for EXC3/4.

14.5 Erection – $\square A_1$ inspection of $\square A_1$ trial erection (see BS EN 1090-2:2008+A1:2011, 12.7.1)

The checks needed during trial erection vary according to the type of bridge and the method of erection. The following checks should be carried out, where relevant, but do not represent a comprehensive list:

- $\square A_1$ a) dimensions critical to assembly to other parts of the structure; $\square A_1$
- b) overall horizontal and vertical alignment and twist;
- c) evidence of correct re-establishment of alignment of units in staged trial erection;
- d) temperature differentials in box girders;
- e) fit up of bolted joints and site welding preparations;
- f) alignment of bolt holes;
- g) identification marks of members and their orientation, including packer plates.

Table 4 Minimum extent of supplementary NDT of shop welds in steel grades up to and including S355 and quantified service category F56

Weld type	Orientation ^{A)}	Thickness (t) or throat (a) ^{B)} mm	Proportion of joints tested %	
			Magnetic particle (MT) or penetrant testing (PT)	Ultrasonic testing (UT) ^{C)}
Butt	Transverse	$t < 8$	100	Not applicable
		$8 \leq t \leq 20$	20	50 ^{D)}
		$t > 20$	50	100
	Longitudinal	$t < 8$	50	Not applicable
		$8 \leq t \leq 20$	5	0
		$t > 20$	10	10
Fillet	Transverse	$t \leq 20$	5	No requirement
		$t > 20, a \leq 10$	10	No requirement
		$t > 20, 10 < a \leq 15$	20	0
		$t > 20, a > 15$	20	10
	Longitudinal	As per transverse fillet but reduced by 2 levels ^{E)}		

^{A)} Transverse applies to all welds orientated within 60° of the longitudinal axis of members, except for connection zones where all orientations are deemed to be transverse. Connection zones are all locations within 200 mm of a main structural connection, loading point or support position.

^{B)} t = the nominal maximum parent metal thickness in the joint;
 a = the nominal fillet weld throat dimension (including any specified penetration).

^{C)} Testing conditions to BS EN 1714 should be as follows – examination level B, evaluation level DAC – 14 dB.

^{D)} 100% for single sided butt where no access to root side.

^{E)} See 14.3.1 for explanation of change in level.

Table 5 Adjustments in proportions of supplementary NDT for conditions other than those covered by Table 4 and Table 6

Condition	Change in level ^{A)}
Site welded joints	+1
Automatic and robotic welded joints ^{B)}	–1
Standard proprietary products manufactured on a mass production basis ^{B)}	–1
Steel grades above S355 and below S500	+1
Steel grades S500 and above	+2
Quantified service category F36 (relative to F56)	–1
After a non-conformance with acceptance criteria in Table 9 or Table 10 Applicable to all joints of similar type tested in the same production batch To be maintained until the cause has been identified and rectified and defects eliminated	+2 (minimum, depending on degree of severity of non-conformance)

^{A)} See 14.3.1 for explanation of change in level.

^{B)} Not applicable to transverse butt welds of F90 and above.

Table 6 Minimum extent of supplementary NDT of shop welds in steel grades up to and including S355 and quantified service categories F71 to F140

Weld type	Orientation ^(A)	Thickness (t) ^(B) or throat (a) mm	Proportion of joints tested %								
			Magnetic particle (MT) or penetrant testing (PT)			Ultrasonic testing (UT) ^(C)			Radiographic testing (RT) ^(D)		
			F71	F90	F112 and F140	F71	F90	F112 and F140	F90	F112	F140
Butt	Transverse	t < 8	100	100	100	Not applicable	Not applicable	Not applicable	20	100	100 ^(E)
		8 ≤ t ≤ 20	50	100	100	100	100	100	0	20	100 ^(E)
		t > 20	100	100	100	100	100	100	0	50	100 ^(E)
Fillet	Longitudinal	t < 8	100	100	100	Not applicable	Not applicable	Not applicable	10	50	100
		8 ≤ t ≤ 20	20	50	100	10	20	100	0	10	100
		t > 20	20	50	100	10	20	100	0	10	100
	Transverse	t ≤ 20	20	100	100	No requirement	No requirement	No requirement	No requirement		
		t > 20, a ≤ 10	50	100	100	10	20	20			
		t > 20, 10 < a ≤ 15	100	100	100	20	50	50			
	t > 20, a > 15	100	100	100	50	100	100				
Longitudinal	As per longitudinal butt weld										

A) and B) as per Table 4, A) and B).

C) Testing conditions to BS EN 1714 should be as follows:

- quantified service categories F71 and F90: examination level B, evaluation level DAC –14dB;
- quantified service category F112: examination level C, evaluation level DAC –17dB;
- quantified service categories F140: examination level C, evaluation level DAC –20dB;
- transverse indication scans required for longitudinal welds.

D) Applies to in-line butt welds only. BS EN 1435 test class B, should be used.

E) Not relevant for designs based on Table 8.3 in BS EN 1993-1-9:2005

Table 7 Weld acceptance criteria for visual inspection
All dimensions in mm

Main criterion	Imperfection type ^{A)}	Dimensional parameter ^{B)}		Joint type	Weld type	Acceptance limits ^{B), C)} to quantified service category [] applies to longitudinal welds only ^{D)}		Remedial action in event of non-conformance ^{E)}		
		Description	BS EN ISO 6520-1:2007 ref no.			Symbol	BS EN ISO 5817:2007 ref no.		F56 (For F36, see ^{F)})	F71 to F140
Overall joint geometry	Weld location error	—	Dr	—	All	Fillet	Dr ±10	[±10]	As per F56	Refer to welding co-ordinator for remedial action
	Incorrect weld type	—	Dr	—	All	All	NP	[NP]	As per F56	Refer to welding co-ordinator for remedial action
	Inadequate weld length	—	Dr	—	All	All	Dr –0	[–5]	As per F56	Add extra weld length
	Linear misalignment	5071, 5072	h	3.1	In-line butt	Butt	$h \leq 0.2t$ $h \leq 4$	[0,3t] [5]	See Table 8	Remove existing weld, realign joint, remake preparations and check with MT or PT, reweld to AWPS, check with UT
		507	h	—	Cruciform	All	$h \leq 0.4t$ $h \leq 6$	[0.4t] [6]	See Table 8	
	Angular misalignment	508	β	—	In-line butt	Butt	$\beta \leq 2^\circ$	[3°]	See Table 8	Correct using approved procedure, check with MT or PT
Surface notches	Root gap ^{G)}	617	h	3.2	Lap, tee, cruciform	Fillet	$h \leq 2$	[3]	See Table 8	Refer to welding co-ordinator for remedial action
	Crack	100 to 106	—	1.1, 1.2	All	All	NP	[NP]	As per F56	Remove imperfections by grinding to approved excavation shape, check with PT, reweld to AWPS, refer to welding co-ordinator for establishment of cause
	Lack of fusion	401, 506	—	1.5, 1.13	All	All	NP	[NP]	As per F56	
	Lack of penetration (unspecified)	402	h	1.6	All	Single sided butt	NP	$[h \leq 0.1t]$ $[h \leq 1]$	As per F56 [NP]	
	Large cavities	2015, 2016, 202, 510	—	2.6 2.7, 1.15	All	Butt	NP	[NP]	As per F56	
	Undercut, under fill etc.	501, 509, 511, 515, 517	h	1.7, 1.8, 1.14, 1.17, 1.19	All	All	$h \leq 0.5$	[1]	See Table 8	Remove by grinding, repair to AWPS
	Pore	2017	d	1.3	All	All	d ≤ 2	[2]	See Table 8	Remove to depth of 3 mm, repair to AWPS
	Toe angle	5051	α	1.12	All	All	$\alpha \leq 90^\circ$	[90°]	See Table 8	Correct with high speed rotary burr or reweld to AWPS
	Damage	601, 603 to 606	—	1.22	All	All	NP	[NP]	As per F56	Grind out to smooth profile, repair by AWPS if h > 1

Table 7 Weld acceptance criteria for visual inspection (continued)
All dimensions in mm

Main criterion	Imperfection type ^{A)}		Dimensional parameter ^{B)}		Joint type	Weld type	Acceptance limits ^{B), C)} to quantified service category [] applies to longitudinal welds only ^{D)}		Remedial action in event of non-conformance ^{E)}
	Description	BS EN ISO 6520-1:2007 ref no.	Symbol	BS EN ISO 5817:2007 ref no.			F56 (For F36, see ^{F)})	F71 to F140	
Loss of cross-section	Insufficient weld throat, ^{a H)}	5213	h	1.20	Tee, lap, cruciform	Fillet	NP ^{G)} [h ≤ 1] ^{G)}	As per F56	Increase size using same AWPS
	Insufficient leg length, ^{z H)}	521	h	—	Tee, lap, cruciform	Fillet	NP ^{G)} [h ≤ 0.1z] ^{G)} [h ≤ 2] ^{G)}	As per F56	Increase cross sectional area using methods above, depending on imperfection type
	Multiple con-forming surface imperfections	201, 202, 501, 509, 511, 515, 5213	h, l, d, l _p	4.2, 4.1	All	All	See ^{I)}	As per F56	Remove by grinding or blast cleaning
Surface condition	Deposits	602, 613, 614, 615	—	1.23	All	All	Not permitted if surface to receive ^{A1)} corrosion protection ^{J)} ^{A1)}	See Table 8	

A) The three digit BS EN ISO 6520-1 designation is deemed to include all four digit sub-categories.

B) Symbols are as defined by BS EN ISO 5817 or BS EN ISO 6520-1.

Dr = the dimension (or weld type) specified on the drawings. NP = not permitted.

C) Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply.

D) Longitudinal welds are those not deemed to be "transverse"; see Table 4, ^{A)}.

E) AWPS = approved welding procedure specification for repair, qualified in accordance with 9.2.2.

F) For joints in any orientation to F36, the imperfection limits given for longitudinal welds [] for F56 are applicable.

G) Where a root gap h has been observed in a tee, cruciform or corner joint, the nominal required fillet weld dimensions, as measured with a weld gauge, should be increased as follows, unless compensating penetration beyond the root has been proven: minimum required throat size a + 0.7h; minimum required leg length z + h (on affected leg only). See also ^{H)}.

H) Both a and z measurements should be checked, irrespective of which has been specified on the drawings. They are related as follows:

Angle between fusion faces	120°	110°	100°	90°	80°	70°	60°
	2.0	1.74	1.56	1.41	1.31	1.22	1.15
z/a							

I) All permitted imperfections resulting in loss of cross-section should be summed and assessed as follows:

$\Sigma hl + \Sigma 0.5dt \leq 4.5t$ or $\leq 9t$. Σhl should include subsurface imperfections assuming h = 3; see Table 10, ^{K)}. Measurement length l_p = 100 mm. For fillet welds "a" should be substituted for "t".

^{A1)} See EXC3/4 in BS EN 1090-2:2008+A1:2011, 7.5.17. Should not be permitted on uncoated steels to BS EN 10025-5 and BS EN 10088-1. ^{A1)}

Table 8 Weld acceptance criteria for visual inspection for quantified service categories F71 to F140 where limits differ from those for F56 in Table 7
All dimensions in mm

Imperfection type ^{A)}		Acceptance limits according to quantified service category ^{B), C)} [] applies to longitudinal welds only ^{D)}				Remedial action in event of non-conformance
		F71	F90	F112	F140	
Linear misalignment	In-line butt	$h \leq 0.15t$ [0.2t] $h \leq 4$ [5]	$h \leq 0.1t$ [0.2t] $h \leq 3$ [4]	$h \leq 0.05t$ [0.2t] $h \leq 3$ [4]	$h \leq 0.05t$ [0.2t] $h \leq 3$ [4]	As per Table 7
	Cruciform	$h \leq 0.3t$ [0.4t] $h \leq 5$ [6]	$h \leq 0.2t$ [0.4t] $h \leq 4$ [6]	$h \leq 0.1t$ [0.3t] $h \leq 3$ [5]	$h \leq 0.1t$ [0.2t] $h \leq 3$ [3]	
Angular misalignment		$\beta \leq 2^\circ$ [3°]	$\beta \leq 1.5^\circ$ [2°]	$\beta \leq 1^\circ$ [2°]	$\beta \leq 0.5^\circ$ [2°]	As per Table 7
Root gap ^{E)}		$h \leq 2$ [2]	$h \leq 2$ [2]	$h \leq 1$ [1]	$h \leq 0.5$ [0.5]	As per Table 7
Undercut, underfill		$h \leq 0.3$ [h ≤ 1]	NP [h ≤ 1]	NP [h ≤ 0.5]	NP [h 0.5]	As per Table 7
Porosity		$d \leq 1.5$ [1.5]	$d \leq 1$ [1]	NP [NP]	NP [NP]	As per Table 7
Toe angle		$\alpha \geq 110^\circ$ [90°]	$\alpha \geq 150^\circ$ [90°]	$\alpha \geq 165^\circ$ [110°]	$\alpha \geq 175^\circ$ [110°]	As per Table 7
Deposits		Not permitted if surface to receive A_{T} corrosion protection ^{I)} A_{T}	NP [NP]	NP [NP]	NP [NP]	See ^{F)}
Variation in root or cap longitudinal profile ^{B)}		$\Delta h \leq 3$ ^{G)} [Δh ≤ 3]	$\Delta h \leq 2$ ^{G)} [Δh ≤ 2]	$\Delta h \leq 1$ ^{G)} [Δh ≤ 1]	$\Delta h \leq 0.5$ ^{G)} [Δh ≤ 0.5]	See ^{H)}

A) Imperfection types as designated in Table 7, ^{A)}.

B) Symbols are as defined by BS EN ISO 5817 or BS EN ISO 6520-1.

NP = not permitted. Δh = the maximum variation in cap or root profile measured along weld axis over any length of 3 mm.

C) Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply.

D) Longitudinal welds are those not deemed to be "transverse"; see Table 4, ^{A)}.

E) Correct fillet weld sizes as per Table 7, ^{G)}.

F) For F112 and above, remove with high speed rotary burr.

G) Transverse welds outside connection zones are exempt from this restriction (see Table 4, ^{A)}).

H) Correct by tapering slope to shallower angle or repair to AWP5.

A_{T} ^{I)} See EXC3/4 in BS EN 1090-2:2008+A1:2011, 7.5.17. Should not be permitted on uncoated steels to BS EN 10025-5 and BS EN 10088-1. A_{T}

Table 9 Weld acceptance criteria for magnetic particle and penetrant testing

Imperfection type	Acceptance standards	Indication pattern	Acceptance limits according to quantified service category ^{A)} [] applies to longitudinal welds with longitudinal linear indications only ^{B)}				Remedial actions in event of non-conformance ^{C)}
			F56 (For F36, see ^{D)})		F71	F90 to F140	
			Level 2	[Level 3]	Level 1	[Level 2]	
Surface notches identified in Table 7 and Table 8	BS EN ISO 23278 and BS EN ISO 23277	Isolated	NP	[NP]	NP	[NP]	Remove by high speed burr machining with machining marks in longitudinal direction. Repair to AWPS if non-conformance with Table 7 and Table 8 depth requirements (h).
		Grouped ^{E)}					

A) NP = not permitted.

B) Longitudinal welds are those not deemed to be "transverse"; see Table 4, ^{A)}.

C) AWPS = approved welding procedure specification for repair, qualified in accordance with 9.2.2.

D) For joints in any orientation to F36, the imperfection limits given for longitudinal welds [] for F56 are applicable.

E) "Grouped" should be deemed to apply to any indications separated by less than 2.5 mm.

Table 10 Weld acceptance criteria for ultrasonic testing with limited optional radiographic testing
 All dimensions in mm

Imperfection type ^{A)}		Dimensional parameter ^{B)}	Location in cross-section or throat	Acceptance limits according to quantified service category ^{B), C)} [] applies to longitudinal welds only ^{D)}						Remedial action in event of non-conformance ^{E)}	
Description	BS EN ISO 6520-1, ref no.	Symbol BS EN ISO 5817:2007 ref no.		F56 (For F36, see ^{F)})	F71	F90	F112	F140			
Cracks	100 to 106	— 2.1, 2.2	Full depth	NP ^{H)}	NP ^{H)}	NP ^{H)}	NP ^{I)}	NP ^{J)}	NP ^{J)}		
Pores ^{G)} , inclusions ^{G)} , cavities ^{G)} , lack of fusion, lack of penetration	2011, 2014, 2015, 2016, 202, 203, 301 to 304, 401, 402	h, l 2.3, 2.5, 2.6 to 2.13	Within 6 mm of any surface	h ≤ 3 l ≤ 10	h ≤ 3 l ≤ 5	NP ^{H)} NP ^{H)}	NP ^{I)} NP ^{I)}	NP ^{J)} NP ^{J)}	NP ^{J)} NP ^{J)}		
			Deeper than 6 mm from any surface	h ≤ 3 l ≤ 1.5t	h ≤ 3 l ≤ 10	h ≤ 3 l ≤ 5	NP ^{H)} NP ^{H)}	NP ^{I)} NP ^{I)}	NP ^{J)} NP ^{J)}		
Uniformly distributed or clustered porosity	2012, 2013	h, l, l _p , H, L 4.2	Full depth	Σl ≤ 1.5t ^{J)} l _p = 100 H ≥ 6 L ≥ 10	Σl ≤ 1.5t ^{J)} l _p = 100 H ≥ 6 L ≥ 10	Σl ≤ 1.5t ^{K)} l _p = 100 H ≥ 6 L ≥ 10	Σl ≤ 1.5t ^{K)} l _p = 100 H ≥ 6 L ≥ 10	NP NP NP NP	NP NP NP NP		
		2.3, 2.4	Full depth	Not permitted if obstructs detection or evaluation of imperfections above						NP ^{L)}	

A) Imperfection types as designated in Table 7, ^{A)}.

B) Symbols are as defined by BS EN ISO 5817.

C) NP = not permitted. H = the clear gap between adjacent imperfections measured in through thickness direction. L = the gap between ends of adjacent imperfections measured along weld axis. Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply. If surface breaking imperfections are detected by UT, the criteria given in Table 7, Table 8 and Table 9 apply.

D) Longitudinal welds are those not deemed to be "transverse"; see Table 4, ^{A)}.

E) AWPS = approved welding procedure specification for repair, qualified in accordance with 9.2.2.

F) For joints in any orientation to F36, the imperfection limits given for longitudinal welds [] for F56 are applicable.

G) Radiographic testing may be used to assist in interpretation of these imperfections.

H) Rejection level DAC –14dB.

I) Rejection level DAC –17dB.

J) Rejection level DAC –20dB.

K) If permitted surface imperfections resulting in loss of cross-section also exist, the criteria in Table 7, ^{I)} also apply.

L) Also, not permitted when checked by radiographic testing.

Table 11 Production tests on run off coupon plates

Weld type	Quantified service categories	Material grades	Test type	Testing rate
In-line transverse butt weld in tension	F90 and above	All	UT + 3 macros	1 in 5
	F56 and above	S355 to S460 ML, NL	Charpys	1 in 10
		S460 to S690 Q	Tensile	1 in 5
		S420 to S690 QL, QL1	Tensile and Charpys	1 in 5
Longitudinal butt or fillet	F90	All	UT + 3 macros ^{A)}	1 in 20
	F112 and above	All	UT + 3 macros ^{A)}	1 in 5

^{A)} A tack weld should be included in the coupon plate if used in production and at least one macro should be taken at each end of the tack weld.

Annex A (informative)

Background to the development of European and International execution standards and their relationship to previous British execution standards

A.1 The European Committee for Standardization (CEN)

BS EN 1993-1-1, *Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings* has been prepared by CEN Technical Committee 250, subcommittee 3 (CEN/TC250/SC3). BS EN 1993-1-1 states that the design rules are dependent on the steelwork being fabricated and erected in accordance with BS EN 1090, which was anticipated to contain a specification for execution of steel structures.

The responsibility for drafting the execution specification was given to a dedicated CEN Technical Committee (CEN/TC135).

The general design rules for structural steelwork were published as a draft for development in 1992 (DD ENV 1993-1-1). The design rules were subjected to a two year trial period by the Member States, followed by submission of comments which were taken into account by the project teams in their preparation of the final parts of BS EN 1993.

DD ENV 1090 was published in six parts. The general specification for structural steelwork including buildings (Part 1) was published by CEN in 1996. In 1998 BSI published it together with a UK National Application Document (NAD) as DD ENV 1090-1, to enable designers to use it in conjunction with other related British Standards. DD ENV 1090-2 to DD ENV 1090-6, which included cold formed thin gauge members and sheeting, high strength steels, hollow section lattice structures, bridges and stainless steels, were produced by CEN over a four-year period. These later parts only provided modifications and additions to the general specification in DD ENV 1090-1.

BSI Technical Committee B/525/10 produced a comprehensive NAD, CEN ENV 1090-5: *Execution of steel structures – Part 5: Supplementary rules for bridges*, which was available for industry, but not formally published by BSI.

Following the ENV period, CEN/TC135 decided to merge the separate parts of DD ENV 1090 into one new part (EN 1090-2) covering all structural steel application areas, to be drafted by one working group. Another working group was set up to draft EN 1090-3, an equivalent specification for aluminium structures. A third working group was set up to prepare a new Part 1, covering conformity assessment for both steel and aluminium.

One of the main conclusions from the ENV comments was that there were wide variations in steelwork specification practice amongst the Member States and across different steelwork applications. Therefore, a degree of flexibility needed to be built into the standard if it was to be acceptable to most Member States. CEN/TC135 introduced the concept of an execution class for this purpose, with four levels which could be selected by the specifier. It was decided that the choice of execution class should be related to the level of reliability required by the designer for the proposed design. The selection of level of structural reliability was a design matter and some guidance had already been provided by CEN/TC250 in EN 1990, Annex B, *Eurocode: Basis of structural design*, which sets out the fundamental principles

and terminology on which the other Eurocodes are based. A new term “service category” was also introduced into BS EN 1090-2, which depended on whether or not the design of the structure (or component) was considered to be susceptible to fatigue loading. No method for quantifying which service category applied in any structural situation was given. The execution class was intended to be dependent on the service category.

Therefore, BS EN 1090-2 could only be used if the reliability level (related to consequence class), the service category and its relationship to the execution class was known. EN 1990, Annex B establishes principles and recommends a method of adjusting the reliability level based on varying the load factor and the degree of independence of the design checker and inspection supervisor. However, it does not cover the concepts of execution class or service category.

The final draft of EN 1090-2, prEN 1090-2, was put out by CEN for public consultation in 2005. By this time the general steel design rules, EN 1993-1-1, had already been out to public consultation, amended, finally approved by CEN/TC250 and published by CEN. A large number of comments were received on prEN 1090-2. These included particular concerns from the UK about the technical basis of a proposed relationship, given in an informative annex, between the reliability level (expressed as consequence class), the service category and the execution class. The UK put forward detailed proposals for improving the technical basis by quantifying the service category and relating the variable technical requirements directly to that parameter. This was based on principles already used in BS 5400 and in the International standard for steel structures, ISO 10721 (see A.2).

At final vote the UK voted negatively to the document, together with two other Member States. The UK’s main concern was that, even if the informative recommendations for determining execution class were followed, there would be situations where either the design resistance values assumed in BS EN 1993 would be invalid, or some of the requirements would result in an economic penalty and represent a barrier to trade.

In view of the specialist technical issues involved, this Published Document offers expert guidance to potential specifiers of bridge steelwork. These take account of the target safety levels assumed in BS EN 1993, including the values of the partial resistance factors and other nationally determined parameters in its National Annexes.

A.2 International Organization for Standardization (ISO)

During the 25 year development period for the Eurocodes, ISO Technical Committee 167 drafted an international standard for steel structures, ISO 10721. Two subcommittees were set up to do the drafting. Subcommittee 1 was responsible for ISO 10721-1, *Steel structures – Part 1: Materials and design* and Subcommittee 2 for ISO 10721-2, *Steel structures – Part 2: Fabrication and erection*. ISO/TC167 was well supported by members from Europe, North America, Asia and Africa in particular. Much of the development work produced by the Eurocode 3 project teams was taken into account during the drafting of ISO 10721-1. The two subcommittee and the plenary meetings were held at the same venues and times, so that there was a consistent relationship between the design rules and the execution specification. The UK was a major contributor throughout

the work of the two subcommittees and provided experts in design of steel buildings, bridges, towers and masts. BSI also held the secretariat for subcommittee 2.

ISO 10721-1 was published by ISO in 1997 and ISO 10721-2 was published in 1999. One of the important features of the two standards was the linking of the execution requirements for welding in ISO 10721-2 to the static and fatigue design rules in ISO 10721-1. This was done by using a parameter similar to the quantified service category. This approach was consistent with the method used to link the execution requirements in BS 5400-6 to the design rules in Part 3 and Part 10 of that standard. A similar system was adopted in BS 8118 and in PD 6705-3.

International standards are primarily aimed at assisting countries or regions, such as Europe, which do not have their own standards. It is CEN policy to use ISO standards as a basis for European standards whenever possible and, in many cases, they are adopted without amendment. BSI did not adopt ISO 10721 as a British Standard as the UK has its own equivalent standards. However ISO 10721-2 has been used as a reference standard in BS 5950 for structural use of steelwork in buildings which are likely to be subjected to significant fatigue loading. It was also used in the drafting of the UK NAD for ENV 1090-1 and ENV 1090-5. However, it was not used in the development of EN 1090-2.

The recommendations in this Published Document have taken account of the principles adopted by ISO 10721.

A.3 Comparison of main features of BS EN 1090-2:2008+A1:2011 and BS 5400-6

Some of the most significant differences between BS EN 1090-2:2008+A1:2011 and BS 5400-6 relating to bridges are detailed below.

- a) Scope of application: BS EN 1090-2:2008+A1:2011 applies to all types of structural steelwork, whereas BS 5400-6 is specific to bridges.
- b) Reference standards: BS EN 1090-2:2008+A1:2011 refers normatively to more than 100 new European standards or parts of standards, many of which have been published in the last ten years. Many replace earlier British Standards, some of which are still referenced in BS 5400-6.
- c) Material grades: The range of steel grades for plates and sections has been increased from S460 in BS 5400 to S690 (or S960 with special provisions) in BS EN 1090-2:2008+A1:2011. BS 5400-6 only covers hot rolled structural hollow sections, whereas BS EN 1090-2:2008+A1:2011 covers both hot and cold rolled structural hollow sections. BS 5400-6 covers cast iron whereas BS EN 1090-2:2008+A1:2011 does not.
- d) Product forms: BS EN 1090-2:2008+A1:2011 covers high strength cables whereas BS 5400-6 does not.
- e)  Execution  methods: BS EN 1090-2:2008+A1:2011 allows laser and plasma cut holes with conditions. These processes are not covered by BS 5400-6.
- f) Weld procedure qualification: BS 5400-6 requires weld procedures to be qualified by testing. BS EN 1090-2:2008+A1:2011 allows other methods to be used to qualify procedures.

- g) Personnel qualification: BS EN 1090-2:2008+A1:2011 has qualification requirements for welding co-ordinators, welders and weld inspectors. BS 5400-6 does not address this.
- h) Quality management: BS EN 1090-2:2008+A1:2011 addresses the subject of quality documentation, including quality plans, in a more explicit manner. BS 5400-6 does not address this, although recording of testing is covered in some of the referenced standards.
- i) Quality control: BS EN 1090-2:2008+A1:2011 is based on FPC which is on-going, and testing is not specific to any particular contract or structure. BS 5400-6 does not address FPC and the specified scope of testing is contract-specific.
- j) Acceptance levels: As a result of the FPC basis for quality control [see i)], BS EN 1090-2:2008+A1:2011 target quality levels need to be high enough to cover the most quality-sensitive design situations allowed by BS EN 1993. The BS EN 1090-2:2008+A1:2011 weld acceptance levels are based on arbitrary criteria, some of which are not necessary for structural integrity. BS 5400-6 quality levels are fitness-for-purpose (FFP) based and provide the minimum which is structurally acceptable for each contract.
- k) Weld testing: BS 5400-6 defines the scope for each method of testing to be used for different elements of the bridge and the acceptance criteria are specified according to the method of testing used. BS EN 1090-2:2008+A1:2011 does not specify these matters. Coupon testing of selected butt welds is required by BS 5400-6, but is optional in BS EN 1090-2:2008+A1:2011.
- l) Non-conformances: The rate of non-conformance of welds is likely to be higher with the FPC acceptance levels. BS EN 1090-2:2008+A1:2011 states that this is not necessarily a cause for rejection provided the imperfection can be accepted on a FFP basis, which is not defined. BS 5400-6 levels, being FFP based, normally result in a lower rejection rate, but where non-conformances occur, repair is normally required without further consideration.
- m) Preloaded bolting: A wider range of bolt types and tightening methods is given in BS EN 1090-2:2008+A1:2011 than in BS 5400-6 which references BS 4395 and BS 4604 (now both withdrawn). Tension control bolts (HRC bolts) and load indicating washers are covered in BS EN 1090-2:2008+A1:2011.
- n) Geometrical tolerances: BS EN 1090-2:2008+A1:2011 has more comprehensive requirements for checking geometrical tolerances than BS 5400-6. BS EN 1090-2:2008+A1:2011 also includes tolerances needed for fit-up and other purposes which are not directly related to the resistance of components.
- o) Surface treatment: BS EN 1090-2:2008+A1:2011 covers the application of surface coatings for corrosion protection, which is not covered in BS 5400-6.

Annex B (informative)

Method of determination quantified service category and guidance for use in drafting specifications

B.1 General

Different structural types and/or different parts of the same structure can be subjected to significant differences in static and/or cyclic stressing. The quality of the work required to provide a consistent value of γ_M across such a wide range of conditions can vary considerably. There would be a severe economic penalty if one quality level was specified which would give a safe degree of reliability for all the conditions permitted by BS EN 1993. Therefore, a range of quantified service categories, designated F36, F56, F71, F90, F112 and F140, is recommended which enables safe, but economical quality levels to be specified for the full range of conditions (see B.2).

The issue of quantified service category should be considered during the design process. By restricting the stress levels in some components, it might be possible to achieve economies in execution by limiting the maximum required category throughout the structure.

B.2 Determination of quantified service category

B.2.1 Definition

The quantified service category is dependent on the orientation and intensity of the static and cyclic stressing at a cross-section of a member or in a joint. The quantified service category is defined in Table B.1 in terms of the static utilization factor and the required fatigue strength.

Table B.1 Definition of quantified service categories

Level of service stresses		Quantified service category	Static utilization factor k^A	Minimum required value of reference fatigue strength $\Delta\sigma_C^B$
Static	Fatigue			
Reduced	Very low	F36	Tension	$\Delta\sigma_C \leq 36 \text{ N/mm}^2$
			Shear	
			Compression	
Full	Low	F56	—	$\Delta\sigma_C \leq 56 \text{ N/mm}^2$
Full	Significant	F71	—	$56 < \Delta\sigma_C \leq 71 \text{ N/mm}^2$
		F90	—	$71 < \Delta\sigma_C \leq 90 \text{ N/mm}^2$
		F112	—	$90 < \Delta\sigma_C \leq 112 \text{ N/mm}^2$
		F140	—	$112 < \Delta\sigma_C \leq 140 \text{ N/mm}^2$

A) The static utilization factor, k , is the ratio of the ultimate limit state (ULS) design action on the member cross-section or joint divided by its design resistance. Where the resistance depends on an interaction formula for more than one stress mode, a pro-rata value of k should be used as the limit. This should apply to all static failure modes at the joint or member in question.

B) The minimum required value of $\Delta\sigma_C$ is the lowest value for which the damage $D_L \leq 1$ for safe life design (see BS 1993-1-9 and PD 6695-1-9). The quantified service category depends on the direction of stress fluctuation. The criterion does not apply to $\Delta\tau$.

B.2.2 Calculation procedure

The procedure for determining the quantified service category (or categories) in a bridge is detailed below.

- a) Ascribe a design fatigue reference strength value $\Delta\sigma_c$ equal to 56 N/mm^2 to all parts of the bridge. Carry out a fatigue check in accordance with BS EN 1993-1-9 and PD 6695-1-9 using this detail category and nominal (or modified nominal) stress ranges. If all parts of the bridge pass this check, then quantified service category F56 applies to the whole bridge.
- b) If any parts of the bridge fail the check in a), those parts should be re-checked with a value of $\Delta\sigma_c$ of 71 N/mm^2 ascribed to those parts. If those parts pass the check then their quantified service category will be F71.
- c) If any of these parts fail the check in b), they should be re-checked with a value of $\Delta\sigma_c$ of 90 N/mm^2 . The same principles should be applied until all parts pass the checks.

NOTE Those parts which contain detail categories according to BS EN 1993-1-9 which have an equal or lower value to the F number need not be checked.

B.3 Use in drafting execution specifications

B.3.1 General principles

The selection of requirements determined by means of the quantified service category can have a significant effect on the ease of attaining the quality, and on the extent and sophistication of the inspection/testing needed to assure that quality. In practice, the quantified service categories needed in the different parts of a bridge depends on the type of loading, type of bridge, its size and member arrangement, the material grade used, and type of details used. These factors dictate the level of cyclic stressing and the minimum quantified service category required. Usually, more heavily fatigue-loaded bridges require more than one category in different parts of the structure.

The two solutions in this situation are to:

- a) specify that all parts of the bridge conform to the requirements of the highest quantified service category on the bridge; or
- b) specify the required quantified service category for each detail separately.

Solution a) could result in significant over-specification in many parts of the structure, particularly in a general bridge specification where a high quantified service category would have to be assumed as a default. This could result in increased cost, increased time for $\mathbb{A}_1$ execution $\mathbb{A}_1$ and inspection, and a higher incidence of non-conformances and repair. It could also draw concentrated resources away from parts that need them to parts which do not.

Solution b) is likely to require more time from the designer for him to designate the quantified service categories. This information needs to be transferred to the fabrication shop and, in some cases, the site. This results in complex communication of the quality control requirements, which could result in extra cost, delay and increased risk of error in designation.

B.3.2 Recommended procedure

The recommended procedure is a compromise between the two solutions detailed in B.3.1.

- a) Estimate the quantified service category which is sufficient to cover at least 95% of the structure. If there are structurally distinct parts of the structure requiring different quantified service categories, consider treating these parts separately, e.g. main truss girder and steel deck. Table B.2 gives typical examples of how quantified service categories can vary with different types of bridge construction.
- b) Check that the extent to which the chosen quantified service category for the bridge or element of the bridge is adequate (see B.2.2). If there are only isolated parts requiring a higher category then two options can be adopted:
 - amend design so that it conforms with the chosen quantified service category; or
 - only identify those parts which require a higher category (see Figure B.1 for a recommended method).

If a significant number of parts require a higher category, the higher category should be adopted.
- c) The requirements from step b) should be indicated in the specification for the whole structure, or the main parts of the structure if a distinction is made between the parts.

The use of F36 for a general category is not recommended, except where considerations of stiffness/deflection as opposed to strength are an overriding factor throughout the design (see also B.3.3).

Table B.2 Typical examples of likely maximum quantified service categories in different types of bridge elements

Quantified service category	Application ^{A)}		
	Pedestrian	Highway	Railway
F56	Most ordinary types	- Supporting towers and columns - Main girders on medium to long spans - Composite bridges with multiple girders	Main girders on medium to long span bridges with heavy ballasted or concrete decks.
F71	Special cases where very susceptible to crowd or wind induced oscillation	- Cross girders - Short span non-composite bridges	Main girders on short span heavy ballasted or deck bridges.
F90		Steel decks with thin road surfacing	Main girders, cross girders and steel decks on short light weight steel bridges.

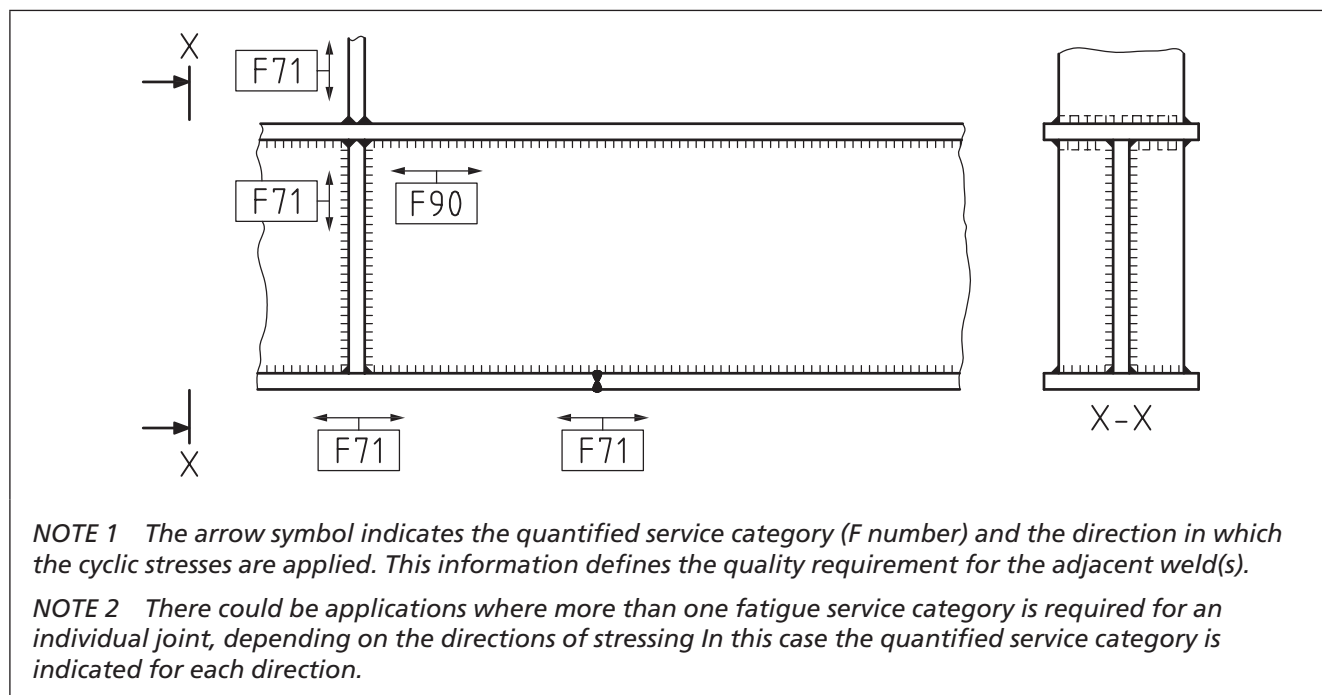
^{A)} This table gives indicative guidance only, assuming steel grades up to S355. For higher grades the categories are likely to increase proportionately to the steel grade. The actual maximum quantified service categories should be checked for each specified design.

B.3.3 Use $\mathbb{A}_1$ during execution $\mathbb{A}_1$

In the event of marginal non-conformances with the fitness-for-purpose based quality criteria occurring in the course of $\mathbb{A}_1$ execution $\mathbb{A}_1$, the

design requirements for the details affected can be reassessed using a lower quantified service category. If acceptable on that basis, they might not require rectification.

Figure B.1 Method of designation of quantified service categories on drawings F71 to F140



Annex C (informative) Explanatory notes on selected recommendations

C.1 Thickness tolerances

Thickness tolerance class can have two main effects. Too negative a tolerance can result in a reduction in both static and fatigue resistance due to increase in stresses through loss of cross section. The most severe effect is on the buckling resistance of semi-compact plate elements. Too positive a tolerance can result in a higher steel dead weight. Both these effects are most pronounced for thinner plates.

Class A negative tolerances are adequately covered by that part of the UK γ_M value which is needed for geometrical deviations, (the other part being for deviations in mechanical properties). Class A positive tolerances are adequately covered by the UK $\gamma_{G,j}$ value.

Tolerance Class D might not be adequately covered by the UK γ_M value for the lower thickness.

Tolerance Classes B and C might not be adequately covered by the UK $\gamma_{G,j}$ value for the upper thickness.

C.2 Surface conditions

Weld repairs on steel products are a potential source of notch-like flaws, which can have an adverse effect on life when cyclic stresses are high.

Welding of steels in accordance with BS EN 10025-6 needs to be subject to special controls to avoid impairment of mechanical properties.

There is also a higher risk of introducing hydrogen cracks through local weld repairs.

C.3 Internal discontinuities

Where cyclic stresses are high in the through-thickness direction, there is an increased risk of initiating a fatigue crack from a planar internal discontinuity normal to the direction of stressing. BS EN 1993-1-9 does not provide a detail category above 71 for normally welded joints of this type, except in an orthotropic deck cross girder-to-open stringer cruciform connection where the former is 12 mm or less. This material is generally no less susceptible to lamellar flaws than thick material. Such joints could be subjected to high tensile weld shrinkage stresses which can dominate over any applied compressive stresses.

In the region of load bearing stiffeners/diaphragms high local stresses could be present, which could reduce the load carrying capability if laminations are present. Bearing stiffeners on one side of a web are potentially more at risk as the full shear force in the web has to pass through one surface only if there is a mid plane discontinuity.

C.4 Z Testing

Steels from modern mills are likely to have adequate through-thickness properties due to the low level of impurities (particularly sulphur), compared to the limits permitted by the product standards.

A1 Constructors **A1** normally know when it is necessary to request through-thickness testing or restrictions on impurities from a particular supply source. Guidance to assist in such decisions is given in BS EN 1011-2:2001, Annex F and PD 6695-1-10.

C.5 Cast products

BS EN 1993 does not give design rules for steel castings. Therefore, it is not possible to give specific guidance on the selection of grades, qualities and options from BS EN 10340 or any extra requirements. Castings can be used for proprietary products such as bearings, cable terminations etc. The casting designer's calculations and the manufacturer's quality and testing requirements should be reviewed prior to acceptance by the bridge designer. In the case of castings designed by the bridge designer, expert advice should be sought to ensure that the quality and testing requirements are consistent with the design requirements. Particular aspects are:

- mechanical properties including tensile, proof, elongation and impact requirements;
- selection of geometry with regard to control of stress concentrations and castability;
- weldability (where relevant), including preheat and post-weld heat treatment requirements;
- location and frequency of mechanical coupon test samples;
- inspection methods before and after machining and/or welding; and
- acceptance criteria for casting and/or welding imperfections, taking into account location with respect to stress concentrations, impact properties and level of fatigue stressing.

C.6 Welding consumables for weathering steels

Avoiding unplanned loss of throat through the corrosion of unprotected welds is essential to their long term design resistance. The recommended consumable options in BS EN 1090-2:2008+A1:2011, Table 6 have been proven to give comparable corrosion resistance in weld metal to that in parent weathering steels. Matching filler wires can sometimes give rise to a higher risk of weld metal cracking due to the higher weld metal copper content.

Designers commonly specify grinding butt weld caps flush after welding to reduce the risk of ponding of water on exposed surfaces. When C-Mn consumables are used in the main body of multipass welds, the weld metal should be left at least 3 mm below the surface planes, both on the sides and the ends of the weld, prior to depositing the weather resistant capping runs.

C.7 Preloaded bolting assemblies

The risk of thread stripping, both during tightening and under service loading, is reduced by using the recommended products. This risk is higher with thinner nuts and when nuts have to be tapped oversize where hot dipped galvanized assemblies are used, which is a very common requirement in UK bridges. HV nuts are thinner than HR nuts. In the event that a stripping problem occurs on property class 8.8 bolts, the use of property class 10 nuts might overcome this.

A passivation process might be needed after hot dipped galvanizing to enable site paint coats to adhere adequately to the exposed parts of the bolt assembly. The lubrication during manufacture can be applied to the nut after the etchant has been washed off, the nut dried and the threads tapped. The use of lubrication reduces the tightening torque, usually reduces the variation in k factor and reduces the risk of bolt breakage during tightening.

Electroplating and acid pickling of grade 10.9 bolts carries a risk of hydrogen embrittlement. Heat treatment procedures to mitigate against this are used, but might not always be reliable.

C.8 Hardness of free edge surfaces

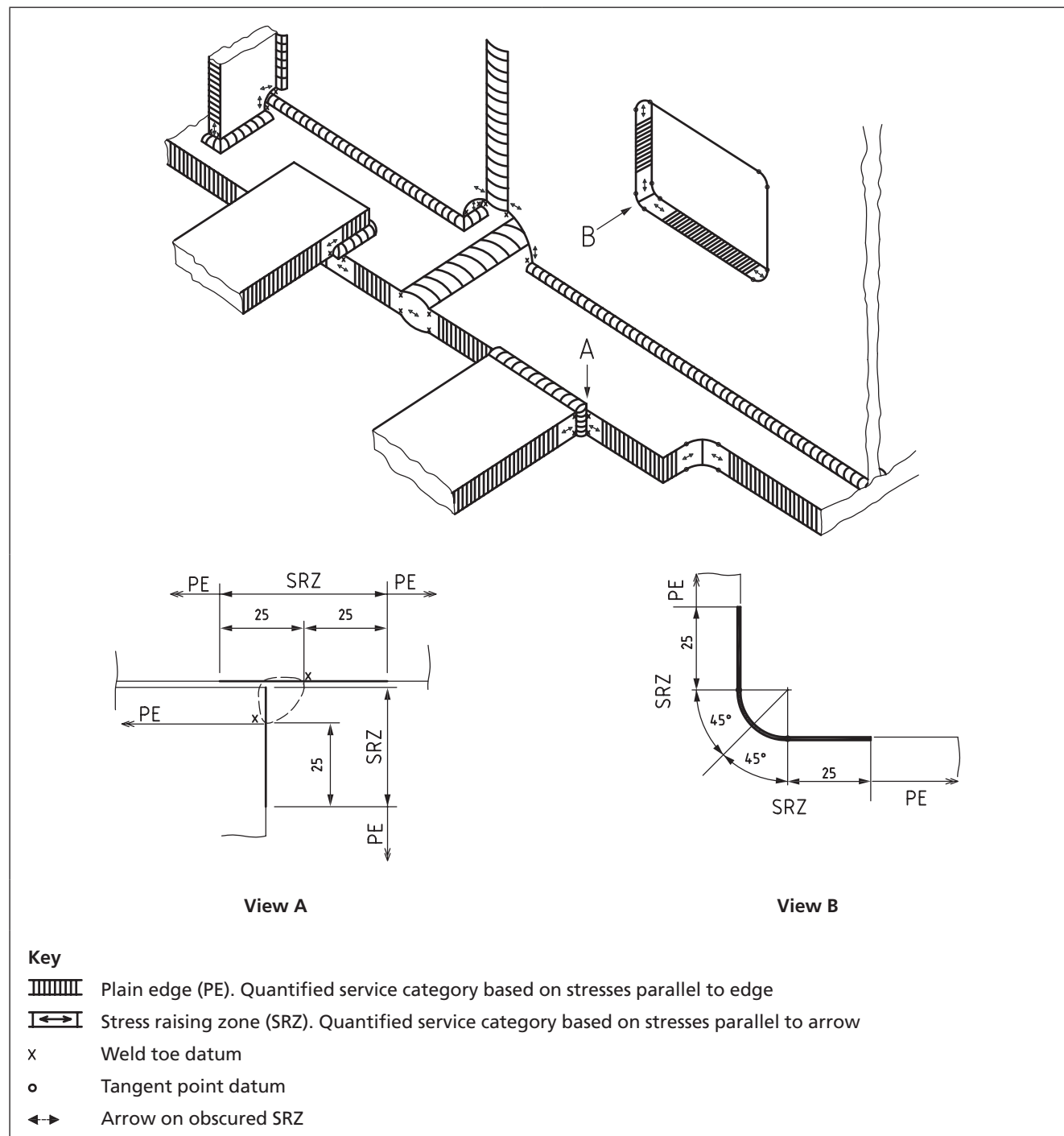
The hard thin layer of metal close to the thermally cut edge has a microstructure with very reduced ductility which is susceptible to microcracking in the event of subsequent plastic straining, whether during execution or in-service. The design fracture toughness requirements of the adjacent unaffected material is normally sufficient to resist fracture from pre-existing microcracks, but not necessarily from a crack which initiates in a hardened zone under high applied tensile strain and which needs to be arrested. Pre-existing microcracks can also cause premature initiation of fatigue cracks in locations subject to high cyclic stressing. The recommended limitations given in 8.4 aim to reduce these risks.

The relaxation of the hardness limits for machine plasma cut edges in certain conditions in 8.4 is based on the superior quality of surface finish usually achieved with this process. To assist with interpretation of the conditions in 8.4c), typical examples showing the zones which are governed by plain and stress raising features are illustrated in Figure C.1, together with the relevant stress direction for assessing the quantified service category limits. For elements whose design

is governed by stiffness or control of deflection, e.g. intermediate transverse web stiffeners, F36 can be assumed to apply, except where any applied stress requirements show that a higher quantified service category applies.

There is normally a hardness gradient in the first millimetre of material from the cut edge. The zone of any excess hardness is normally less than this, depending on the cutting process.

Figure C.1 Definition of plain edge and stress raising zones for machine plasma cut edge surfaces



C.9 Execution of holing

The practical difficulties of ensuring that the local hardness and quality of thermally cut holes in production according to BS EN 1090-2:2008+A1:2011, 6.6.3a) are such that the process should be restricted to joints which are stressed well below the limits permitted in BS EN 1993-2, BS EN 1993-1-9 and BS EN 1993-1-10.

C.10 Elongation of holes by drifting

The recommended tolerance clauses are based on the consideration of the importance of fit-up in preloaded connections. Generally, the more severe the distortion due to drifting, the greater the out-of-plane deformation of the hole ring.

C.11 Quality management requirements

The weld quality management requirements of BS EN ISO 3834 are an important element in the assurance of adequate welding quality in the final bridge. The comprehensive requirements of BS EN ISO 3834-2 are usually adequate for controlling the most stringent quality conditions covered by BS EN 1993-2 and BS EN 1090-2. BS EN ISO 3834-1:2005, Annex A compares the requirements for BS EN ISO 3834-2, BS EN ISO 3834-3 and BS EN ISO 3834-4. Many of the requirements for BS EN ISO 3834-2 and BS EN ISO 3834-3 are similar. BS EN ISO 3834-4 has few specific requirements.

For the smaller and lighter range of bridges using simple materials and constructional details, the use of **A1** constructors **A1** certified to BS EN ISO 3834-3 might be adequate. This avoids unnecessary rejection of potentially competent tenderers.

Bridge **A1** constructors **A1** certificated to BS EN ISO 3834 are limited by the type of construction prescribed by the certificating body, which approves the full details of the welding management system in greater detail than is covered in BS EN ISO 3834.

C.12 Tack weld procedures

The main risks from the presence of tack welds are hydrogen cracking due to too low a heat input, moisture and high restraint at the assembly stage. If such cracks are not detected prior to welding of the joint and the root pass does not fuse the whole of the tack, they can remain in the final weld and can even extend during the later passes. These cracks are mainly detrimental to the performance of transversely stressed joints.

The other risk, which is more prevalent with automatic welding, is that lack of fusion can occur at the beginning or end of the tack weld due to the sudden change in joint profile. This is detrimental to the performance of longitudinally stressed joints, e.g. web-to-flange joints.

Whilst the size of such flaws is not usually large enough to cause a fracture, where cyclic stressing requirements require a quantified service category of F71 or above, there is a risk that the fatigue life can be reduced. Whilst this level of stressing might only be required occasionally, it is preferable to have an approved weld procedure in place to eliminate this risk if the welding organization is qualified for quantified service category F71 or above (see 9.1).

C.13 Weld procedure qualification

Acceptance criteria for procedure qualification testing should be set higher than that required for normal production. This ensures that there is some margin for unavoidable deviations in production, which can be easier to control in a procedure test. In some cases, the criteria might be the same, but they should not be lower than the acceptance criteria required from production. This principle applies to all forms of testing in all structural materials.

C.14 Welding co-ordination

Whilst BS EN ISO 14731 gives general principles for the role and qualification of welding co-ordination personnel, the full details are determined as part of the certification conditions, defined by the BS EN ISO 3834 certification body for each individual A_1 constructor A_1 (see 9.1). The certification body takes account of any limitations on the type of bridgework to be undertaken by the organization when considering the requirements for the degree of authority, the previous experience and the technical training of the welding co-ordination personnel employed for that work.

C.15 Temporary attachments

Risk of damage during removal and the difficulty of repair to the quality required for the highest fatigue stressing situations are the reasons for the recommendation in 9.4.3. Note that the part of the attachment weld metal which remains below the member surface constitutes part of the permanent material.

C.16 Permanent steel backing

The addition of a permanent steel backing can reduce the detail category of a butt weld. It could also introduce a potential corrosion initiation. These matters should be checked by the designer.

Unwelded butting backing components orientated parallel to the stressing direction constitute a very severe notch with a fatigue detail category less than $\Delta\sigma_c = 56 \text{ N/mm}^2$. Depending on cross section, they could also increase the risk of brittle fracture.

C.17 Welding of bolted joint components

Welding of heat treated nuts, bolts or washers can temper the material and reduce their mechanical properties. The high carbon levels can result in hydrogen cracking where small weld deposits are used on the larger component sizes.

C.18 Fit-up of preloaded bolted joints

Adequate fit-up quality in the snug-tight condition is essential for preloaded joints, otherwise the structural performance might be impaired. This can take various forms dependent on the joint geometry and loading type. For example:

- On double covered slip resistance connections, differences in the inner element thickness on each side of the joint causes gaps on

the thinner side which can lead to a greater share of clamping force on the thick side. The slip resistance of the thinner side is reduced. This can result from adverse rolling tolerances.

A more severe condition of this type can occur when the splice plates are integrally welded on one side of the joint, e.g. in the diagonal to chord gusset joints in a truss, resulting in loss of clamping force.

- In double covered slip resistance joints where there is misalignment between the elements on each side of the joint in members which are stiff relative to each other, e.g. box chords in a truss, there can be gaps on opposite sides of the joint. When the bolts are fully tightened, the reduction of the misalignment can result in overstressing of the adjacent welds.
- In joints subjected to cyclic tension forces across the joint plane, e.g. end plated cross girder to main girder connections, the design could depend on the faying surfaces around the bolt holes remaining in compressive contact under all conditions of applied loading to prevent undue cyclic tension in the bolts. For this to be achieved the surfaces need to be in contact at the snug-tight stage.

C.19 Preloading force

The minimum specified preloading force should not be lower than that given in BS EN 1090-2:2008+A1:2011, Table 19, otherwise the design assumptions made using BS EN 1993-1-8 could be invalid.

C.20 Torque method

The torque method is likely, in practice, to give a lower pre-tension than the methods involving a final nut rotation. This is because the method does not take advantage of any increase in the bolt strength above the minimum required by the product standard. It is also wholly dependent on the torque-tension k value, which has to be conservative to avoid bolt overstretching (over which there is no control as there is with the turn methods).

The torque method is the only safe method where bolts might need to be undone and retightened in-service, as the turn methods usually involve incremental stretching.

C.21 Combined method

The recommended increase in turn angles is to allow for an extra margin for:

- out of parallel of grip surfaces;
- angular misalignment of bolt head axis or nut thread axis allowed by product standards; and
- out of alignment of ply holes in stack.

In view of the high reliance on the k value for prevention of the bolt stretching prior to the application of the final turn, it is important to take account of the fact that k values can be affected by storage time and conditions.

C.22 Part turn method

The recommendations have been based on the BS 4604-1 method, which has been widely used in the UK, together with the bedding torque values for the Highways Agency *Specification for Highways Works*, Series 1800 [1].

The advantage of this method over the combined method is that the bedding tension is typically in the region of 20% to 30% of the ultimate bolt strength, whereas, in the combined method, it is likely to be more than 70%. Therefore, there is no danger of stretching the bolt at step 1 and no need to use a K1 or K2 bolt assembly.

The range of grip lengths in Table 3 is as given in BS 4604-1.

C.23 Scope of weld inspection

The scope of weld inspection in BS EN 1090-2:2008+A1:2011 is based on the principles of FPC, which is not specific to any one contract passing through the works at any time (see BS EN 1090-2:2008+A1:2011, **12.4.2.2**, note 2). For FPC, the supplementary NDT methods are not defined and only the principles for selection of method in BS EN 12062 have to be followed (see BS EN 1090-2:2008+A1:2011, **12.4.2.4**). BS EN 12062 does not give any advice on suitability for verification of different imperfection types and sizes.

In specific contracts, the extent and methods of testing of specific joints can be defined (see BS EN 1090-2:2008+A1:2011, **12.4.2.2**). Table 4, Table 5 and Table 6 of this Published Document define the methods and extent for a wide range of conditions, based on the following principles.

- a) The methods and extent are dependent on the degree of difficulty in detection and evaluation of the acceptable imperfections, their expected risk of occurrence and their adverse effect on resistance.
- b) The acceptance limits for imperfections which are considered are based on fitness-for-purpose criteria, given in Table 7, Table 8, Table 9 and Table 10.
- c) The acceptable size of imperfections becomes smaller with increasing quantified service category (see **C.24**), and this has a major effect on the method and extent of inspection required.
- d) The methods are chosen according to the joint type, size and orientation with respect to the critical stress direction, as well as the type of imperfection measurement required.

C.24 Weld acceptance criteria

The acceptance criteria in BS EN 1090-2:2008+A1:2011 are indirectly associated with an unquantified service category via BS EN 1090-2:2008+A1:2011, Annex B, which is informative. The selection via execution class in BS EN 1090-2:2008+A1:2011, **7.6** is therefore arbitrary and can often be more stringent than that required for procedure qualification to BS EN ISO 15614-1. In other cases, particularly in the case of fatigue critical applications in EXC1 and EXC2, and in some cases in EXC3 and EXC4, the criteria can be inadequate for safe performance. BS EN 1090-2:2008+A1:2011, **7.6** makes it clear that the FPC acceptance criteria can be higher than necessary for the safe performance of the welded component and that FFP based criteria

may be applied to assess whether rejection and repair are necessary. However, no such criteria are given in BS EN 1090-2:2008+A1:2011.

BS EN ISO 5817, which forms the basis for the FPC acceptance criteria specified in BS EN 1090-2:2008+A1:2011, 7.6, makes it clear that not all of the criteria are assessable by NDT. This raises the question of how such criteria can be verified in the final product, i.e. whether the specification requirements are capable of practical implementation. In other cases, some of the criteria bear little relation to the safe performance of the component, and can be unnecessarily onerous.

BS EN ISO 5817 also states that the quality levels, D, C and B given in that standard refer to production quality and not the fitness-for-purpose of the manufactured product [see BS EN ISO 5817:2007, 3.2 for the definition of fitness-for-purpose (FFP)]. In the 1992 edition the levels D, C and B were defined as "moderate", "intermediate" and "stringent", indicating that the differentiation was based on ease of achievement in practical production. There is no direct correlation in practice between ease of achievement and FFP across a wide range of different performance requirements.

Therefore FFP based acceptance criteria have been provided in Table 7, Table 8, Table 9 and Table 10 for assessing welds in bridges to ensure safe performance and avoid unnecessarily stringent testing and quality requirements. The recommendations in Table 7, Table 8, Table 9 and Table 10 are based on the principles established in BS 5400-6, ISO 10721-2 and the proposed FFP based specification clauses submitted to CEN/TC135 by the UK at the time of enquiry. The main features are listed below.

- a) The acceptance criteria are dependent on the quantified service category.
- b) The acceptance criteria only include those requirements which are essential for structural performance.
- c) The acceptance criteria for each inspection method are given in separate tables in terms appropriate to each method.
- d) Relaxation of imperfection limits has been given for longitudinal welds.
- e) Differentiation in limits for buried imperfections is made according to their position in the cross section. Restrictions are also given on the minimum separation distance between imperfections.
- f) Reference is made to BS EN ISO 6520-1 and BS EN ISO 5817 for imperfection terminology, definitions, reference numbers and dimensional symbols whenever they are given in those standards.
- g) The acceptance criteria in Table 7, Table 8, Table 9 and Table 10 represent the physical limits which are acceptable for performance purposes. No allowance has been made for measurement error. In cases of doubt, particularly in the assessment of a buried imperfection to Table 10, the imperfection should be rejected and its true dimension verified by excavation for the purposes of calibration of the NDT measurement technique.

Some of the more important features of the FFP criteria in Table 7, Table 8, Table 9 and Table 10 and their comparison with the FPC criteria in BS EN ISO 5817 are given below.

Profile limitations given in the FPC criteria are not included unless they have a negative effect on resistance. This includes excess weld

metal BS EN ISO 5817 imperfection numbers 1.9, 1.10, 1.11 and 1.21. Such stress concentration effects are generally controlled by toe angle. These FFP toe angle limits lead to less restriction for low quantified service categories but are tighter for higher categories. Similarly, there is no control stipulated for asymmetry of leg lengths. These can be controlled for FPC purposes, e.g. distortion, cost of consumables or, in some cases, design considerations, e.g. clearance, drainage. However, for FPC level B in particular, the limits are very restrictive and leave a small margin against undersize non-conformances.

The FFP limits for surface notches tend to be more restrictive than allowed by FPC level B, particularly as the quantified service category increases.

The FFP criteria do not permit undersize fillet weld throats, which is the same as for FPC level B. FPC level C does allow sub-size throats. The reason for not allowing sub-size throats for FFP is that it is not practicable to assess the internal condition of fillet welds by NDT, and some allowance has to be made for the undetected presence of such imperfections such as lack of root penetration, lack of side wall fusion, root gap, porosity, etc. all of which can reduce the effective throat.

The FPC criteria do not give a limit on leg length. In fillet welded tee, cruciform and corner joints, which are stressed transversely, the failure plane is close to or on the fusion boundary of the stressed element. For asymmetric welds with convex caps the limits given, even for level B, do not prevent shortfalls on leg length even if the throat measurement is within limits. For this reason strict controls on leg length are included for FFP.

For FFP assessment of volumetric imperfections reliance is put on ultrasonic testing, except where radiographic inspection might be needed for the highest quantified service categories (see Table 10). Characterization of types of internal imperfection is not required except in the case of cracks. A limit of 3 mm in height is assumed, although this can mean restricting length in some cases. This is considered to be a minimum height for UT assessment purposes. Some of the FPC imperfections have height limits below 3 mm, which cannot be assessed by commercial NDT techniques.

The FPC criteria for buried imperfections do not distinguish between near surface and deeper zones, the former being more critical on a FFP basis. Neither do the FPC criteria for multiple imperfections (imperfection number 4.2 in BS EN ISO 5817) give any limits on minimum clearance between adjacent imperfections. For these reasons the FPC criteria for buried imperfections can be inadequate.

The detailed FPC criteria for porosity can only be assessed using radiography, which is not commonly used for structures. The FFP criteria for porosity have been simplified for this reason.

In summary, some of the FPC range of criteria can be either excessive or inadequate when judged on a FFP basis, depending on the imperfection type and the required quantified service category.

The above system of specific inspection and FFP acceptance criteria means that:

- the customer has a clearly defined level of assurance that satisfactory performance in service can be achieved for each bridge contract; and
- the A_1 constructor A_1 is able to estimate the production and testing costs for each bridge contract at the time of tender.

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