STRUCTURAL STEEL REUSE

ASSESSMENT, TESTING AND DESIGN PRINCIPLES

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Published by:
SCI, Silwood Park, Ascot,
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T: +44 (0)1344 636525
F: +44 (0)1344 636570
E: reception@steel-sci.com

www.steel-sci.com

To report any errors, contact:
publications@steel-sci.com

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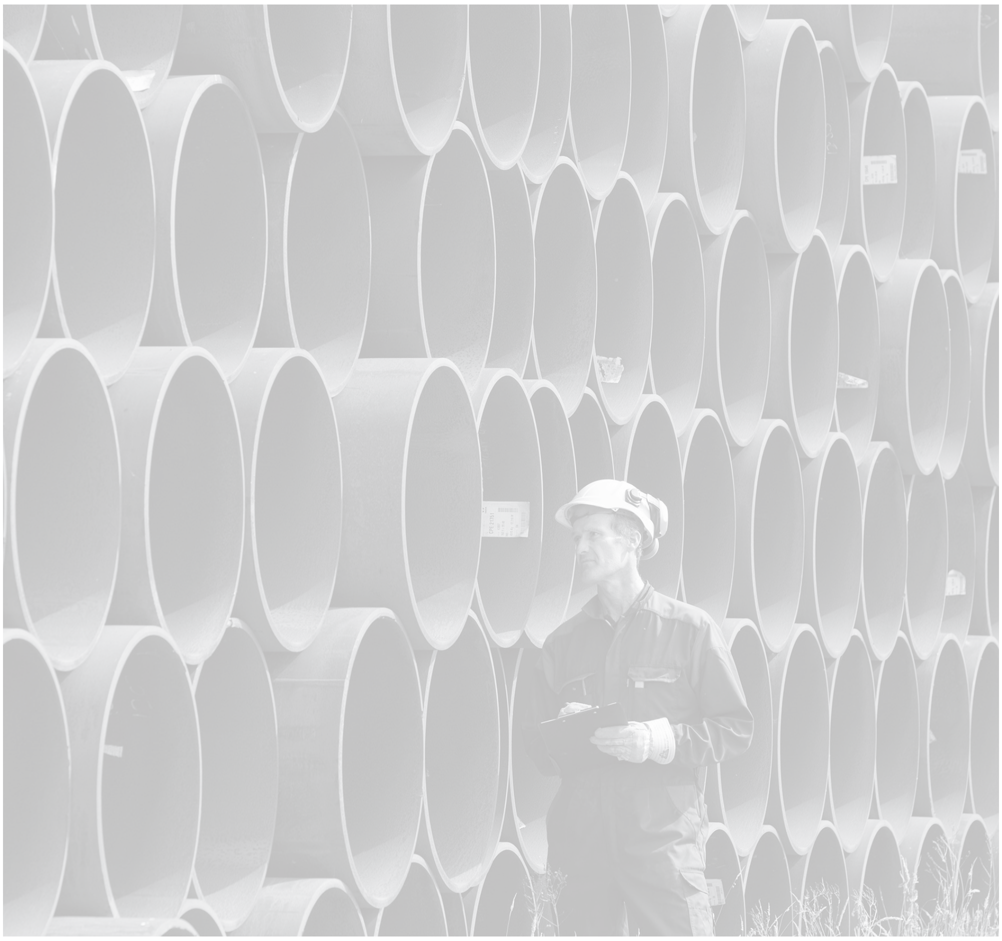
D G Brown BEng, CEng, MICE
R J Pimentel MEng, MSc
M R Sansom BEng, PhD, CEnv, MICE



SUMMARY

The environmental advantages of re-using reclaimed structural steel are considerable, compared to the common practice of recycling by re-melting scrap. There are also potential cost savings compared to the use of new steel.

This protocol recommends data collection, inspection and testing to ensure that reclaimed structural steelwork can be reused with confidence. Certain conservative assumptions about the material characteristics may be made, or testing should be undertaken to determine the properties with greater confidence.

The reuse of reclaimed steel is limited to applications where the reclaimed members were not subjected to fatigue, for example, steelwork from bridges. Reclaimed steel from structures which have experienced extreme loads such as fire or impact are not considered to be suitable for reuse and therefore are not covered by this protocol. Steel used in construction before 1970 is excluded from these recommendations.

This protocol recommends that steelwork is reclaimed in groups of members that have the same form, size, original function and are from the same source structure, as described in Section 6.1. Assembling groups in this way allows certain material properties to be established by testing one or more representative members from the group.

It is recommended that the only modification necessary for structural design is to verify buckling resistance using $\gamma_{M1,mod}$=1.15 γ_{M1}. This might lead to changes in the structural solution required for a given design scenario (for example additional restraints might be required) but not necessarily a change in member size, as member buckling might not be the critical verification. Within the protocol scope, described in Section 2, the use of γ_{M0} and γ_{M2} values proposed in the National Annex to EN 1993-1-1 is considered to be appropriate for reclaimed steel.

This protocol notes that material characteristics declared under CE marking procedures are designed to ensure that the material is as specified in design. When using reclaimed steel, the design is based on the material properties (either tested or based on conservative assumptions), maintaining the relationship between the design assumptions and material resistance with an adequate level of reliability.

This protocol recommends that re-certified and re-fabricated reclaimed structural steelwork can be CE Marked in accordance with BS EN 1090.

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INTRODUCTION

This document has been prepared to help facilitate the reuse of structural steel sections reclaimed from existing building structures. The principal focus of this protocol is the reclamation and reuse of individual members within a new structure, rather than the reuse of an entire building structure in a new location.

The protocol proposes a system of investigation and testing to establish material characteristics, with advice for designers completing member verifications of reclaimed steelwork. The protocol places important responsibilities on the holder of reclaimed steelwork including identification, assessment, control procedures and declarations of conformity.

The protocol is founded on the principle that given appropriate determination of material characteristics and tolerances, re-fabricated reclaimed steelwork can be fabricated and CE marked in accordance with BS EN 1090[1].


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OBJECTIVE AND SCOPE

The objective of this protocol is to facilitate the increased uptake of structural steel reuse. Reuse involves reclaiming steelwork, establishing material properties, maintaining records of the reclaimed material and declaring material properties. This protocol also covers the use of material manufactured to an alternative specification, i.e. not manufactured to a European product standard.

The scope of this protocol covers steel reclaimed from any geographical location, as material characteristics are established by test. Although the primary focus of the protocol assumes the reclaimed steelwork will be used in construction in the UK (and thus British Standards are referenced), the document has been prepared to facilitate reuse in any country which has adopted the Eurocode suite of Standards.

The scope of this protocol is limited to:

- Steelwork erected after 1970;
- Steelwork which has not been subject to fatigue, e.g. not reclaimed from bridges;
- Steelwork which has not been subject to significant strains, e.g. plastic hinges;
- Steelwork without significant loss of section due to corrosion;
- Steelwork which has not been exposed to fire.

This protocol anticipates that the primary use of reclaimed steelwork will be as plain members, i.e. with existing connections removed or redundant, used within a new structure. However, the reuse of steelwork with existing connections is not excluded, nor the reuse of a complete (or partial) structure, re-erected in a different location.

2.1 Drivers for re-use of structural steelwork

Structural steel sections are robust and dimensionally stable elements that are generally bolted together to form structural assemblies which are inherently demountable. As such, structural steel is seen as an obvious candidate for reclamation and reuse as opposed to the current, common practice of recycling by remelting. Reusing structural steel yields significant environmental savings compared to recycling.

There is growing pressure on the construction industry to be more resource efficient, reduce waste and to lower embodied carbon impacts. More recently, circular economy concepts are being promoted, particularly at the EU level, with a roadmap developed to support a shift towards a resource efficient, low carbon European economy. Increased structural steel reuse will support both of these aims and stimulate new business opportunities in the UK in particular, by substituting steel imports.

Although new steel and scrap steel prices are volatile, analysis reveals that the long-term price (2000-2016) differential between the cost of UK structural steel and scrap sections is over £300 per tonne. This represents the potential profit opportunity through structural steel reuse. Although additional costs (relative to recycling) will be incurred through deconstruction, testing, storage, re-fabrication, etc. structural steel reuse can yield cost savings or at least provide an economical feasible alternative to the use of 'new' structural steel.

This protocol aims to help facilitate the widespread uptake of structural steel reuse.

2.2 Reclaim, stock and reuse process

Although the procedures described in this protocol relate to steel sections reclaimed from an existing structure, the process is equally applicable to unused 'new' steel, for example, resulting from a cancelled project. Fabricated (but not erected) steel is likely to have known provenance and comprehensive documentation, which will be reflected in less onerous design constraints compared to reclaimed steelwork. If steel has been fabricated but not erected, it is likely that material properties and fabrication procedures will be documented and can be assumed to be appropriate. This is especially true for steelwork fabricated since July 2014, when CE marking of structural steelwork according to BS EN 1090 became mandatory.

The overall process from reclamation of steelwork to re-use in another structure is summarised below. Subsequent sections and appendices provide more detail.

Overall process

1. A building is offered for salvage of the steelwork for reuse. Considerations include the acceptability of the source material, (see Section 5.3), the demountability of the structure, the increased cost of careful demolition, etc.
2. A business case is established between the stockholder and the company responsible for demolition.
3. Important details of the anticipated reclaimed steel are recorded as described in Section 5.4.
4. Reclaimed steelwork is received by the stock holder, grouped and listed as described in Section 6.1. The necessary grouping has an important impact on the extent of testing required.
5. Members are inspected and tested in accordance with Section 7, with the information appended to the stock data. The testing regime involves non-destructive and/or destructive testing, with the opportunity to make conservative assumptions about certain material characteristics. The seller of the stock is responsible for declaring the necessary characteristics as the material is sold.

6. Material is sold, with an accompanying declaration of the material characteristics by the holder of the reclaimed stock. The declaration covers all relevant material properties which allow the fabricated steelwork to be CE marked to BS EN 1090 (see Section 3).
7. Structural design and member verification are completed with certain modifications, following the recommendations provided in Section 4.

2.3 Alternative specification of source material

Unused (not fabricated) steel might be placed on the market having been manufactured to an alternative product standard, for example steel manufactured to an American, or offshore manufacturing standard. This unused material would be expected to have appropriate original certification declaring the material properties.

If the material can be shown to comply in all respects with a weldable structural steel reference standard (as listed in Section 1.2.2 of BS EN 1993-1-1[2]), and tolerances within the limitations of BS EN 1090-2[3], the material can be used in design, using the procedures specified in BS EN 1993-1-1 and without modification of the γ_{M1} value as proposed for reclaimed steelwork (see Section 4.5).

A declaration of the material properties must be provided by the stockholder.


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CE MARKING OF RECLAIMED STRUCTURAL STEELWORK

3.1 CE Marking

CE Marking of structural steelwork is addressed in BS EN 1090-1. All fabricated steelwork placed on the EU market must be CE Marked. Basic material (rolled sections, plate, etc.) must be CE Marked to the relevant product standard and the fabricated steelwork must be CE Marked to BS EN 1090-1.

Steel manufacturers declare that their product meets the relevant product standard; steelwork contractors declare that the fabricated steelwork meets the requirements of the execution standards BS EN 1090-1 and BS EN 1090-2.

BS EN 1090-2 generally anticipates that 'new' steelwork is used in construction works, as stated in clause 5.1. Reclaimed steelwork must clearly be treated differently, as it might have been manufactured to a withdrawn standard and is most unlikely to have any documented test results from time of manufacture. BS EN 1090-2 sanctions the use of other materials by stating that: "*If constituent products that are not covered by the standards listed are to be used, their properties are to be specified. The relevant properties to be specified shall be taken from the following list:*

a. *Strength (yield and tensile);*
b. *Elongation;*
c. *Stress reduction of area requirements (STRA), if required;*
d. *Tolerances on dimensions and shape;*
e. *Impact strength or toughness, if required;*
f. *Heat treatment delivery condition;*
g. *Through thickness requirements (Z-quality), if required;*
h. *Limits on internal discontinuities or cracks in zones to be welded if required.*

In addition, if the steel is to be welded, its weldability shall be declared as follows:

i. *Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608 or;*
j. *A maximum limit for the carbon equivalent of the steel, or;*
k. *A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated."*

BS EN 1090-2 requires that documentation must be used to declare the relevant material characteristics. It is mandatory that this documentation is provided by the holder of the stock when selling the material.

3.2 CE Marking of reclaimed steel

There will be no difference in the fabrication processes, procedures, standards or tolerances for either new steel or reclaimed steel. It is therefore appropriate that re-fabricated, reclaimed structural steelwork can be CE Marked in accordance with BS EN 1090.

In addition to careful control of the fabrication process, material properties must be declared according to BS EN 1090-2 clause 5.1. When using reclaimed steel, this is the stockholder's responsibility.

3.3 Declaration of properties

The purpose of declaring material properties is so that the material used in construction meets the appropriate standard and that properties required by design are confirmed, e.g. the required material strength assumed in the member verifications has actually been provided.

Generally, a structural designer specifies certain material characteristics (which have been assumed in the design process), which are then confirmed as actually used in the structure by the declaration of properties. With reclaimed structural steel, the relationship is reversed, so that the design verifications are based on the properties (either tested or conservatively assumed) of the reclaimed elements. In either approach the objective of the declaration of material properties is to ensure that the design assumptions are compatible with the material.

The requirements of BS EN 1090-2 and the testing regime for reclaimed steelwork are discussed in Section 3.4.

3.4 Material properties to be declared for reclaimed steelwork

The test regime described in Section 7 is intended to allow the necessary material properties according to BS EN 1090-2 clause 5.1 to be declared, based on dimensional survey, by non-destructive tests, by destructive tests or by making conservative assumptions. A summary of the necessary material properties and how they are to be assessed is presented in Table 3.1.

Section 3.5 provides a commentary on each material property that must be declared.

Item	Property	To be declared	Procedure
a)	Strength (yield and tensile)	Yes	Determined by destructive and non-destructive tests.
b)	Elongation	Yes	Determined by destructive tests.
c)	Stress reduction of area requirements (STRA)	If required	Generally not required to be declared.
d)	Tolerances on dimensions and shape	Yes	Based on dimensional survey.
e)	Impact strength or toughness	If required	If required, determined by destructive tests. Conservative assumption as the default.
f)	Heat treatment delivery condition	Yes	Conservative assumption as the default.
g)	Through thickness requirements (Z-quality)	If required	Generally not required to be declared.
h)	Limits on internal discontinuities or cracks in zones to be welded	If required	Generally not required to be declared.
In addition, if the steel is to be welded, its weldability shall be declared as follows:			
i)	Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608, or	Yes	Not applicable for reclaimed steelwork.
j)	A maximum limit for the carbon equivalent of the steel, or;		Maximum to be declared from manufacturer's test certificates.
k)	A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated		Determined by non-destructive and destructive tests.

Table 3.1 – Material properties to be declared for reclaimed steelwork according to BS EN 1090-2

3.5 Commentary on the required properties

3.5.1 Strength

Yield strength and ultimate strength should be determined by non-destructive and destructive tests. The use of non-destructive tests is limited to establishing the steel grade. The declared yield strength and ultimate strength should be the values specified in product standards appropriate for that grade, not the values determined from the tests. Because the protocol is limited to steel used in construction after 1970, the yield strengths and ultimate strengths taken from the product standard are considered to be reliable.

Non-destructive testing is also used to identify any inconsistencies between members within a group. Within this protocol, a group is a number of reclaimed members, having the same form, original function, size and details, from the same building and being less than 20 tonnes in total. More details on member groups are given in Section 6.1.

Destructive tests are used to establish the yield strength and ultimate strength of one or more representative samples from the group (see Section 7.2) to confirm the correct material grade for the group has been identified.

3.5.2 Elongation

The use of reclaimed steelwork is limited to applications where significant ductility is not required, i.e. plastic global analysis is not recommended, and is limited to the reuse of relatively 'modern' steel (see Section 5.3). The demands on elongation are therefore limited, and likely to be met by the reclaimed steelwork.

Elongation must be specified according to BS EN 1090-2 clause 5.1 and determined by destructive testing.

3.5.3 Tolerances on dimensions and shape

Reclaimed elements must be checked against geometric tolerances. Elements within tolerance are acceptable and satisfy the assumptions made in the design standard.

Table 3.2 lists the standards to be used when assessing dimensions and tolerances.

Products	Dimensions	Tolerances
I and H sections	EN 10365[4]	EN 10034[5]
Hot-rolled taper flange I sections	EN 10365	EN 10024[6]
Channels	EN 10365	EN 10279[7]
Equal and unequal leg angles	EN 10056-1[8]	EN 10056-2[9]
T Sections	EN 10055[10]	EN 10055
Plates, flats, wide flats	-	EN 10029[11] EN 10051[12]
Bars and rods	EN 10017[13], EN 10058[14], EN 10059[15], EN 10060[16], EN 10061[17]	EN 10017, EN 10058, EN 10059, EN 10060, EN 10061
Hot finished hollow sections	EN 10210-2 [18]	EN 10210-2
Cold formed hollow sections	EN 10219-2 [19]	EN 10219-2
Fabricated profiles and member bow imperfections	EN 1090-2	EN 1090-2

Table 3.2 – Dimensions and tolerances for structural steelwork

3.5.4 Through thickness requirements

Through thickness properties are generally not required for reclaimed sections, such as beams or columns. Some joint details may require the steel plate to have through thickness properties. If through thickness properties are required, reclaimed plate must be tested as specified in BS EN 1993-1-10[20].

3.5.5 Impact strength or toughness

A certain impact strength or toughness (commonly known as the Charpy value) might be required for a specific project, such as for thick, highly stressed steelwork exposed to low temperatures. However, for internal steelwork which is not subjected to fatigue, a conservative assumption about the material toughness is appropriate.

If material toughness must be determined, destructive tests are required in accordance with the requirements of the relevant standard, e.g. Clause 10.2.2 of BS EN 10025-1.

3.5.6 Heat treatment delivery condition of hollow sections

Hollow sections are cold formed to BS EN 10219[21] or hot finished to BS EN 10210[22]. Conservatively, it is recommended that all reclaimed hollow sections are assumed to be cold formed according to EN 10219.

3.5.7 Declaration of chemical composition

Chemical composition is important to establish the durability and particularly the weldability of the reclaimed structural steel. The stockholder must provide a declaration of chemical composition, based on non-destructive and destructive tests. The chemical composition declaration must provide measures of certain chemical elements according to the relevant standard. The intent of this declaration is to enable the carbon equivalent value (CEV) to be calculated, which is a key measure of weldability.

DESIGN RECOMMENDATIONS

This section summarises the recommendations for structural design and verification of reclaimed structural steel members.

4.1 Structure scope

This protocol has been prepared on the basis that reclaimed steel can be used in Consequence class 1, 2 or 3 structures (see Table B1 of BS EN 1990). Use of reclaimed steelwork in Consequence class 3 structures places additional requirements on the testing regime to determine material characteristics.

Reclaimed steel should not be used in structures subject to fatigue, or in plastically analysed structures which rely on the formation of plastic hinges. Similarly, the use of reclaimed steel in structures subject to seismic loading is excluded, unless the steel plays no part in resisting the seismic action, for example as a pin-ended floor beam.

4.2 Ductility and residual strains

Elongation of steel is a mandatory declaration according to clause 5.1 of BS EN 1090-2 and must be determined by a destructive test.

Plastic global analysis is not recommended when reclaimed steel is reused. The limitations on the ratio between the ultimate strength (f_u) and the yield strength (f_y) as well as the minimum elongation appropriate for elastic global analysis are given in the National Annex to EN 1993-1-1.

Careful visual inspection of every reclaimed member, and assessment against the tolerances referenced in Section 3.5.3 should ensure that the element has not undergone plastic deformations and therefore the residual strains, and reserves of ductility, are no different to that of 'new' steel.

4.3 Global analysis

Designers should not undertake plastic global analysis, as this demands a high level of ductility. Although elongation of steel will be demonstrated by test, it is still considered prudent to restrict practice to elastic global analysis.

4.4 Cross sectional resistance

Reclaimed steel is assumed to be sufficiently ductile to permit the use of a plastic cross-sectional resistance, for example, in bending or shear. The design resistances presented in BS EN 1993-1-1 should be used.

For cross sectional resistance, the National Annex recommended values for γ_{M0} and γ_{M2} should be used for steelwork erected after 1970 that complies with this testing protocol. Further guidance and background is provided in Appendix A.

4.5 Buckling resistance

For reclaimed steel, a modified value of $\gamma_{M1,mod}$=1.15 γ_{M1} is recommended, which reflects the increased uncertainty when using reclaimed steel.

Justification for this recommendation is given in Appendix A.

For 'new' steel, for example from a cancelled project - not erected, which has appropriate documentation, the current value of γ_{M1} from the National Annex to EN 1993-1-1 should be used. The UK National Annex[23] recommends γ_{M1}=1.00.

4.6 Steel toughness and sub-grade

It is assumed that all steel used in construction since 1970 has a minimum Charpy V-notch impact value of 27 J at 20 °C, which corresponds to the JR subgrade according to BS EN 10025. The reclaimed steel sub-grade may be assumed to be JR without testing.

Clause 5.1 of BS EN 1090-2 states that a declaration of steel subgrade is not mandatory. Where the declaration of the reclaimed steel subgrade is required, for example, for external steelwork exposed to low temperatures, the steel subgrade needs to be determined by tests. Tests and relevant documentation is a stockholder responsibility.

Since the scope for the reuse of reclaimed steel is limited to structures where fatigue is not a design consideration (Section 4.1), the limiting thickness values presented in SCI Publication P419[24] are recommended for use in the UK. SCI P419 adopts the procedures of the Eurocode, but reduces the calculated crack growth for applications where fatigue is not a design consideration.

For internal steelwork used in the most onerous circumstances ("Combination 10"):

- S275 JR – the limiting thickness is 77.5 mm
- S355 JR – the limiting thickness is 35 mm

For external steelwork used in the most onerous circumstances (“Combination 10”):

- S275 JR – the limiting thickness is 32.5 mm
- S355 JR – the limiting thickness is 16.5 mm

“Combination 10” refers to the column identification provided in Table 2 and Table 3 of PD 6695-1-10[25] and Table 5.1 and Table 5.2 of SCI P419.

The preceding values fully respect the requirements of the UK National Annex. For less severe details, and lower stress levels, i.e. a lower combination, the limiting thickness increases and SCI P419 should be consulted for a less onerous value.

4.7 Revised thickness limits for use outside the UK

The thickness limits given in SCI P419 and summarised in Section 4.6 are only appropriate for the UK, as they include all the provisions of the UK National Annex to BS EN 1993-1-10.

Table 4.1 follows the same format as Table 2.1 of EN 1993-1-10, but adopts the reduced crack growth assumed in SCI publication P419. The values in Table 4.1 can be used in countries other than the UK, when fatigue is not a design consideration, subject to any requirements of the specific National Annex of the country of construction.

4.8 Connection design

This protocol anticipates that the primary use of reclaimed steelwork will be as plain members, i.e. with existing connections removed or redundant.

If new connections to the reclaimed steelwork require welding of some components, the carbon equivalent value (CEV) will be required in order to develop appropriate welding procedures. The chemical composition of the steelwork is a mandatory declaration according to clause 5.1 of BS EN 1090-2. The declared CEV should be the maximum value determined from the non-destructive and destructive tests (see Appendix E). A high CEV will generally not be detrimental unless the joint has a high combined thickness (the sum of the thickness of all the elements meeting at the joint).

If connections are to be re-used, previous research[26] indicates that it may be assumed that the strength of the weld material is at least equal to the base steelwork . This advice does not cover workmanship – it is recommended that any existing welds that are to be reused are carefully inspected and tested.

Table 4.1 – Limiting thickness values when fatigue is not a design consideration

		Charpy energy CVN		Reference temperature, T_{Ed} (°C)																				
				10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
Steel grade	Sub Grade	at T (°C)	J_{min}	$\sigma_{Ed} = 0.75\,f_y(t)$							$\sigma_{Ed} = 0.5\,f_y(t)$							$\sigma_{Ed} = 0.25\,f_y(t)$						
S235	JR	20	27	200	200	200	195	125	87	63	200	200	200	200	200	200	161	200	200	200	200	200	200	200
	J0	0	27	200	200	200	200	200	195	125	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S275	JR	20	27	200	200	200	133	91	64	47	200	200	200	200	200	170	121	200	200	200	200	200	200	200
	J0	0	27	200	200	200	200	200	133	91	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	M,N	-20	40	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S355	JR	20	27	200	177	114	77	54	40	30	200	200	200	200	147	104	76	200	200	200	200	200	200	200
	J0	0	27	200	200	200	177	114	77	54	200	200	200	200	200	200	147	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	177	114	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	K2,M, N	-20	40	200	200	200	200	200	200	177	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S460	Q	-20	30	200	200	200	200	147	96	65	200	200	200	200	200	200	187	200	200	200	200	200	200	200
	M, N	-20	40	200	200	200	200	200	147	96	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL	-40	30	200	200	200	200	200	200	147	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL1	-60	30	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S690	Q	0	40	200	137	89	58	40	28	20	200	200	200	174	115	78	55	200	200	200	200	200	200	200
	Q	-20	30	200	200	137	89	58	40	28	200	200	200	200	174	115	78	200	200	200	200	200	200	200
	QL	-20	40	200	200	200	137	89	58	40	200	200	200	200	200	174	115	200	200	200	200	200	200	200
	QL	-40	30	200	200	200	200	137	89	58	200	200	200	200	200	200	174	200	200	200	200	200	200	200
	QL1	-40	40	200	200	200	200	200	137	89	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL1	-60	30	200	200	200	200	200	200	137	200	200	200	200	200	200	200	200	200	200	200	200	200	200


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ASSESSMENT OF RECLAIMED STEELWORK FOR REUSE

5.1 Introduction

All structural steel reclaimed for reuse, is to be inspected and tested. Central to the testing regime is the grouping of fundamentally identical members into groups, whereby one (or more) members are assumed to be representative of the entire group, thus moderating the requirements for testing. The data to be recorded, initially and after subsequent testing, is set out in Appendix B.

Without traceability of each component, the value of the reclaimed material will be compromised. It is therefore important for material stockists to maintain full traceability of the reclaimed steelwork, including the grouping and labelling of members.

5.2 Preliminary assessment

Assessment of the reclaimed steelwork begins before the existing structure is deconstructed, with the collection of relevant data. Section 5.4 describes the initial data to be collected, and Section 7 the general principles of the testing regime.

In addition to the assessment of the steel elements, the preliminary assessment should consider the method of deconstruction and a safe method of work.

5.3 Admissibility of reclaimed steelwork

The following scope for reclaimed steel is necessary to complement recommendations in this protocol:

- Steelwork no older than 1970;
- No built-up members (unless welds are tested);
- No spliced members (the individual lengths of a member with a bolted or welded splice can be disassembled/cut and reclaimed; otherwise, welds need to be tested);

- No significant section loss due to corrosion (loss exceeding 5% of the element thickness is considered significant);
- No signs of fire exposure;
- No evidence of plasticity observed in the steel surface or corrosion protection;
- Members must meet the geometric tolerances of BS EN 1090-2 (straightening can be performed if tolerances are not met).

The limitation to steel produced after 1970 relates to the material properties assumed by modern design standards. Steel from 1970 was considered as part of the Eurocode programme and the development of product and design standards. It is therefore assumed that steel produced after 1970 meets the material properties assumed in product standards such as BS EN 10025 and BS EN 10219.

5.4 Assessment and initial data collection

Before deconstruction and reclamation of the steelwork, data about the existing structure is to be collected, and visible steelwork assessed. The following data should be recorded from the existing structure and steelwork:

- A description of the structure and its use. This should include a description of how the building is stabilised;
- The age of the structure, which may be from records, or local information;
- A preliminary listing of the steel members;
- A preliminary inspection of the members for damage, obvious repairs, significant corrosion;
- Any evidence of plasticity.

5.5 Inspection requirements undertaken by stock holder

After reclamation, the responsibility of the holder of the stock is to inspect every member and maintain records that include:

- Dimensions (cross section and length);
- Straightness (assessed against the tolerances);
- Any significant loss of section;
- Signs of damage, or plastic strain.


VDA

RESPONSIBILITIES OF THE HOLDER OF STOCK

The organisation holding the reclaimed steel stock has important responsibilities involving the examination and testing of the steelwork, including maintaining the grouping of reclaimed members, keeping of comprehensive records and formal declarations of material properties when the reclaimed steelwork is distributed into the supply chain.

A listing of the necessary records is provided in Appendix B.

6.1 Member grouping

Reclaimed steel members are to be considered as a group, provided they are from the same original source structure and meet the following requirements:

- Structural steel erected after 1970;
- Of the same serial size;
- Same structural function, e.g. rafters, floor beams, columns, bracings, etc.;
- Identical detailing (length, connections, etc.).

If steelwork originally manufactured to an alternative specification, e.g. an American product standard rather than a BS EN, is to be placed on the market (see Section 2.3), material manufactured to different product standards should not be mixed within a group – the source and manufacturing standard of all material in a group should be consistent.

A group should comprise a maximum of 20 tonnes. Several groups of 20 tonnes will be required if large numbers of the same member are reclaimed. Grouping in this way allows certain material characteristics to be established for the group by testing one or more representative members from the group.

In this protocol, the concept of a ‘group’ has special significance, as outlined above. In product standards such as BS EN 10025-2, a similar term is ‘test unit’, indicating a collection of steel products of a specified total maximum weight of the same form, grade and quality and delivery condition. A ‘test unit’ can contain products of various thickness, whereas in this protocol, a ‘group’ is limited to members of the same serial size. In product standards, tests are specified to be undertaken from samples in the test unit; in this protocol, tests are specified to be undertaken from samples in the group.

6.2 Records

Records must be maintained for each group of reclaimed structural steel members, including:

- Details of the source structure;
- Unique identification of the group to which reclaimed members belong;
- Unique identification of every single element within the group;
- Records of physical inspection, including tolerances on cross-section and bow imperfections;
- Hardness test result and consequent material grade for each individual member;
- Destructive tensile tests results for yield strength, ultimate strength and elongation;
- Non-destructive and destructive tests to determine the CEV;
- Any assumed material properties such as sub-grade or heat treatment delivery conditions.

6.3 Declarations

When reclaimed steelwork is distributed into the supply chain, it must be accompanied by a formal declaration, following the requirements of BS EN 1090-2.

The declaration must make clear which properties have been assumed, and which have been determined by test, noting that the determination is by group and in accordance with the guidance in this protocol.

TEST PROGRAMME

7.1 Introduction

This section describes the tests to be undertaken by the holder of the reclaimed steelwork. It is required that the company holding the stock maintains appropriate records of test results, and makes appropriate formal declarations of the test results when the steel is sold.

A comprehensive listing of the data to be recorded is given in Appendix B.

Details of the testing requirements are presented in Appendices C to F, referenced in Table 7.1.

Table 7.1 – Testing requirements

Products	Appendix
Yield strength, ultimate strength and elongation	C
Impact toughness (if required)	D
Product analysis to determine CEV	E
Section dimensions and member straightness	F

7.2 Non-statistical and statistical testing

The recommendations of this protocol require 100% non-destructive testing of the reclaimed structural members in combination with non-statistical or statistical destructive testing.

The non-destructive testing of all reclaimed members establishes that a group of members (see Section 6.1) can be represented by destructive test results from one or more representative members from the group.

Non-statistical testing requires just one destructive test, taken from a member in each group, to confirm the results obtained from the non-destructive tests. Non-statistical testing is recommended for Consequence class 1 or 2 structures. Non-statistical testing is equivalent to the requirements for 'new' steel specified in the product standard.

Statistical testing requires more destructive testing to assess material characteristics in accordance with BS EN 1990. Statistical testing is recommended for reclaimed steel to be used in Consequence class 3 buildings, or when the provenance or quality of the original source material is considered to be unreliable. Statistical testing exceeds the requirements for 'new' steel specified in the product standard.

Table 7.2 relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition to Consequence class.

Table 7.2 – Testing approach related to Consequence class

Consequence class	**NDT**	**Minimum number of DT**	**Acceptance approach**
CC1	All members to be subject to non-destructive tests to establish yield strength, ultimate strength and CEV	1	Non-statistical (maximum value of CEV)
CC2		1	Non-statistical (maximum value of CEV)
CC3		3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)

FABRICATION ISSUES

8.1 General comments

All fabricated steelwork should conform to the requirements of BS EN 1090-2.

8.2 Existing coatings on reclaimed steelwork

In most situations, it is envisaged that any existing coating is to be entirely removed prior to fabrication. The reuse of steelwork with its original protection is likely to be limited to situations when the entire structure is dismantled, relocated and reconstructed, largely in its original form.

If the reuse of steelwork with corrosion protection is considered, the following issues should be considered:

- Existing corrosion protection systems are likely to need remedial work after dismantling the structure, and after any fabrication activity;
- Existing corrosion protection systems might contain hazardous substances, prohibited under current legislation;
- Although corrosion protection systems for internal steelwork might be more durable than originally anticipated, the original level of protection is likely to have diminished and to be less than recommended under current guidance.

Fire protection coatings are highly sensitive to humidity and are uniquely linked to the original member. For both of these reasons, no reliance should be placed on any original fire protection coatings.

8.3 Bolt holes and welds in reclaimed steel

The reuse of members with holes for structural bolts is permitted if all geometric and design requirements according to BS EN 1993-1-1 and BS EN 1993-1-8[27] are fulfilled.

If bolt holes are located within the critical cross-section and reduce the cross-section by more than 15%, the net cross-sectional properties should be used in member verification.

As a detailing recommendation for reclaimed steel with existing holes, new connections within 100 mm of existing holes should be avoided.

If present, larger holes, e.g. for passage of services, must be assessed on an individual basis during member verification.

In general, it is recommended that redundant welded fittings, e.g. stiffeners or cleats, need not be removed.

8.4 Existing connections

Special care is needed if existing connections are to be re-used. In particular, any welding should be subject to careful inspection and test.

The steel grade of connecting plates and other fittings should be assessed by non-destructive tests following the recommendations in Appendix C.3. The steel elongation is assumed to be at least equal to that obtained for the main structural members.

As a general recommendation, at least the same amount of weld testing required by BS EN 1090-2 (Table 24) should be applied to reclaimed steel elements. Visual inspection of 100% of the welds is recommended.

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CREDITS

iv Cleveland Steel and Tubes stockyard, Thirsk Photo courtesy of Cleveland Steel and Tubes

vi Photo courtesy of North Lincs Structures

18 Schiphol bus station

22 Fokker distribution centre, Schiphol airport

26 NTS warehouse, Thirsk Photo courtesy of Cleveland Steel and Tubes

APPENDIX A DESIGN RECOMMENDATIONS

A.1 ENV 1993-1-1 background

The data used to develop the Eurocode material factors reviewed material test results taken between 1969 and 1989. In ENV 1993-1-1, a value of γ_{M1}= 1.10 was initially proposed, with values of γ_{M0}= 1.00 for major axis bending and γ_{M0}= 1.10 for minor axis bending. The introduction of a different approach for lateral torsional buckling curves allowed the reduction from γ_{M1}= 1.10 to γ_{M1}= 1.00 . Later, it was proposed that by taking into account strain hardening, it was possible to justify the use of γ_{M0}= 1.00 for both major and minor axis bending. These are the material factors currently recommended by the Eurocode.

A.2 The value of γ_{M1}

The buckling resistance of a member is based on the design strength, the cross sectional properties and a choice of buckling curve. The choice of buckling curve is associated with an initial imperfection which allows for physical imperfections, residual stresses, cross sectional variations, etc.

The procedures recommended in this protocol are intended to ensure that the assumed design strength is conservative. Members must meet the dimensional and straightness tolerances in BS EN 1090-2, meaning that the choice of buckling curve is the same for both new and reclaimed steel. Since the reclaimed steel is limited to steel used in construction after 1970, it is assumed that the residual stresses will not be significantly different from the stresses present when the design models in ENV 1993-1-1 were developed and calibrated.

Nevertheless, some degree of uncertainty is inevitably associated with the use of reclaimed steelwork. In addition to member straightness, other imperfections in the cross sections or torsional imperfections can contribute to a reduced resistance due to the increase of second order effects. Even if all geometric tolerances are satisfied, a degree of uncertainty will remain as the assessment processes are likely to be less reliable than those undertaken for the continuous production of new steel. A conservative value of γ_{M1} is suggested in this protocol to address this uncertainty.

The recommended value for $\gamma_{M1,mod}$ is based on increasing the target reliability index (β) from 3.8 to 4.3 for a 50-year reference period (see Table B2 of BS EN 1990). The recommendation for $\gamma_{M1,mod}$ (for all steel grades) is based on principles expressed in BS EN 1990 with a conservative assumption for the partial factor associated with the uncertainty of the resistance model (γ_{Rd}).

The recommended value of $\gamma_{M1,mod}$ is given by:

$\gamma_{M1,mod} = K_{\gamma M1} \times \gamma_{M1}$, where $K_{\gamma M1} = 1.15$.

For the UK and based on the recommended value of γ_{M1} in BS EN 1993-1-1, $\gamma_{M1,mod} = 1.15$.

Adoption of $\gamma_{M1,mod}$ will only have an impact on the design of members where buckling is the critical verification. For members subject to buckling, it might be necessary to introduce additional intermediate restraints if the original buckling resistance is to be maintained in the redesigned reclaimed steel member.

A.3 The values of γ_{M0} and γ_{M2}

As ENV 1993-1-1 was based on tests performed on steel produced as early as 1969, it is reasonable to assume that there are no concerns with cross section resistance for reclaimed steel from the subsequent decades.

No change in the recommended value for γ_{M0} or γ_{M2} is therefore proposed for verification of cross sections in accordance with BS EN 1993-1-1. The cross sectional resistance depends on dimensional characteristics and material strength, which have both been verified for every reclaimed member.

A.4 Consequence class 1 structures

The recommended value of $K_{\gamma M1} = 1.15$ should be used for Consequence class 1 structures such as agricultural buildings. It is recommended that the factor $K_{FI} = 0.90$ (see BS EN 1990 Table B3) is applied to all partial factors if designing a Consequence class 1 structure.

A.5 Consequence class 2 structures

The recommended value of $K_{\gamma M1} = 1.15$ should be used for Consequence class 2 structures.

A.6 Consequence class 3 structures

The recommended value of $K_{\gamma M1}$= 1.15 should be used for Consequence class 3 structures.

Although BS EN 1990 allows designers to apply the factor K_{FI} = 1.10 to all partial factors (see EN 1990 Table B3) when designing a Consequence class 3 structure, normal practice in the UK is to increase design supervision and inspection during execution (Tables B4 and B5 of BS EN 1990) as an alternative to the K_{FI} factor.

APPENDIX B
DATA RECORDS AND INFORMATION

B.1 Data records

The following data should be recorded and associated with each structural member:

Building information

- Building age, location
- Form of construction, e.g. braced, continuous, etc.
- Any related information, such as drawings, modifications, records.

Individual members

- Section size,
- Length,
- Group (see Section 6.1),
- Member individual identification,
- Tolerance check (section dimensions and bow imperfections)
- Comments, e.g. stiffeners or fabricated features,
- Coating;
  - Coating type (and thickness if determined),
  - Condition of coating,
- Material properties;

Material properties shall be determined by non-destructive tests and/or by destructive tests. The test results, together with any derived values, shall be recorded for the following properties:

- Yield and ultimate strengths (non-destructive and destructive tests),
- Elongation (destructive tests),
- Chemical composition (non-destructive and destructive tests),
- Carbon Equivalent Value (CEV),
- Impact toughness (by destructive tests, if required).

Conservative assumptions may be made to define:

- Impact toughness (assumed, if not tested)
- Heat treatment.

The product standard used to infer relevant material properties shall be stated, e.g. BS EN 10025 or BS EN 10219.

Stockholder records

- Stockholder details (name and other relevant information);
- Internal report/documentation number (based on stockholder records);
- Other quality records (testing laboratories, etc.).

APPENDIX C STRENGTH AND ELONGATION

Within this protocol, material strength and elongation are assessed by both destructive and non-destructive tests. In the following section guidance is provided on both types of testing.

C.1 Measured strength and assumed steel grade

The results of non-destructive and destructive tests should be compared with the values presented in Table C.1 in order to determine the steel grade. The values in Table C.1 have been developed from reference[28].

	Yield strength (N/mm²)		Ultimate strength (N/mm²)			
Steel grade	**Minimum**	**Mean**	**Minimum**	**Mean**	**f_y / f_u mean**	**Standard**
S235	267	293	397	432	1.47	EN 10025-2; EN 10219
S275	313	343	452	492	1.43	EN 10025-2; EN 10219
S355	391	426	505	540	1.26	EN 10025-2; EN 10219
S460	490	529	560	595	1.12	EN 10025-3/4; EN 10219

Table C.1 – Steel grade identification from test results

The values in Table C.1 are appropriate for steel with thicknesses between 3 mm and 60 mm.

Every element within a group must comply with the minimum yield strength from Table C.1 in order for the associated grade to be assumed.

C.2 Non-destructive hardness tests

Every reclaimed member is to be subjected to a non-destructive hardness test in order to establish a value for the yield strength and the ultimate strength of the steel. A relationship exists between measured hardness and steel strength which is considered sufficiently accurate to establish the material grade. The relationship between measured hardness and material strength depends on the type of hardness test performed.

Hardness testing should be completed on the flanges of reclaimed elements, at locations of lower stress in service. For simply supported beams, locations near the end of the element are recommended. Any surface treatment must be removed from the area to be tested.

The material hardness should be taken as the mean of three measurements in the same location.

Results from each member in a group should be assessed in accordance with BS EN 1990 to determine the representative value for the whole group. Once the hardness value for the group has been established, the yield strength and ultimate strength should be calculated and compared with Table C.1 to establish the steel grade.

C.2.1 Assessment of hardness test results

The hardness of an individual member should be taken as the average of three measurements. If this average value for an individual member differs by more than 10% from the average value for the group of members, the inconsistent member should be removed from the group.

The characteristic value of hardness H_v of the entire group should be determined using Table D1 from BS EN 1990, assuming "V_x unknown" and calculated using the following expression:

$$H_v = m - k_n V_x$$

where:

H_v is the characteristic value of hardness for the group

m is the sample mean value (mean hardness of the members within the group)

V_x is the standard deviation of the results

k_n is taken from Table D1 of BS EN 1990 for "V_x unknown", presented as Table C.2

Table C.2 – Values of k_n for the 5% characteristic value (BS EN 1990 Table D1).

Number of members in the group (*n*)	1	2	3	4	5	6	8	10	20	30	∞
V_x unknown	-	-	3.37	2.63	2.33	2.18	2.00	1.92	1.76	1.73	1.64

C.2.2 Correlation between hardness and material strength

If the Vickers hardness is tested, the following relationship between hardness and strength can be used to estimate the material properties[29]:

$f_y = 2.70\ H_v - 71$

$f_u = 2.50\ H_v + 100$

where:

H_v is the Vickers hardness value for the group, determined in accordance with C.2.1

f_y is the yield strength

f_u is the ultimate strength

BS EN ISO 18265[30] can also be used to estimate ultimate strength based on hardness values.

C.2.3 Calculation example

In this example, 20 steel members have been identified as a group. Each member was subject to a non-destructive hardness test. Three measurements were taken from each member and the mean result calculated. The mean of the 20 results was calculated as 169.5. The standard deviation was calculated as 5.06.

As 20 members have been tested, $n = 20$ and $k_n = 1.76$

For the group, $H_v = 169.5 - 1.76 \times 5.06 = 160.6$

If $H_v = 160.6$, then according to Section C.2.2:

$f_y = 2.7 \times 160.6 - 71 = 362\ \text{N/mm}^2$

and

$f_u = 2.5 \times 160.6 + 100 = 502\ \text{N/mm}^2$

According to Table C.1 the steel is identified as S275, as the yield strength is greater than 313 kN/mm² and the ultimate strength is greater than 452 kN/mm².

C.3 Destructive tensile tests: non-statistical and statistical testing regimes

C.3.1 General guidance for destructive testing

The location of samples for destructive tests should be selected according to the recommendations of the product standard. Annex A of BS EN 10025-1 provides guidance for hot rolled members and plates. Annex C of BS EN 10219-1 provides guidance for hollow sections.

Destructive tensile tests are used to determine the following properties of the steel:

- Yield strength,
- Ultimate strength,
- Yield to ultimate ratio,
- Elongation at failure.

The declared yield strength, ultimate strength and elongation should be based on the results of the destructive tests, not on the non-destructive tests. The declared yield strength and ultimate strength should be the strengths given in the appropriate product standard for the determined steel grade, which is identified using results of the destructive tests, not on the non-destructive tests

C.3.2 Non-statistical testing

In addition to the 100% non-destructive testing of every member, a single destructive test (taken from any member in the group) is required to confirm the assessment described in Section C.2. A single test has no statistical value, and is therefore described as 'non-statistical'.

Non-statistical destructive testing (i.e. one single destructive test from a group) is recommended for steel to be used in Consequence class 1 or Consequence class 2 structures.

C.3.3 Statistical testing

If reclaimed steel is to be used in Consequence class 3 structures, a greater degree of reliability is required. In addition to the 100% non-destructive testing of every member, the mechanical properties of the steel members should be determined by increasing the number of destructive tests, and completing an assessment in accordance with BS EN 1990.

A minimum of three destructive tests are required, taken from members within a group. Increasing the number of tests will improve the precision of the calculated values and will generally result in higher values.

The characteristic value of yield strength and ultimate strength of the entire group should be determined using Table D1 from BS EN 1990, assuming "V_x known" and calculated using the following expression:

$X_d = m - k_n V_x$

where:

X_d is the characteristic value of interest (yield strength, or ultimate strength),

m is the sample mean value;

V_x is the standard deviation;

k_n is taken from Table D1 of BS EN 1990 for "V_x known", presented as Table C.3

Table C.3 – Values of k_n for the 5% characteristic value (BS EN 1990 Table D1)

Number of tests	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**20**	**30**	**∞**
V_x known	-	-	1.89	1.83	1.80	1.77	1.74	1.72	1.68	1.67	1.64

The use of "V_x known" is justified because the coefficient of variation for both yield strength and ultimate strength is known.

If statistical testing is completed, the calculated values from the destructive tests should be used to determine the steel grade from Table C.1.

APPENDIX D
IMPACT TOUGHNESS

D.1 Destructive tests

Unless destructive tests are conducted, it should be assumed that the steel is subgrade JR. There may be economic benefits in completing destructive tests to demonstrate that reclaimed steel is of a tougher sub-grade, particularly on thicker sections.

If required, destructive tests should be used to establish the steel sub-grade of members within a group, based on the testing of one representative member. In accordance with BS EN 10025-1, six samples are required for testing purposes, taken from locations identified in Annex A of BS EN 10025-1.

APPENDIX E CHEMICAL COMPOSITION

E.1 Introduction

The chemical composition of reclaimed steel should be determined so that the Carbon Equivalent Value (CEV) can be calculated using the expression given in BS EN 10025-1 Section 7.2.3 or BS EN 10219-1 Section 6.6.1.

The chemical composition should be assessed using non-destructive and destructive techniques. The CEV for the group should be taken as the maximum CEV from any test, including both the non-destructive test results and the destructive test results.

The chemical composition of each individual member should be tested and recorded. If the measured carbon or manganese content for an individual member differs by more than 10% from the average value for the group, the inconsistent member should be removed from the group.

The anticipated chemical composition of a specific steel can be found in Section 6.6.1 of the relevant part of BS EN 10025 and BS EN 10219.

E.2 Non-destructive tests to establish chemical composition

Optical emission spectroscopy can be used to determine the chemical composition of a steel member. Although this technique is considered to be a non-destructive test method, a small burr is left on the surface of the steel.

E.3 Destructive tests to establish chemical composition

The chemical composition of the steel can be established by analysing swarf from a drilled cavity. The member should be drilled in a low stress location.

For Consequence class 1 and Consequence class 2 structures, destructive tests on one representative member should be used to establish the chemical composition for all members in the group.

For Consequence class 3 structures, where a minimum of three destructive tests are recommended (see Table 7.2), no statistical analysis should be undertaken.

APPENDIX F GEOMETRIC TOLERANCES

F.1 Cross section dimensions

The cross sectional dimensions (depth, breadth, flange thickness, web thickness, wall thickness, etc.) must be measured for all members. A declaration of the measured dimensions must be provided by the stockholder.

If the section dimensions fall outside the permitted deviations according to the product standard (see Table 3.2), the measured dimensions should be used to determine the cross sectional properties.

F.2 Bow imperfections (lack of straightness)

The straightness of every member, in both axes, should be measured and compared with the permitted deviations in BS EN 1090-2. Members falling outside the permitted deviations should be straightened as part of the fabrication process.

STRUCTURAL STEEL REUSE –

ASSESSMENT, TESTING AND DESIGN PRINCIPLES

The environmental advantages of re-using reclaimed structural steel are considerable, compared to the common practice of recycling.

The publication proposes a system of investigation and testing to establish material characteristics, with advice for designers completing member verifications of reclaimed steelwork. It places important responsibilities on the holder of reclaimed steelwork including identification, assessment, control procedures and declarations of conformity.

The protocol is founded on the principle that given appropriate determination of material characteristics and tolerances, (re)fabricated reclaimed steelwork can be fabricated and CE marked in accordance with BS EN 1090.

Complementary titles

P138 | Appraisal of existing iron and steel structures

P419 | Brittle fracture selection of steel sub-grade to BS EN 1993-1-10

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SCI
Silwood Park, Ascot, Berkshire. SL5 7QN UK
T: +44 (0)1344 636525
F: +44 (0)1344 636570
E: reception@steel-sci.com
www.steel-sci.com