

Protocol for reusing structural steel



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EXECUTIVE 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.

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

It is recommended that the only modification necessary for design is to verify buckling resistance using $\gamma_{M1} = 1.15$. This may lead to more restraint being necessary for a given design scenario but not a change in member size.

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 (tested or conservatively assumed), maintaining the relationship between design assumptions and material resistance. It is therefore appropriate that re-fabricated, reclaimed structural steelwork may be CE Marked in accordance with EN 1090.

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1 INTRODUCTION

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

The protocol proposes a system of investigation and test to establish material characteristics, with advice for designers completing member verifications. The protocol places important responsibilities on the holder of salvaged 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 salvaged steelwork may be fabricated and CE marked in accordance with BS EN 1090¹.

1.1 Drivers for re-use of structural steelwork

Structural steel sections are inert, robust and dimensionally stable elements that are generally bolted together to form structural assemblies which are inherently demountable. As such, they are 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 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) may be incurred through deconstruction, testing, storage, re-fabrication, etc. structural steel reuse can yield cost savings.

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

1.2 Salvage, stock and re-use process

The overall process from reclamation of steelwork to re-use in another structure is summarised below. Subsequent sections and appendices provide more detail. Although the core concept relates to steel sections salvaged from an existing structure, the process is equally applicable to unused “new” steel (for example, resulting from a cancelled project). “New” steel is likely to have known provenance and comprehensive documentation, reflected in less onerous design constraints compared to reclaimed steelwork.

Overall process

1. A building is offered for salvage of the steelwork for reuse. Considerations include the acceptability of the source material, (see Section 4.3), the demountability of the structure, the increased cost of careful demolition, *etc.*
2. A business case is established between the holder of stock and the company responsible for demolition.
3. Important details of the anticipated salvaged steel are recorded as described in Section 4.1.
4. Salvaged 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 4, with the information appended to the stock data. The testing regime involves a combination of non-destructive and optional destructive testing, with the opportunity to make conservative assumptions about certain material characteristics. Testing may be completed at any convenient time, but 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 salvaged stock.
7. Structural design and member verification is completed with certain modifications, as described in Section 3.

1.3 Alternative specification of source material

Unused steel may be placed on the market having been manufactured to an alternative material Standard (for example steel manufactured to an American, or offshore manufacturing Standard). This unused material would be expected to have appropriate original certification, such that its properties may be verified.

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 EN 1993-1-1), and tolerances within the limitations of EN 1090-2, the material may be used in design, using the characteristics specified in the European Standard.

If the material does not comply in all respects with a weldable structural steel reference Standard, the principles in this protocol may be used to establish appropriate limitations in design and use, such as prohibiting the use of global plastic analysis.

2 CE MARKING OF SALVAGED STRUCTURAL STEELWORK

2.1 CE Marking

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

Steel manufacturers declare that their product meets the relevant Standard; Steelwork contractors declare that the fabricated steelwork meets the requirements of EN 1090-1¹ and EN 1090-2².

EN 1090-2 generally anticipates that “new” steelwork is used in construction works, as stated in clause 5.1. Salvaged steelwork must clearly be treated differently, as it may have been manufactured to a withdrawn Standard and is most unlikely to be linked to the test results from time of manufacture. 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.”

EN 1090-2 requires that documentation (which may be test reports, inspection certificates or declarations of compliance) must be used to declare the relevant material characteristics.

2.2 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 conservative assumptions regarding the material properties, or based on more precise declarations if the material has been tested.

In either approach the simple objective is to ensure that the design assumptions are compatible with the material properties.

2.3 CE Marking of reclaimed steel

For reclaimed steel, the declared material properties are consistent with those assumed in design. There is 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 may be CE Marked in accordance with EN 1090.

2.4 Properties to be declared for salvaged steelwork

The test regime described in Section 4 is intended to allow the following properties to be declared, based on dimensional survey, by non-destructive tests, by destructive tests or by making a conservative assumption. Section 4 also describes the logic leading to the declarations which can be made.

- Steel grade (based on non-destructive tests)
- Steel sub-grade (conservative assumption, or optional destructive tests)
- Tolerances (based on inspection)
- Maximum Carbon Equivalent (conservative assessment, or optional test).

The use of salvaged steelwork is limited to applications where significant ductility is not required, and limited to the salvage of relatively “modern” steel (see Section 4.3), so elongation is assumed to be adequate.

3 DESIGN RECOMMENDATIONS

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

3.1 Structure scope

This protocol has been prepared on the basis that reclaimed steel is to be used in consequence class 1 or 2 structures (see Table B1 of EN 1990).

The use of reclaimed steel is not recommended for consequence class 3 structures. Consequence class 3 structures include grandstands and public buildings where the consequences of failure are high.

If salvaged steel is to be used in a consequence class 1 structure, such as an agricultural building, it is recommended that the K_{FI} factor appropriate for reliability class RC1 from Table B3 of EN 1990³ is applied to the partial factors. Thus, for Consequence class 1 structures, the design value of all actions will be reduced by the factor $K_{FI} = 0.9$.

Reclaimed steel is not to be used in structures subject to fatigue.

Reclaimed steel is not recommended for use in structures subject to seismic actions, as this demands guaranteed ductile behaviour.

The preceding qualifications limit this protocol to steel to be used in Execution Class 1 and Execution Class 2 structures. This protocol may be used for Execution Class 3 structures not subject to fatigue.

3.2 Analysis and member cross section resistance

Designers should not undertake plastic global analysis, as this demands elongation of the steel (ductility) – which has not been demonstrated by the test regime in this protocol. Initial inspection of each member (see Section 4.1) is designed to exclude members from reuse that have already formed a plastic hinge.

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 EN 1993-1-1⁴ should be used.

For cross sectional resistance, the UK National Annex recommended values for γ_{M0} and γ_{M2} should be used.

3.3 Buckling resistance

For reclaimed steel, the recommended value of γ_{M1} is 1.15, which reflects the increased uncertainty when using reclaimed steel without full documentary support.

Justification for this recommendation is presented in Appendix A.

For “new” steel, (for example from a cancelled project), which has appropriate documentation, the current UK National Annex value of γ_{M1} may be used (in 2019, $\gamma_{M1} = 1.0$).

3.4 Steel sub-grade

The steel sub-grade may be assumed to be JR without test, or may be determined by a destructive test.

Since the scope for the re-use of salvaged steel is limited to structures where fatigue is not a design consideration (Section 3.1), the limiting thickness values presented in SCI Publication P419⁵ are recommended.

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

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.

3.5 Connection design

The use of reclaimed structural steel presents no specific issues with respect to connection design.

According to Section 6.2, the steelwork contractor will assume the maximum carbon equivalent value (CEV) when developing and selecting weld procedures. Assuming the maximum value will only be detrimental with larger welds between thick components, when tests to determine the CEV may be advantageous.

4 ASSESSMENT AND TESTING

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.

Assessment of the reclaimed steelwork, begins before the existing structure is deconstructed, with the collection of relevant data. Section 4.1 describes the initial data to be collected, and Section 4.2 the testing regime, based on group size.

The data to be recorded, initially and after subsequent testing, is identified in Appendix B.

4.1 Initial data collection and assessment

Before deconstruction and reclamation commences, data about the existing structure is to be collected, and visible steelwork assessed.

4.1.1 Existing structure

The following data should be recorded.

- A description of the structure. 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 components, with numbers in each group, *e.g.* numbers of rafters, numbers of floor beams.
- A preliminary inspection of the members for damage, obvious repairs, significant corrosion.
- Any evidence of plasticity.

4.2 Inspection and test 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 given in EN 1090-2)
- Any loss of section
- Signs of damage, or plastic strain.

4.2.1 Testing

Every member is to be subjected to non-destructive hardness tests to establish the steel grade. Other material characteristics are assumed, but may optionally be determined by destructive testing.

4.3 Admissibility

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

- Steelwork no older than 1970.
- No built-up members.
- No spliced members (the individual lengths of a member with a bolted splice may be disassembled and reclaimed).
- No localised section loss.
- No evidence of plasticity observed in the steel surface or corrosion protection.
- Members must meet the geometric tolerances of EN 1090-2.

The limitation to steel produced after 1970 relates to the material properties assumed by modern design Standards. Steel from this era was included in the testing programme undertaken as part of the Eurocode development. Thus it is assumed that steel used after 1970 meets the properties assumed in manufacturing Standards such as EN 10025⁶.

5 FABRICATION ISSUES

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

Unless tests are undertaken to determine the precise carbon equivalent value (CEV) for the reclaimed steel, the CEV presented in Table 6.1 should be assumed.

The recommendation to assume the maximum CEV permitted in material Standards since 1970 should not present any particular problem in developing appropriate weld procedure specifications for the vast majority of welding. Testing to ascertain the actual CEV may be advantageous if large welds to thicker elements are proposed.

6 ASSESSMENT AND TEST PROGRAM

This section describes the tests to be undertaken by the holder of the reclaimed steelwork stock. 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.

The test data to be recorded is listed in Appendix B.

The test requirements under this protocol involve non-destructive testing of every reclaimed structural member to determine the material grade, by a hardness test.

Based on the material grade established by the hardness test, other material characteristics may be assumed. In some circumstances, it may be advantageous to establish certain material characteristics such as sub-grade and Carbon Equivalent Value (CEV) by destructive testing. Destructive testing may be undertaken on groups of members, as described in Section C.5, where limited tests are used to characterise all the material in the group. The destructive testing requirements are no less than that required for “new” steel, tested in accordance with EN 10025-1.

6.1 Member grouping

A single batch of structural members is identified as:

- Taken from the same original structure
- Having the same serial size and structural function (e.g. rafters, floor beams, columns)
- Having the same material grade, as established by the non-destructive testing of every member.

6.2 Assumed carbon equivalent value (CEV)

Unless tests are undertaken so that the CEV may be calculated, the assumed CEV is the maximum permitted in the material Standard. Within the time period covered by this protocol, structural steel will be in accordance with either EN 10025 or BS 4360. Table 6.1 presents the maximum CEV from EN 10025-2⁷, EN 10025-4⁸ and BS 4360⁹, with the maximum of either value to be assumed for salvaged steel.

Table 6.1 CEV according to material Standards

Steel Grade	EN 10025-2	EN 10025-4	BS 4360	Assumed value
S275	0.42		0.41	0.42
S355	0.47		0.45	0.47
S460		0.46	0.51	0.51

6.3 Assumed steel sub-grade

Unless destructive tests are conducted, it should be assumed that all steel is JR. There may be economic benefit in completing destructive tests to demonstrate that salvaged steel in a particular group is of a tougher sub-grade (see Appendix C.5).

7 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 salvaged members (see Section 6.1) and the keeping of comprehensive records and formal declarations of material properties when the salvaged steelwork is distributed into the supply chain.

7.1 Records

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

- Details of the source structure.
- Unique identification of the group to which salvaged members belong.
- Records of physical inspection, including tolerances on cross section and bow imperfections.
- Hardness test result and consequent material grade for each individual member.
- Any non-destructive determination of CEV for identified groups of salvaged members.
- Any destructive test results for identified groups of salvaged members.

7.2 Declarations

When salvaged steelwork is distributed into the supply chain, it must be accompanied by a formal declaration, following the pattern established in EN 10025-1.

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.

8 REFERENCES

- 1 BS EN 1090-1:2009+A1:2011. Execution of steel structures and aluminium structures. Requirements for conformity assessment of structural components, BSI.
- 2 BS EN 1090-2:2018. Execution of steel structures and aluminium structures. Technical requirements for steel structures, BSI.
- 3 BS EN 1990:2002+A1:2005. Eurocode. Basis of structural design, BSI.
- 4 BS EN 1993-1-1:2005+A1:2014. Eurocode 3. Design of steel structures. General rules and rules for buildings, BSI.
- 5 SCI P419 Brittle fracture selection of steel sub-grade to BS EN 1993-1-10,
- 6 BS EN 10025-1:2004. Hot rolled products of structural steels. General technical delivery conditions, BSI
- 7 BS EN 10025-2:2004. Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, BSI.
- 8 BS EN 10025-4:2004. Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels, BSI.
- 9 BS 4360:1990. Specification for weldable structural steels, BSI.
- 10 BS 5502-22:2003+A1:2013. Buildings and structures for agriculture. Code of practice for design, construction and loading, BSI.

Appendix A RECOMMENDED VALUE OF γ_{M1}

A.1 Basis for recommendation

The recommendation for $\gamma_{M1} = 1.15$ (for all steel grades) is based on principles expressed in EN 1990 and introduces some conservatism in the design buckling resistance of members.

Numerically, 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 EN 1090-2 and gross plastic yielding is excluded, meaning that the choice of buckling curve is the same for new and recycled steel. Nevertheless, some degree of uncertainty is inevitably associated with the use of reclaimed steelwork, which is reflected in an increased γ_{M1} value.

The recommended value for γ_{M1} is based on increasing the target reliability index from 3.8 to 4.3 for a 50 year reference period (see Table B2 of EN 1990). This increase in the target reliability index corresponds to a consequence class 3 structure.

An alternative approach when designing a consequence class 3 building is to increase all actions by the factor $K_{F1} = 1.1$, in accordance with Table B3 of EN 1990. It is judged that increasing the design value of the actions is too onerous when the uncertainty is primarily related to member resistance, not the applied actions.

No change in the recommended value for γ_{M0} or γ_{M2} is proposed for verification of cross sections in accordance with 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.1.1 Consequence class 1 structures

The recommended value of $\gamma_{M1} = 1.15$ is judged to be too onerous for consequence class 1 structures such as agricultural buildings. The recommendation that the factor $K_{F1} = 0.9$ (see EN 1990 Table B3) be applied to all partial factors if designing a consequence class 1 structure goes some way to reduce the penalty of adopting the recommended value of γ_{M1} .

If agricultural buildings designated as Class 2 are designed in accordance with Table 1 of BS 5502-22¹⁰ the classification factor given in Table 7 may be applied in addition to the K_{F1} factor.

Appendix B DATA RECORDS

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

Building information

- Building age
- Form of construction
- Any related information, such as drawings, modifications, records.

Individual members

- Section size
- Length
- Group (see Section 6.1)
- Tolerance check
- Comments, e.g. stiffeners or fabricated features
- Coating
 - Coating type (and thickness if determined)
 - Condition of coating
- Material properties

Properties may be assumed, determined by non-destructive tests or by destructive tests. In each case the test results should be recorded, with the determined value of the property considered.

- Yield and ultimate strengths (non-destructive or destructive tests)
- Carbon Equivalent Value (assumed, or by test)
- Impact toughness (assumed or by test)

Appendix C DETERMINATION OF STEEL PROPERTIES

Destructive testing may be used to establish all material properties, including:

- Yield strength, by a tensile test.
- Ultimate strength, by a tensile test.
- Sub-grade (impact toughness), by a Charpy test.
- Carbon Equivalent Value, by chemical analysis.

Certain non-destructive tests may be used to determine the yield strength, ultimate strength and CEV.

C.1 Non-destructive testing to establish steel strength

Every reclaimed member is to be subjected to a hardness test in order to establish the yield and 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 hardness and steel strength depends on the type of hardness test undertaken.

C.2 Measured strength and assumed steel grade

Extensive data collection has established mean, minimum and upper limits for yield strength and ultimate strength of structural steel, which are proposed for inclusion in a revised version of EN 1993-1-1. The minimum and upper limits may be used to determine the steel grade of salvaged members, based on the results of the non-destructive testing.

Table C1 may be used to establish the steel grade, based on test results.

Table C.1 Steel grade identified by tested steel strengths

Yield strength (N/mm ²)			Ultimate strength (N/mm ²)			Assumed steel grade
Minimum	Maximum	Mean	Minimum	Maximum	Mean	
313	375	344	452	532	492	S275
391	461	426	505	576	541	S355
490	568	529	560	628	594	S460

If steel falls outside the limits in Table C1, the member should be excluded from the group.

C.3 Non-destructive testing to establish CEV

Optical emission spectroscopy may 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 bur is left on the surface of the steel.

Once the chemical composition has been determined, the CEV may be calculated using the expression given in EN 10025-1.

C.4 Destructive test to establish CEV

The chemical composition of the steel (and thus the CEV) may be established by analysing swarfe from a drilled hole.

C.5 Destructive tests for impact toughness

If required, destructive tests may be used to establish the steel sub-grade of members of a batch. In accordance with EN 10025-1⁶, six samples are required for test, taken from locations identified as identified in Annex A of EN 10025-1.

For every 20 tonnes in a batch, one set of tests from one single member may be used to determine the Charpy value for all members in that batch.

Thus:

- In a batch (same building, same serial size, same grade, same structural function) that comprises 6 floor beams with a total weight of 1.5 tonnes, destructive tests on one beam may be used to establish the sub-grade of all six members in that batch
- In a batch (same building, same serial size, same grade, same structural function) that comprises 40 rafters with a total weight of 22 tonnes, destructive tests on two different beams must be used to establish the sub-grade of all 40 members in that batch.