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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 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.

In this protocol, the reuse of reclaimed structural 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 also 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 (using destructive procedures) one or more representative members from the group.

If material properties are assessed based on the procedure proposed in section 7.3, it is recommended that the only modification necessary for structural design is to verify buckling resistance using a modified value for 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.

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 EN 1090.

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1. Objective, scope and summary of procedures

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

1.1 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 EU 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) will be incurred through deconstruction, storage, testing, re-fabrication, reconditioning, etc. structural steel reuse can yield cost savings or at least provide an economical feasible alternative to the use of 'new' structural steel.

1.2 Reclaim, stock and re-use 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 without documentation. 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 2013, when CE marking of structural steelwork according to EN 1090 [1] [3] became mandatory.

The overall process from reclamation of steelwork to re-use in another structure is summarised below. Subsequent Sections and the Annexes 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 5.2), 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 5.2.
4. Reclaimed steelwork is received by the stockholder, 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 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 (as constituent products; structural element or a structure), 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 reclaimed steelwork to be CE marked to EN 1090 (see Section 2).
7. Certification of weldings by a stakeholder or a new fabricator in order to CE marked structural elements or structures; for existing structures without documentation, welds need to be tested;
8. Structural design and member verification are completed with certain modifications, following the recommendations provided in Section 4.

1.3 Alternative specification of source material

Unused, unfabricated steel might be placed on the market having been manufactured to an alternative material standard, for example steel manufactured to an American, or offshore material or manufacturing standard. This unused material would be expected to have appropriate original certification/documentation declaring the material properties. A declaration of the material properties must be provided by the stockholder.

If the steel 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 [2]), and tolerances within the limitations of EN 1090-2, the steel can be used in design, using the procedures specified in EN 1993-1-1 and without modification of the γ_{M1} value as proposed for reclaimed steelwork, as long as the steelwork was never erected.

1.4 Classification of reclaimed steelwork

Within the scope of the project, three different reclaimed steel classes are defined, for which different testing and design requirements are proposed. The three reclaimed steel classes are:

- **Class A** – Material documentation is available;
- **Class B** – Material documentation is not available. A comprehensive assessment of material, member and section properties and characteristics is undertaken to produce new documentation;
- **Class C** – Material documentation is not available. Conservative assumptions are assumed for the design.

Examples of steelwork classified as “Class A” include steelwork reclaimed from a cancelled project (never erected) or steelwork reclaimed from different sources, for which documentation is available. For cases where documentation is available but the steelwork was already erected and disassembled, a conservative value of γ_{M1} is recommended in combination with an assessment of geometric tolerances (essentially bow imperfections). An optional testing procedure for Class A steel is proposed with the intent of confirm the traceability of the reclaimed steelwork (rather than to justify material characteristics).

It is envisaged that “Class B” steel will cover (currently) most of the practical applications of reclaimed steelwork. “Class B” steel deals with reclaimed steelwork with no documentation for which material re-certification is required. Recommendations from EN 1090-2 section 5.1 need to be followed to achieve such re-certification. “Class B” steel requires a comprehensive testing procedure where relevant material characteristics are justified and geometry tolerances are inspected against EN1090-2 requirements. The testing procedure comprehends a combination of non-destructive and destructive tests together with inspection of geometric tolerances. Conservative measures for the value of γ_{M1} are recommended, as some uncertainty in the member and section imperfections (other than bow) are recognized. Even with inspection, the procedures used to assess geometric tolerances will certainly be less reliable in comparison with “new” steel.

“Class C” steel is only recommended for projects that represent a low risk for human safety, as higher uncertainty in material characteristics is recognized. “Class C” steel envisages that no testing is undertaken (instead conservative material properties are assumed based on the location and age of the structure). If welding is necessary, CEV (carbon equivalent value, see section 2.5.7) may be assessed by non-destructive tests. It is required that geometric tolerances according to EN1090-2 are assessed (usually during fabrication; straightening can be performed). Conservative measures for the value of γ_{M1} are recommended for this approach. CE marking is not envisaged using the Class C reclaimed steel approach. However, this may change in the future based on recent initiatives from the European Union to facilitate the circularity of construction products [127]. It is expected that the Construction Products Regulation (CPR) may be revised in the future to facilitate the reuse of steel (and other construction products).

The material partial factor is adjusted with a factor $k_{\gamma_{Mi}}$. $\gamma_{Mi,mod}$ is obtained using $K_{\gamma_{Mi}} \times \gamma_{Mi}$, where γ_{Mi} shall be obtained from EN 1993-1-1 or the National Annex for use in a country. The $K_{\gamma_{Mi}}$ values can be defined for different regions/countries. For in-situ reuse of steelwork erected after 1970, the conservative value of γ_{M1} is not recommended (i.e. $k_{\gamma_{M1}}=1$).

A summary of the three reclaimed steel classes is presented in Figure 1.1.

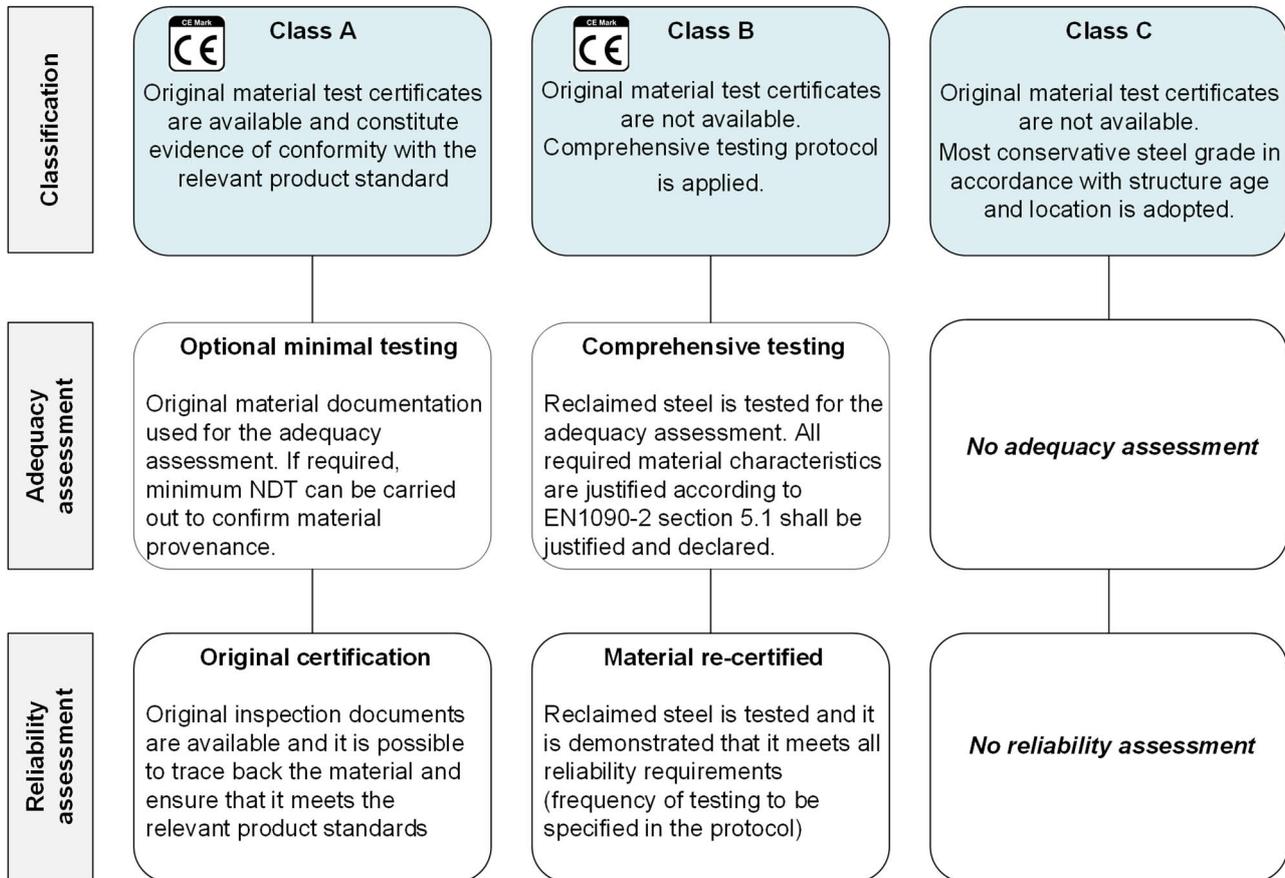


Figure 1.1 - Overall framework for classification of reclaimed steel material

To use the existing steelwork, it is necessary to undertake the following assessments:

- **Adequacy assessment:** intended to assess the necessary material characteristics according to material/product standard or EN 1090-2 section 5.1;
- **Reliability assessment:** intended to justify that the reliability requirement for the design procedures according to the Eurocodes are met.

The testing and design process for each of the reclaimed steel classes is presented in Figure 1.2 and Table 1.1.

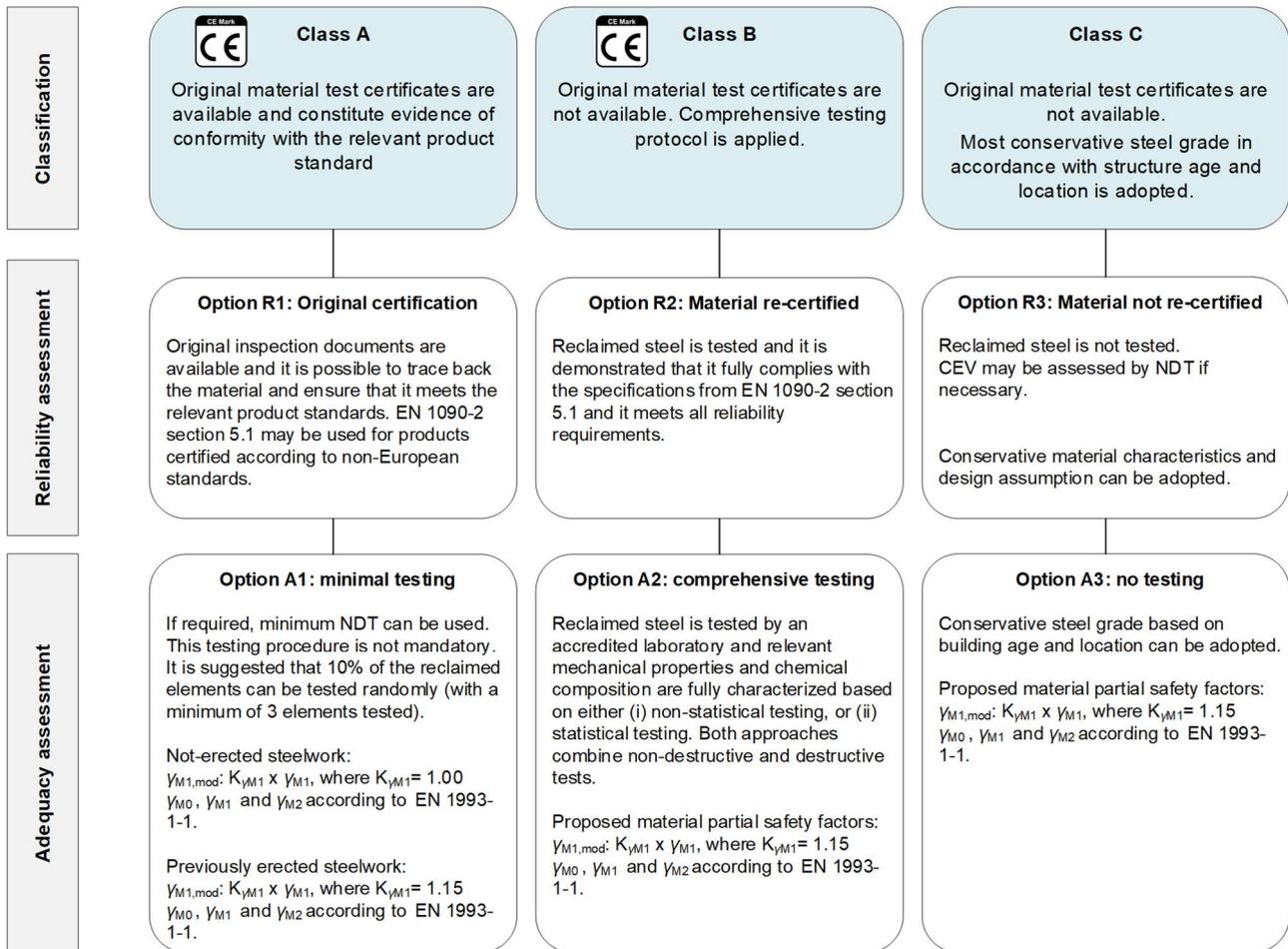


Figure 1.2 - Overall framework for classification of reclaimed steel material with design considerations.

Table 1.1. Resume of reuse-protocol for steelwork erected after 1970

| Property/procedure | Reclaimed steelwork class | | |
|------------------------|---|------------------------------|-------------------|
| | Class A | Class B | Class C |
| Test programme | Minimal (optional) | Comprehensive | No testing |
| Adequacy assessment | Yes | Yes | No |
| Reliability assessment | Yes | Yes | No |
| % of NDT | 10% (randomly) – with a minimum of 3 tests per group | 100% | - |
| Minimum number of DT | - | 1 for CC1 and CC2, 3 for CC3 | - |
| Geometric tolerances | Visual inspection or assessed if steelwork was previously erected | Assessed | Assessed |
| CE marking | Yes | Yes | No |
| Global analysis | Elastic | Elastic | Elastic |
| Section analysis | Elastic/plastic | Elastic/plastic | Elastic/plastic |
| $k_{\gamma M0}$ | 1.00 | 1.00 | 1.00 |
| $k_{\gamma M1}$ | 1.00/1.15 ^{1, 2} | 1.15 ² | 1.15 ² |
| $k_{\gamma M2}$ | 1.00 | 1.00 | 1.00 |
| CC1 structures | Yes | Yes | Yes |
| CC2 structures | Yes | Yes | Not recommended |
| CC3 structures | Yes | Yes | Not recommended |

1 – For the cases where the steelwork was never erected the value of $K_{\gamma M1}=1$ can be used;

2 – For in-situ reuse of steelwork erected after 1970, the conservative value of γ_{M1} is not recommended (i.e. $k_{\gamma M1}=1$)

NDT – Non-destructive testing; DT – Destructive testing; CC – Consequence class according to EN 1990 [4]; $k_{\gamma Mi}$ – The material partial factor is adjusted with a factor $k_{\gamma Mi}$. $\gamma_{Mi,mod}$ is obtained using $K_{\gamma Mi} \times \gamma_{Mi}$, where γ_{Mi} shall be obtained from EN 1993-1-1 or the National Annex for use in a country. The $K_{\gamma Mi}$ values can be defined for different regions/countries.

1.5 Overall assessment, testing and design processes flowchart

The flowchart in Figure 1.3 illustrates the process of reusing structural steel from a building first erected (using new steel) after 1970. The flowchart also maps each individual step/action to the relevant document section.

PROGRESS D2.1 [88] provides a pre-deconstruction audit (collecting documentation, visual inspection, leading to an initial decision about the reusability of the steel). This protocol provides complementary guidance for the pre-deconstruction audit in Section 5.

Pre-deconstruction audits are required so that relevant building documentation is collected and the feasibility of reusing the existing steelwork is assessed. This protocol provides complementary guidance for two phases: (i) preliminary assessment and (ii) comprehensive assessment.

Preliminary assessment is intended to confirm or adapt the proposed reuse scenario or simply classify the steelwork as not appropriate for reuse. Limited resources are allocated for this step, in terms of inspection and testing.

After completing the preliminary assessment, a comprehensive assessment must be undertaken. The comprehensive assessment implies additional inspection and eventual testing to justify the material properties of the reclaimed steel.

For Class A reclaimed steel, testing is not mandatory as material documentation exists.

Testing is mandatory for Class B reclaimed steel. Class B may be seen as the standard case of an existing building with no material documentation and for which CE marking is required.

Class C reclaimed steel can rely on conservative assumptions for the material properties but a more thorough inspection of the structure (or individual elements) is still required to evaluate the admissibility of the reclaimed steel.

After the pre-deconstruction audit, some of the existing members may be classified as not suitable for reuse, which should be sent for recycling.

If building documentation and/or material certificates are not available, it will be necessary to produce that documentation. Class C does not require testing, but documentation referring to the assumed properties is still required.

Depending on the reuse scenario, documentation for the existing structure may be also necessary (for example, the case of on-site or relocation reuse where no original documentation is available).

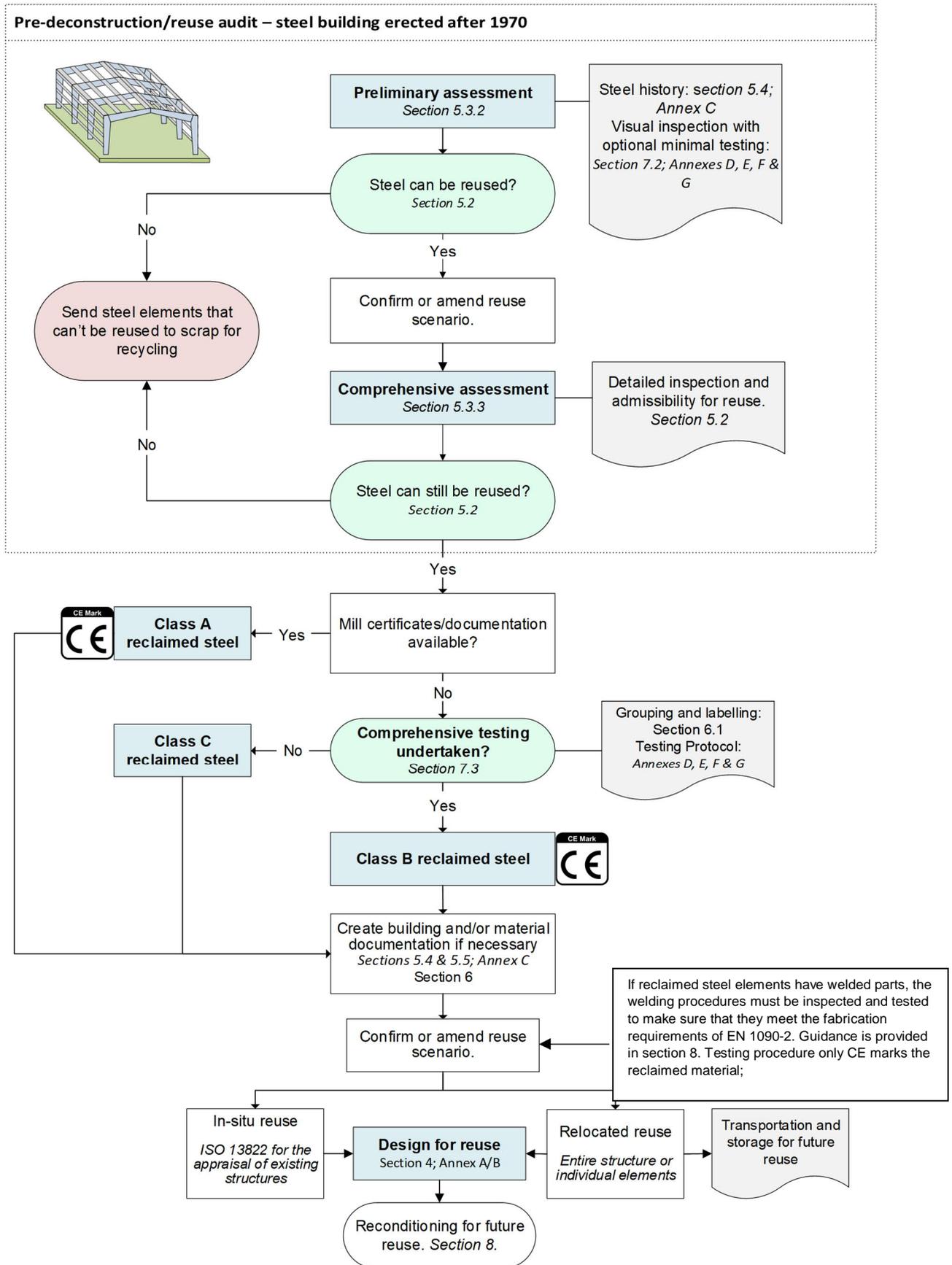


Figure 1.3 - Overall assessment, testing and design processes flowchart

1.6 Summary of testing programmes flowchart

The following flowchart presents the available testing procedures covered in this protocol. The applications of the reclaimed steelwork based on the test programme are described and the flowchart also maps each individual step/action to the relevant document section.

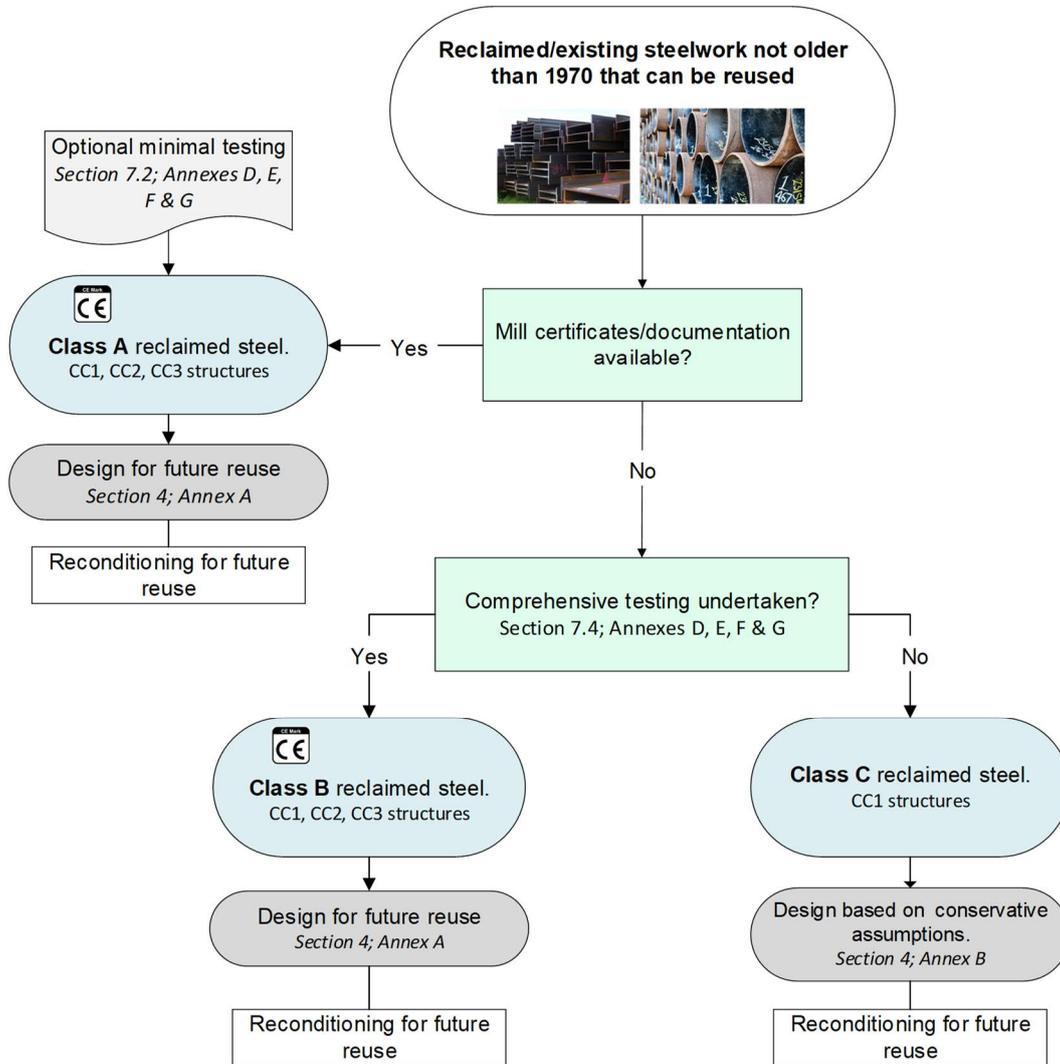


Figure 1.4 - Testing flowchart

If reclaimed steel elements have welded parts, the welding procedures must be inspected and tested to make sure that they meet the fabrication requirements of EN 1090-2. Guidance is provided in section 8. Testing procedure only CE marks the reclaimed material.

2. CE marking of reclaimed structural steelwork

2.1 CE Marking

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

Steel manufacturers declare that their products meet the relevant product standard; steelwork contractors declare that the fabricated steelwork meets the requirements of the execution standards EN 1090-1 [1] and EN 1090-2 [3].

EN 1090-2 generally anticipates that 'new' steelwork is used in construction works. Reclaimed steelwork must clearly be treated differently, as it might have been manufactured to a withdrawn Standard and is generally unlikely to have any documented test results from the 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 must be used to declare the relevant material characteristics. It is mandatory that this documentation is provided by the holder of the reclaimed stock when selling it.

2.2 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 EN 1090.

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

The previous statement is related to plain reclaimed elements without any welding procedures. If reclaimed steel elements have welded parts, the welding procedures must be inspected and tested to make sure that they meet the fabrication requirements of EN 1090-2. Guidance is provided in Section 8.

2.3 Declaration of properties

The purpose of declaring material properties is so that the material used in construction meets the appropriate product 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 may be 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 being used.

The requirements of EN 1090-2 and the testing regime for reclaimed steelwork are discussed in Section 2.4.

2.4 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 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 recommended assessment procedures is presented in *Table 2.1*.

Table 2.1. *Material properties to be declared for reclaimed steelwork according to EN 1090-2*

| 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: | | | |
| Item | Property | To be declared | Procedure |
| i) | Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608 [5], 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. |

Section 2.5 provides a commentary on each material property that must be declared.

2.5 Commentary on the required properties

2.5.1 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 grouping 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) to confirm that the material grade for the group has been correctly identified.

2.5.2 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 5.2). The demands on elongation are therefore limited, and likely to be met by the reclaimed steelwork covered by the scope of this protocol (see also Section 4.3).

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

Historical review of steel elongation

Based on historical data for old steels and iron (see Annex J), the Eurocode ductility requirements are likely to be fulfilled for the reclaimed steelwork. It is unlikely that steelwork erected after 1970 does not comply with the minimum elongation requirements currently imposed by the Eurocodes. Even wrought iron (produced since 1900) was showing approximately 15% elongation at failure, which is adequate for common structural applications. The previous UK material standards for structural steel such as BS 15 (version from 1948) [28] provided a minimum elongation value of 16% for the available structural steels. Later, BS 4360 (version from 1969) [29] reported a minimum elongation at failure of 19% for the available structural steels. However, elongation needs to be declared according to EN1090-2 and therefore a minimum destructive test is required to establish this material property. The testing programme will be discussed in section 7.

2.5.3 Tolerances on dimensions and shape

Reclaimed elements can be checked against geometric tolerances according to the relevant product standard. Elements within tolerance are acceptable and satisfy the assumptions made in the design Standard. This means that a reclaimed element can be labelled as a “IPE500” if the dimensions and tolerances of a “IPE500” according to the EN 10365 [7] and EN 10034 [8], respectively are justified and documented.

Table 2.2 lists the Standards to be used when assessing dimensions and tolerances.

Table 2.2. *Dimensions and tolerances for structural steelwork*

| Products | Dimensions | Tolerances |
|--|---|--|
| I and H sections | EN 10365 [7] | EN 10034 [8] |
| Hot-rolled taper flange I sections | EN 10365 | EN 10024 [9] |
| Channels | EN 10365 | EN 10279 [10] |
| Equal and unequal leg angles | EN 10056-1 [11] | EN 10056-2 [12] |
| T Sections | EN 10055 [13] | EN 10055 [13] |
| Plates, flats, wide flats | - | EN 10029 [14]/ EN 10051 [15] |
| Bars and rods | EN 10017 [16], EN 10058 [17], EN 10059 [18], EN 10060 [19], EN 10061 [20] | EN 10017, EN 10058, EN 10059, EN 10060, EN 10061 |
| Hot finished hollow sections | EN 10210-2 [21] | EN 10210-2 |
| Cold formed hollow sections | EN 10219-2 [22] | EN 10219-2 |
| Fabricated profiles and member bow imperfections | EN 1090-2 | EN 1090-2 |

However, there is no limitation to use reclaimed steelwork with bespoke dimensions, i.e. members for which tolerances from Table 2.2 are not met, as long as the design considers measured section properties rather than tabulated standard section sizes. Member bow imperfections still need to be assessed and justified. See also Annex H.

2.5.4 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 specific through thickness properties. If through thickness properties are required, reclaimed plate must be tested as specified in EN 1993-1-10 [6].

2.5.5 Impact strength or toughness

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. The conservative assumption means that a minimum Charpy V-notch impact value of 27 J at 20°C is assumed if no testing is performed. See also section 4.6.

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 EN 10025-1 [24].

2.5.6 Heat treatment delivery condition

Heat treatment delivery conditions have an impact on, for example, the grain size, residual stresses, etc. Practically, this condition will have implications while designing hollow sections. Hollow sections for structural applications are cold formed to EN 10219 [23] [22] or hot finished to EN 10210 [24] [21]. The heat treatment delivery condition will influence the level of residual stresses present in the hollow section, which means that different buckling curves exist for cold formed and hot finished products. It is clear that cold formed will have higher residual stresses, which in turn will lead to a more conservative buckling curve while designing the member. Conservatively, it is recommended that all reclaimed hollow sections are assumed to be cold formed according to EN 10219, as this property cannot be easily tested.

2.5.7 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.

The chemical composition declaration must provide measures of the relevant chemical elements according to the appropriate material standard (see Table 2.3).

Table 2.3. Chemical composition of reclaimed steel: required data

| Products | Dimensions |
|-----------------|--|
| Open sections | EN 10025 parts 2 [25], 3 [26] or 4 [27] sections 7.2 |
| Hollow sections | EN 10219-1 section 6.6 |

3. Quality and accreditation of stockists

Stockists should be ideally accredited to ISO 9001 [70].

Any person responsible for non-destructive tests procedures should be ideally accredited/certified by ISO 9712 [71]. For quality management systems auditing ISO 19011 [70] can be followed.

Any tests carried out to establish whether the mechanical properties of the steel products are appropriate should be undertaken by a laboratory certified to EN ISO IEC 17025 [125] by a certification body. The tests should be carried out in accordance with the requirements for mechanical properties given in EN 10025 or EN 10219, as appropriate.

Test for materials would need to be undertaken as follows:

- By a test house with accreditation to ISO/IEC 17025,
- In accordance with the test methods and procedures given in the product standard (EN 10025 or EN 10219, as examples),
- Test reports should be issued in the form of specific Inspection Certificate in accordance with EN 10204.

See also section 7.4.

4. Design recommendations

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

4.1 Structure scope for the reclaimed steel elements

This protocol has been prepared on the basis that reclaimed carbon steel can be used in Consequence class 1, 2 or 3 structures (see Table B1 of EN 1990 [4]) if a comprehensive testing procedure is undertaken according to section 7.3. 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 subjected to fatigue, or in plastically analysed structures which rely on the formation of plastic hinges (plastic global analysis).

The reuse of reclaimed steel elements in areas where the seismic actions is relevant is only recommended if the reclaimed steel elements are used at least under one of the following conditions: (i) as members of the secondary seismic system (not resisting the horizontal loads), such as a pin-ended floor beam, or (ii) as elements part of a low-dissipation structure (Low Ductility Class) with a behaviour factor of 1, according to EN 1998-1 [134].

4.2 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.

4.3 Ductility and residual strains

Careful visual inspection of every reclaimed member, and assessment against the tolerances referenced in Section 2.5.3, should ensure that the element has not undergone excessive/plastic deformation. A similar careful inspection to ensure that no evidence of plastic local deformations in connecting elements (plates) or signs of local (plate) buckling is found is also recommended.

If the inspection is satisfactory, the level of residual strains, and reserves of ductility, may be assumed as no different to that of 'new' steel.

As stated, plastic global analysis is not recommended when reclaimed steel is reused. The recommendations for seismic design stated in section 4.1 are also intended to limit the level of ductility required for the reclaimed steel elements.

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 EN 1993-1-1 (or in the National Annex to the same standard).

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 EN 1993-1-1 should be used.

For cross sectional resistance, recommended values for γ_{M0} and γ_{M2} according to the National Annex for use in a country should be used for steelwork (erected after 1970) that complies with this testing protocol.

Further guidance and background are provided in Annex A.

4.5 Buckling resistance

4.5.1 Class A reclaimed steelwork

For Class A reclaimed steel, for cases where the steelwork was never erected, the value of γ_{M1} provided by EN 1993-1-1 (or to the National Annex for use in a country) is recommended.

To envisage future reusability, the steelwork may be designed using $K_{\gamma_{M1}} = 1.15$. This is aligned with the design recommendation proposed for reusable single-storey buildings according to D3.1 [89].

For 'new' steel, for example from a cancelled project - not erected, which has appropriate documentation, the current value of γ_{M1} from the appropriate National Annex to EN1993-1-1 (or to the National Annex for use in a country) can be used.

For the cases where the steelwork was previously erected, a modified value of $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ ($K_{\gamma_{M1}} = 1.15$) is recommended, which reflects the increased uncertainty when using reclaimed steel. This recommendation is excluded for in-situ reuse.

Justification for this recommendation is given in Annex A.

4.5.2 Class B and C reclaimed steelwork

For reclaimed steel from Class B, a modified value of $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ ($K_{\gamma_{M0}} = 1.15$) is recommended, which reflects the increased uncertainty when using reclaimed steel [68]. Justification for this recommendation is given in Annex A. This recommendation is excluded for in-situ reuse.

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 EN 10025. The reclaimed steel sub-grade may be assumed to be JR without testing.

Clause 5.1 of 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 testing. Testing and relevant documentation is a stockholder responsibility.

Since the scope for the re-use 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 [30] 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.

Recommended thickness values for outside the UK, are presented in Section 4.7.

For internal steelwork used in the most onerous circumstances (“Combination 10” – see below):

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 [31] 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 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.

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

| Steel grade | Sub Grade | Charpy energy CVN at T (°C) | Reference temperature, T _{Ed} (°C) | | | | | | | | | | | | | | | | | | | | |
|-------------|-----------|--------------------------------|---|-----|-----|-----|--|-----|-----|-----|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | | | σ _{Ed} = 0.75 f _y (t) | | | | σ _{Ed} = 0.5 f _y (t) | | | | σ _{Ed} = 0.25 f _y (t) | | | | | | | | | | | | |
| | | | 10 | 0 | -10 | -20 | -30 | -40 | -50 | 10 | 0 | -10 | -20 | -30 | -40 | -50 | 10 | 0 | -10 | -20 | -30 | -40 | -50 |
| S235 | JR | 20 | 200 | 200 | 200 | 195 | 125 | 87 | 63 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J0 | 0 | 200 | 200 | 200 | 200 | 200 | 195 | 125 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J2 | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | JR | 20 | 200 | 200 | 200 | 133 | 91 | 64 | 47 | 200 | 200 | 200 | 200 | 200 | 170 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J0 | 0 | 200 | 200 | 200 | 200 | 200 | 133 | 91 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J2 | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| S275 | M,N | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | M,N | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | ML,NL | -50 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | JR | 20 | 200 | 177 | 114 | 77 | 54 | 40 | 30 | 200 | 200 | 200 | 147 | 104 | 76 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J0 | 0 | 200 | 200 | 200 | 177 | 114 | 77 | 54 | 200 | 200 | 200 | 200 | 200 | 147 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J2 | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 177 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| S355 | K2,M,N | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 177 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | M,N | -20 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | ML,NL | -50 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | JR | 20 | 200 | 200 | 200 | 200 | 147 | 96 | 65 | 200 | 200 | 200 | 200 | 200 | 187 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J0 | 0 | 200 | 200 | 200 | 200 | 147 | 96 | 65 | 200 | 200 | 200 | 200 | 200 | 187 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | J2 | -20 | 200 | 200 | 200 | 200 | 200 | 147 | 96 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| S460 | Q | -20 | 200 | 200 | 200 | 200 | 200 | 147 | 96 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | M,N | -20 | 200 | 200 | 200 | 200 | 200 | 147 | 96 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | Q | -40 | 200 | 200 | 200 | 200 | 200 | 200 | 147 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | ML,NL | -50 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | Q | -60 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | Q | 0 | 200 | 137 | 89 | 58 | 40 | 28 | 20 | 200 | 200 | 174 | 115 | 78 | 55 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| S690 | Q | -20 | 200 | 200 | 200 | 137 | 89 | 58 | 40 | 200 | 200 | 200 | 174 | 115 | 78 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | Q | -20 | 200 | 200 | 200 | 137 | 89 | 58 | 40 | 200 | 200 | 200 | 174 | 115 | 78 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | OL | -20 | 200 | 200 | 200 | 200 | 137 | 89 | 58 | 40 | 200 | 200 | 200 | 174 | 115 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | OL | -40 | 200 | 200 | 200 | 200 | 137 | 89 | 58 | 200 | 200 | 200 | 174 | 115 | 78 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | OL1 | -40 | 200 | 200 | 200 | 200 | 137 | 89 | 58 | 200 | 200 | 200 | 174 | 115 | 78 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| | OL1 | -60 | 200 | 200 | 200 | 200 | 137 | 89 | 58 | 200 | 200 | 200 | 174 | 115 | 78 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |

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. However, to reuse of part of structures or entire structures can rely on similar principles.

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 EN 1090-2. The declared CEV should be the maximum value determined from the non-destructive and destructive tests (see Annex 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 indicates that it may be assumed that the strength of the weld material is at least equal to the base steelwork [32]. This advice does not cover workmanship – it is recommended that any existing welds that are to be reused are carefully inspected and tested (see also section 8.5).

UK - review of fabrication processes:

It is likely that the steelwork was manufactured and erected following guidelines that were imposed by the applicable standards in place at the time of construction. For the UK, previous to EN 1090, the National Structural Steelwork Specification for Building Construction (NSSS [33]) was providing the best practice for fabrication and erection of structural steelwork (first published in 1989). Before NSSS, BS 449 [34] (1969 version), provided procedures for weld testing and welders certification according to BS 2645 (published in 1956) [73]. Consequently, it is expected that no major issues/defects will be found in steelwork erected in the UK after 1970. However, testing of welds on reclaimed steel elements is recommended for the cases where fabrication documentation is not available (see also section 8.5). This background is intended to help inform the decision whether or not to test existing welds.

Romania - review of fabrications processes:

For Romania, previous to EN 1090, implemented in 2014, the Romanian Institute for Standardization through STAS 767/0-88 [158] provided the technical requirements for fabrication and erection of non-industrial, industrial and agricultural buildings. The first edition of this standard was issued in 1977. The standard C150-99 [159] provided rules for welding execution, for NDT testing and welders certification. Before the 1999 edition of C150, two other editions were issued, one in 1972 (C150-72) and another one in 1984 (C150-84).

Portugal - review of fabrications processes:

The first Portuguese standard to cover design, execution and erection of steel structures was the RSAE standard published in 1965. General rules for execution were being provided, covering riveted, welded and bolted connections. For welding procedures, it was clearly stated that only accredited personnel were allowed to perform such operations. It was stated that in 1965, a set of standards were already issued for public comments covering welding procedures and accreditation of welding personnel. A comprehensive list of product standards was provided, listing standards issued between 1956 and 1962, covering steel properties, hot rolled products, tensile testes, Charpy tests, bolts, rivets among other topics.

Strengthening existing welded connections:

A fillet weld may be strengthened by adding weld layers in order to achieve the necessary dimensions. Where an old weld is strengthened, the design procedure must rely on the properties of the old weld [32] – that can be assumed as equal to the base steelwork.

Incomplete penetration on the root side can be found on existing but welds. Other types of defects can also occur on the root side of the weld, such as concave root surface, cracks, porosity, melt-through, etc. All these areas can be removed by grinding or routing, and to ensure a complete assessment of all defects, a penetrant test shall be undertaken before repairing the weld. After the defect is removed, the area for welding must be prepared by removing all rough edges on the ground area. After a repair is made, the weld needs to be re-inspected. Required NDT according to EN1090-2 for final acceptance of the weld must be completed after repairing the weld.

4.9 Design of existing structures for future reuse

4.9.1 Introduction

The design of structures using reclaimed structural steel shall follow the recommendations of ISO 13822 [124].

Sections 4.9.3/0 proposes adapted values for the combination of action while designing with existing structures. An existing structure can be a structure subjected to a new structural application or to fulfil the new codes regulations (in-situ reuse) or a structure that was relocated and exposed to a different load level (relocated reuse).

Section 4.9.5 provides a summary of existing guidance about the design of existing structures.

4.9.2 Assessment of performance [122]:

Structures designed and constructed based on existing/old codes/standards, or in accordance with good workmanship when no code applied, may be considered safe for the future use, provided that simultaneously:

- Careful inspection does not reveal any evidence of significant damage, distress or deterioration or displacements;
- The structural system is reviewed, including investigation of critical details checking them for stress transfer;
- The structure has demonstrated satisfactory performance during a sufficiently long time (say more than 15 years) for extreme actions and for the occurrence of environmental effects;
- There will be no changes to the structure and in its use that can significantly affect the actions;
- Predicted deterioration considering the present condition and planned maintenance ensures sufficient durability;
- There have been no changes for a sufficiently long time, which could significantly increase the actions on the structure or affect its durability; and no such changes are anticipated.

If a structure is kept at its original location with a similar application (in-situ reuse), there is no reason to increase the required levels of safety. This means that values of K_{VM1} for existing carbon steel elements erected after 1970 may be taken as equal to 1. The value of K_{VM1} is related to the uncertainty of multiple transportation, disassembly, erection processes as well as in testing procedures to assess geometric imperfections. This uncertainty is not present if the building remains at its original location.

However, the condition of existing steel elements must be assessed, evaluating material properties and geometric tolerances as specified in the current protocol. Bow imperfections may be evaluated for existing columns. The bow tolerance according to EN 1090-2 and second order effects due to the strut action must be considered for the in-service load to calculate the value of actual bow imperfection.

Tolerances based on previous and current UK and Romanian practice are given in *Table 4.2*.

Table 4.2. Review of geometrical tolerances for individual members in the UK and Romania:

| Products | Dimensions | | | | |
|---|---------------------------------|---|---------------------|------------------|---------------------------|
| | BS4 (1962) - [131] | Dorman Long (1964) - [129] | NSSS (1994) - [130] | EN 1090-2 (2018) | STAS 767/0-88 [158] |
| Beam | $L/961$ | $L/961$ | $L/1000$ or 3 mm | $L/1000$ | $L/1000$, but max. 15 mm |
| Column up to (but not including) 9.14 m | $L/714$ | $L/961$ | $L/1000$ or 3 mm | $L/1000$ | |
| Column up to 13.72 m | 9.5mm | $L/961$ | $L/1000$ or 3 mm | $L/1000$ | |
| Columns over and equal to 13.72 m | $L/961 - 4.75$, with L in mm | $9.5 \text{ mm} + 3.175 \cdot \frac{L-13.72}{3.05}$, with L in m | $L/1000$ or 3 mm | $L/1000$ | |

4.9.3 Combinations of actions (Proposal 1)

The application of the partial factor method requires the definition of the design values of the actions, material and product properties, geometrical data, and model uncertainties. The design values for actions, Q_d , are obtained from the characteristic values, Q_k , based on a 50-year reference period and a corresponding target reliability. The target value of the reliability index β is related to the probability of failure, P_f , corresponding to a specified reference period, as follows:

$$\beta = -\Phi^{-1}(P_f) \quad (4.1)$$

Where Φ^{-1} is the inverse standardised normal distribution.

The general actions on single-storey buildings defined in EN 1991-1-1, i.e. densities, self-weight, and imposed loads, are not sensitive to the reference period, and therefore the usual 50-year reference period can still be used. For actions of natural origin, e.g. snow loads and wind actions, EN 1991 gives adjusted values for reference periods other than the 50-year period in (i) Annex D of EN 1991-1-3 for snow loads, and (ii) Note 4 in Clause 4.2 in EN 1991-1-4 for wind loads.

EN 1990 defines three Consequence Classes (CC), depending on the consequences of failure or malfunction of the structure, which are associated with three different Reliability Classes (RC) as follows:

- CC1: *low* consequence for loss of human life, and economic, social or environmental consequences *small or negligible*, associated with RC1 ($\beta_{50\text{-year}} = 3.3$),
- CC2: *medium* consequence for loss of human life, economic, social or environmental consequences *considerable*, associated with RC2 ($\beta_{50\text{-year}} = 3.8$),
- CC3: *high* consequence for loss of human life, or economic, social or environmental consequences *very great*, associated with RC3 ($\beta_{50\text{-year}} = 4.3$).

It is also noted that designs with the partial factors given in the Eurocodes generally leads to a RC2 structure with a β value greater than 3.8 for a 50-year reference period.

The design working life of the structure is not explicitly linked to the consequence class in EN 1990, and can be understood as an assumed period of time for which a structure is to be used for its intended purpose without any major repair being necessary. Clause 2.3(1) of EN 1990 gives the following categories together with indicative design working life for permanent structures:

- Category 3, with a notional design working life of 15~30 years,
- Category 4, with a notional design working life of 50 years,
- Category 5, with a notional design working life of 100 years.

Structures designed to the Eurocodes should perform and remain fit for the appropriate working life. Typical buildings are designed for a working life of 50 years, i.e. category 4, for a *normal degree of reliability* and RC2 ($\beta_{50\text{-year}} = 3.8$). If the design working life is limited, say to 25 years, it may be reasonable to specify a *lower than normal degree of reliability*, $\beta_{50\text{-year}} < 3.8$, but $\beta_{50\text{-year}} \geq 2.5$, which is the limit value for human safety. Likewise, if the design working life is increased, say to 100 years, then $\beta_{50\text{-year}} > 3.8$, corresponding to a *higher than normal degree of reliability*. It should also be highlighted that these β indices and the corresponding probability of failure are only notional values that do not necessarily represent actual failure rates. Gulvanessian et al. [74] clearly explain that the

β indices are used as operational values for code calibration purposes and comparison of reliability levels of structures that naturally depend on the design working life, and are used in the whole system actions – resistances – partial factors.

Clause 2.2(6) of EN 1990 states that the different measures to reduce the risk of failure may be interchanged to a limited extent provided that the required reliability level is maintained. When designing with reclaimed steel, it may be necessary to compensate for a slightly lower partial factor by a high level of quality management and control. This is an example of reliability differentiation by the requirements of the quality levels.

Reliability differentiation may also be applied through (i) the partial factors for actions γ_F , or (ii) the partial factors for resistance, γ_M , which is further elaborated next. The first option is usually preferred.

The partial factors for actions cater for the variability of loading, i.e. loads may be greater than expected, and also loads used to counteract overturning may be less than intended.

A multiplication factor K_{F1} is then applied to the partial factors for unfavourable actions in fundamental combinations for persistent design situations, see Clause 6.4.2.2(3) of EN 1990 and Table 4.3. Notation in the table is as follows, and γ_F are the recommended values:

- $G_{k,j,sup}$ is the upper characteristic (superior) value of permanent action j
- $G_{k,j,inf}$ is the lower characteristic (inferior) value of permanent action j
- $Q_{k,1}$ is the leading variable action
- $Q_{k,i}$ is the accompanying variable action i
- $\psi_{0,i}$ is a combination factor (for variable action i)
- ξ is a reduction factor for unfavourable permanent actions, defined in the National Annexes for use in a country.

It is common practice to lower the required safety level when evaluating and upgrading existing structures, as long as the limits for human safety are not exceeded, see Refs. [75] [76]. This is justified by the fact that, for existing structures, a shorter design life is assumed. Likewise, for designs with reclaimed steelwork, it is reasonable to consider a shorter design life, to up to 30 years – say 15 years (category 3 above), which corresponds to RC1. This leads to a multiplication factor of 0.9. It is recommended, however, that the fundamental combinations of actions are assessed based on Eq. (6.10) of EN 1990, top line in Table 4.3, as highlighted, which leads to a higher value of reliability as compared to Eqs. (6.10a) and (6.10b) of EN 1990.

Table 4.3. Design values of actions for strength (STR) according to EN1990.

| Reuse | Persistent and transient design situations | Permanent actions | | Leading variable action | Accompanying variable actions ($i > 1$) |
|---|--|---------------------------------------|-------------------------------------|----------------------------------|---|
| | | Unfavourable | Favourable | | |
| 15-30 notional design working life ($K_{F1} = 0.9$) | Eq. 6.10 | 1.215 $G_{k,j,sup}$ | 1.0 $G_{k,j,inf}$ | 1.35 $Q_{k,1}$ | 1.35 $\psi_{0,i} Q_{k,i}$ |

It was suggested that combinations factors could be slightly reduced when using reclaimed steel (or while dealing with existing steelwork/structures) by assuming a lower expected structure life time. This option may require higher level of quality management control and inspection to the structure.

For a new building, standard EC0 reliability requirements must be met (even if individual reclaimed elements are used). The examples where the lower partial factors for a notional design working life of 15-30 years can be used are existing buildings (in situ reuse) or the cases where the building is relocated to a different location.

For the cases where a new structure is designed, while promoting the use of reclaimed elements, it's possible to adjust the influence areas of the reclaimed elements (for example, by adjusting the spacing of a floor beam or frame) so that the load level is acceptable according to the standard reliability requirement for a notional design working life of 50 years.

4.9.4 Combinations of actions (Proposal 2)

The following proposed values were derived based on EN1990. Detailed procedures are presented in D3.1 [89]. Table 4.4 shows the benchmark load factors from EN1990 for a CC2 structure. The point of exploring a more complex approach (in comparison with proposal 1) is that in fact two possible scenarios could be included:

One for assessing existing structures, where the absolute minimum values for human safety according to can be specified. A building inspection every 5 years is recommended. This case would be more suitable for in-situ reuse – see Table 4.5;

- An alternative for acceptance of reclaimed materials and relocation, shortening the lifetime of the structure, as introduced in section 4.9.3. This is obtained by assuming a $\beta=3.3$. The additional benefit is to offer a different load factor for permanent loads on single storey buildings. A building inspection every 15 years is recommended (Table 4.6).

The uncertainty relating to permanent loads for single storey building is quite low. Steelwork has very small tolerances. Designers always make allowance for the self-weight of the connections (say between 7-15% of the self-weight of the structure; this can be adjusted after the fabrication model is undertaken), so no concern about the self-weight of the connections as well. Cladding may be inspected and one knows with high confidence their self-weight. As there is little uncertainty about the values for these two self-weight loads, a value of $\alpha_E=-0.28$ [123] may be assumed to reflect that option in the FORM (first order reliability method) according to EN 1990.

Table 4.4 - Suggested partial safety factors for load for ULS – Base model for target $\beta=3.8$.

| CC2 – EN1990 | β | Distribution | w_i | α_E | α_T | N | γ_{Ed} | $\gamma_{q/g}$ | $\gamma_{G/Q, \beta=3.8}$ | $\gamma_{G/Q, calc, EC}$ |
|-----------------------------------|---------|--------------|-------|------------|------------|----|---------------|----------------|---------------------------|--------------------------|
| Permanent loads | 3.8 | Normal | 0.10 | -0.70 | - | - | 1.05 | 1.27 | 1.33 | 1.35 |
| Permanent loads ⁽⁵⁾ | 3.8 | Normal | 0.10 | -0.28 | - | - | 1.05 | | 1.162 | ~1.20 |
| Time invariant variable - Imposed | 3.8 | Gumbel | 0.22 | -0.70 | 1.00 | 10 | 1.05 | 1.43 | 1.50 | 1.50 |
| Time variant variable - Wind | 3.8 | Gumbel | 0.35 | -0.70 | 0.50 | 50 | 1.05 | 1.51 | 1.59 ⁽²⁾ | ~1.50 ⁽⁴⁾ |
| Time variant variable - Snow | 3.8 | Gumbel | 0.30 | -0.70 | 0.50 | 50 | 1.05 | 1.47 | 1.54 ⁽³⁾ | ~1.50 ⁽⁴⁾ |

Table 4.5 - Suggested load factors for the ultimate limit state – Minimum for human safety and reuse.

| CC0 – Limit Human Safety | β | Dist. | w_i | α_E | α_T | N | γ_{Ed} | $\gamma_{q/g}$ | $\gamma_{G/Q}$ | $\gamma_{G/Q,calc,0}$ | $\gamma_{G/Q,calc}$ |
|-----------------------------------|---------|--------|-------|------------|------------|----|---------------|----------------|----------------|-----------------------|---------------------|
| Permanent loads | 2.5 | Normal | 0.10 | -0.70 | - | - | 1.05 | 1.18 | 1.23 | 1.25 | 1.25 |
| Permanent loads ⁽¹⁾ | 2.5 | Normal | 0.10 | -0.28 | - | - | 1.05 | 1.07 | 1.12 | 1.15 | 1.15 |
| Time invariant variable - Imposed | 2.5 | Gumbel | 0.22 | -0.70 | 1.00 | 10 | 1.05 | 1.17 | 1.23 | 1.25 | 1.25 |
| Time variant variable - Wind | 2.5 | Gumbel | 0.35 | -0.70 | 0.50 | 50 | 1.05 | 1.18 | 1.24 | 1.24 | 1.25 |
| Time variant variable - Snow | 2.5 | Gumbel | 0.30 | -0.70 | 0.50 | 50 | 1.05 | 1.16 | 1.22 | 1.22 | 1.25 |

Table 4.6 - Suggested load factors for the ultimate limit state – Suitable for reuse.

| CC2 – Suitable for reuse | β | Dist. | w_i | α_E | α_T | N | γ_{Ed} | $\gamma_{q/g}$ | $\gamma_{G/Q}$ | $\gamma_{G/Q,calc,0}$ | $\gamma_{G/Q,calc}$ |
|-----------------------------------|---------|--------|-------|------------|------------|----|---------------|----------------|----------------|--------------------------|---------------------|
| Permanent loads | 3.3 | Normal | 0.10 | -0.70 | - | - | 1.05 | 1.23 | 1.29 | 1.30 | 1.30 |
| Permanent loads ⁽¹⁾ | 3.3 | Normal | 0.10 | -0.28 | - | - | 1.05 | 1.09 | 1.15 | 1.15 | 1.15 |
| Time invariant variable - Imposed | 3.3 | Gumbel | 0.22 | -0.70 | 1.00 | 10 | 1.05 | 1.32 | 1.39 | 1.40 | 1.40 |
| Time variant variable - Wind | 3.3 | Gumbel | 0.35 | -0.70 | 0.50 | 50 | 1.05 | 1.37 | 1.44 | $1.44 \cdot K_{\beta,W}$ | $1.40^{(4)}$ |
| Time variant variable - Snow | 3.3 | Gumbel | 0.30 | -0.70 | 0.50 | 50 | 1.05 | 1.34 | 1.41 | $1.41 \cdot K_{\beta,S}$ | $1.40^{(4)}$ |

Notes:

1 – It is proposed in reference [123] to consider $\alpha_E = -0.28$ for the permanent loads;

2 – Equivalent to $\beta = 3.50$ to obtain $\gamma_{q,W} = 1.50$ or a $w_{q,W} = 0.25$ (0.25 is a low value for the wind load);

3 – Equivalent to $\beta = 3.65$ to obtain $\gamma_{q,S} = 1.50$ or a $w_{q,S} = 0.25$ (0.25 is a low value for the snow load);

4 – The fact that values for new structures are higher for snow and wind the model used to calculate partial safety factors for existing/reusable structures makes the process conservative. Values for wind and snow in are corrected according to the ratio $\gamma_{G/Q,calc,EC}/\gamma_{G/Q,\beta=3.8}$ for the wind and snow loads: $K_{\beta,W} = 1.50/1.59 = 0.95$; $K_{\beta,S} = 1.50/1.54 = 0.98$.

5 – This may be an option if certain conditions are met such as: reports of on-site claddings weight, where the design values of claddings were justified. This value can be used also for steel self-weight. Additional permanent load shall use 1.35.

The influence of β for the material factors is disregarded on these examples. This can be justified by the fact that the material factors have a low dependency of β because they usually have low coefficient of variation and rely on a normal distribution. The critical differences are always related with time dependant variable loads that use Gumbel distributions (such as wind or snow loads).

4.9.5 Further references for designing existing structures:

- SAMCO Final Report 2006; F08a Guideline for the Assessment of Existing Structures [135]
- Probabilistic Model Code, Parts 1 to 4, Basis of design, Load and resistance models [136];
- New European Technical Rules for the Assessment and Retrofitting of Existing Structures [137];
- Assessment of Existing Steel Structures: Recommendations for Estimation of Remaining Fatigue Life [138];
- Innovative methods for the assessment of existing structures [139];
- Structural Appraisal of existing buildings Part 1 Requirements for structural appraisal [140];
- Structural Appraisal of existing buildings Part 2 Preparing for structural appraisal [141];
- Structural Appraisal of existing buildings Part 3 Structural appraisal procedures [142];
- Structural Appraisal of existing buildings Part 4 Additional considerations and information sources [143];
- Appraisal of Existing Structures, Institution of Structural Engineers [144];
- NEN 8700 – Assessment of existing structures in case of reconstruction and disapproval – Basic Rules [145].
- NEN 8701 – Assessment of existing structures in case of reconstruction and disapproval – Actions [146].
- Eurocodes and structural safety of the existing buildings – considering the publication of the Dutch NEN 8700 [147].
- Assessment criteria for Existing Structures [148].
- Limit states criteria for structural evaluation of existing buildings [149].
- Safety acceptance criteria for existing structures [150].
- Safety philosophy for existing structures and partial factors for traffic loads on bridges [151].
- Probabilistic assessment of existing structures [152].
- Background documentation Eurocode 1 ENV Part 1; 1996 [153].
- Handbook for the Structural Assessment of Large Panel System (LPS) [154];
- Design Manual for Roads and Bridges standards: Volume 0, 1, 2 and 3 [155];
- Reliability analysis for structural design [156];
- Commentary and worked examples to EN 1993-1-10: Material toughness and through thickness properties and other toughness-oriented rules in EN 1993 [157];
- Guideline for Structural Condition Assessment of Existing Buildings, ASCE Standard Guideline, SEI/ASCE 11-99 [160];
- Guideline SIA 462:1994 Assessment of the structural safety of existing buildings, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 1994 [161];
- Standard SIA 269/3:2011 Existing Structures – Steel Structures, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 2011 [32];
- Basics for assessment of existing structures (Milan Holický, Editor), Klokner Institute, Czech Technical University in Prague, 2013 [162].

5. Assessment of reclaimed steelwork for reuse

5.1 Introduction

All structural steel reclaimed for reuse, is to be inspected and tested if no appropriate documentation and traceability are available. 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 (and costs) for testing. The data to be recorded, initially and after subsequent testing, is set out in Annex B.

Without traceability of each component, the value of the reclaimed material will be compromised. It is important therefore for material stockists to maintain full traceability of the reclaimed steelwork, including the grouping and labelling of members. A permanent unique physical label/mark is recommended for each member.

5.2 Admissibility of reclaimed steelwork

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

Table 5.1. Admissibility of reclaimed steelwork

| Admissibility of reclaimed steelwork checklist |
|---|
| Steelwork no older than 1970 (to use Eurocode rules); |
| 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 - [32]); |
| No signs of fire exposure; |
| No evidence of plasticity observed in the steel surface or coating; |
| Members must meet the geometric tolerances of 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 structural steel produced after 1970 meets the material properties assumed in product Standards such as EN 10025 and EN 10219.

Review of other international standards

Swiss Standard SIA 263 (first published in 1956) can be seen as benchmark for accepting reclaimed steel as appropriate for design according to modern design standards. SIA 263 (2013) [35] follows the Eurocodes philosophy for analysis and design. The Swiss standard for existing steel structures SIA269/3 [32] accepts modern design procedures for steel fabricated after 1956.

Therefore, it is sensible to point out that steelwork reclaimed after 1970 can be designed according to Eurocode principles with an appropriate level of reliability.

5.3 Assessment of the existing steelwork

5.3.1 Introduction

Assessment of the reclaimed steelwork begins before the existing structure is deconstructed, with the collection of relevant data. It is recommended to follow the procedure outlined in the EU Construction and Demolition Waste Management Protocol [36] and EU Waste Audit Guideline [37]. According to the Guideline, the audit consists of the steps described in Figure 5 (documentation research, field survey, condition evaluation and recommendations) and its results shall be recorded in a report.

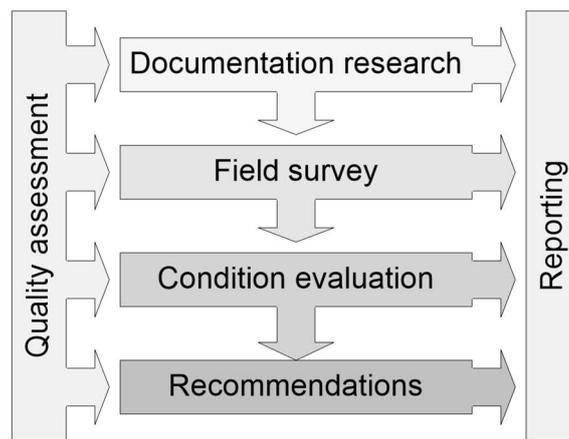


Figure 5. Waste/material audit process [37]

The following text describes the assessment of reusable constructional steelwork to be tested according to this protocol. The complete pre-deconstruction audit procedure including checklists, reporting templates and guidance for non-reusable materials and waste (including hazardous waste) is part of Deliverable D2.1 of PROGRESS project [38].

Section 5.4 describes the initial data to be collected and Section 7 the general principles of the recommended 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. Safe and efficient deconstruction methods are addressed in D2.1 [88].

Before the on-site assessment, data about the existing structure is to be collected and analysed. Construction documents of interest include design drawings, specifications, material test records, and quality assurance reports covering original construction and subsequent modifications to the structure. Section 5.4 provides guidance for this process.

5.3.2 Preliminary assessment: documentation research and general examination

The preliminary assessment shall be performed by an experienced chartered engineering, with possible contributions from personnel with fabrication and erection expertise. The preliminary assessment is a very important step, as it is intended to evaluate the feasibility of reclaiming and reusing the existing steelwork. This assessment needs to consider the expected reuse scenario. The main purpose of this step is to avoid effort and associated costs of a careful inspection, deconstruction and documentation of an existing building which offers limited opportunities for steel reuse. A preliminary overall visual inspection of the building is recommended before undertaking any further recommendations described on the current section.

In the first phase, a study of the available collected documentation is envisaged prior to any field assessment. Available engineering reports, including any previous inspection, maintenance or records of possible modifications shall be also reviewed. Specifications (including possible original Welding Procedure Specifications), shop drawings, erection drawings, and construction records shall be reviewed where available.

The construction date must be identified, as well as the likely materials to be found in the existing building when documentation is not available. Using a similar process, the likely standards that were used for the structural analysis and design shall be identified.

Whenever the structural elements are not visually exposed, measures should be specified to expose a sufficient number of elements for the preliminary assessment (only a representative/limited number of elements need to be exposed - *Table 5.2*).

For the preliminary field assessment, visual inspection and possibly non-destructive tests can be undertaken. An evaluation of the existing structural concept and the adequacy of the existing steelwork and design for the possible future reuse may be undertaken. Mechanisms and nature of possible structural failure shall be evaluated and documented. The preliminary assessment will make sure that any field operation is appropriate and safe for the personal.

A quantitative/empirical evaluation of the existing steelwork is undertaken within this step. It is expected that photographic records and a representative field survey will be created. Hand sketches can be used to describe the structural concept and relevant details. Preliminary calculations may be undertaken based on existing documentation data or based on preliminary material properties assessed by a minimal testing (based on non-destructive tests – procedure according to Section 7.2) to assess the adequacy of the expected reuse scenario.

All collected data must be presented in a report, where any concern/issue found must be documented. Based on the date of construction, the expected (or preliminary tested) steel properties as well as the possible/likely design codes must be clearly identified. The report shall define any urgent safety measures required for the existing building.

Building documentation is extremely valuable for the reuse of existing steelwork. However, it is necessary to ensure that the collected information is updated and refers to the as-built structure. The consistency of the collected documentation must therefore be assessed not only for building geometry and section sizes but also for details (i.e. joints). *Table 5.1* proposes guidance to check the compliance of existing building documentation and the as-built structure. For structures with detailed construction drawings, a limited on-site inspection is recommended. For other cases, where no documentation is available, a more detailed on-site inspection is recommended.

For the cases where documentation is available, but no compliance/agreement is found according to the on-site inspection, the percentage of details and members/cross sections to be checked must be the ones suggested to the cases where no documentation is available (see *Table 5.2*).

Cross-sections should be checked against available documentation. If building documentation is not available, the cross-sections should be compared against relevant catalogues according to building age and location. Geometric tolerances should be allowed for while assessing the cross-sectional dimensions of existing steelwork (see *Table 2.2*).

Table 5.2. Details to be checked for each group of elements (per floor) – Preliminary assessment

| Detailed construction drawings/documentation available: | Percentage of details to be checked: | Percentage of members checked for cross section dimensions | Building dimensions and structural solution |
|---|--|--|--|
| Yes (limited on-site inspection recommended) | 10% (min 3 different detail types) – details selected randomly | 10% (min 3 different sections) – members selected randomly | Minimum inspection for a typical single storey building (say a typical frame): <ul style="list-style-type: none"> • Span; • Eaves height; • Apex height; • Frames spacing; • Vertical and roof bracing arrangement; • Eaves struts; • Fly bracings; • Etc. |
| No (comprehensive on-site inspection recommended) | 25% (min 5 different detail types) – details selected randomly | 25% (min 5 different sections or all sections) – members selected randomly | |
| Note: percentages to be applied to a group of elements with same geometric and load history/structural application (see section 6.1 for grouping definition); by way of example, for a portal frame, the three types of details to be checked can be column-base, apex and eaves connections. Different section can be columns, rafters and vertical and roof bracings. | | | |

The preliminary inspection of a limited number of details and members is intended to assess the geometry and condition of the existing steelwork. The inspection should look for any evidence that may indicate that the steelwork is not good for reuse, being a more detailed inspection not recommended. Problems such as excessive corrosion, excessive/plastic deformation of the structural elements, excessive plastic deformations on the connecting elements, evidence of local or member buckling, fabrication defects, etc.

For the preliminary assessment, tested or inspected elements must be identified and labelled with a physical and reliable method. Each label shall be unique (e.g. number, barcode, QR code or RFID tag) so the original location of each of the components within the building is known.

If any structural element is classified as non-reusable in the current condition, it can be repaired/refurbished or sent for recycling.

5.3.3 Comprehensive assessment: detailed survey and testing

The comprehensive assessment shall be implemented after completing the preliminary assessment described in Section 5.3.2. If the preliminary assessment is satisfactory then the following recommendations for a more comprehensive assessment may be followed.

The consistency of the collected information should be re-assessed according to Table 5.3.

With the comprehensive assessment, a detailed evaluation of the existing structural elements condition is undertaken. A comprehensive visual inspection of all structural elements must be undertaken. This should seek to evaluate the condition of the existing steelwork concerning section loss due to corrosion, excessive/plastic deformation of the structural elements, plastic local deformations in connecting elements (plates), signs of local (plate) or member buckling (evidence of plastic loading history), fabrication defects, damage due to impact loadings, etc.

Table 5.3. Details to be checked for each group of elements (per floor, if applicable).

| Detailed construction drawings/documentation available: | Percentage of details to be checked: | Percentage of members checked for cross section dimensions | Building dimensions and structural solution |
|---|--|--|--|
| Yes (limited on-site inspection recommended) | 25% (min 5 different detail types) – details selected randomly | 25% (min 5 different sections up to all different section) – members selected randomly | Minimum inspection for a typical single storey building (say a typical frame): <ul style="list-style-type: none"> • Span; • Eaves height; • Apex height; • Frames spacing; • Vertical and roof bracing arrangement; • Eaves struts; • Fly bracings; • Etc. |
| No (comprehensive on-site inspection recommended) | 100% | 100% | |

Note: percentages to be applied to a group of elements with same geometric and load history (see section 6.1 for grouping definition); as example, for a portal frame the three types of details to be checks can be base connections, apex and eaves. Three different section can be columns, rafters and vertical bracings.

The evaluation of the coating condition (including blistering, rusting, cracking, flaking or chalking) shall be undertaken. Coating toxicity should also be assessed and documented, justifying that the existing system can be reused (if applicable; for example, reuse of elements with intumescent painting is not recommended) - see also section 8.2. Depending of the reuse scenario, structural elements may need to be exposed, which means that careful deconstruction (and partial demolition of non-structural elements) may be required.

It is recommended that all reusable elements are permanently and physically identified and labelled with a reliable method. Each label shall be unique (e.g. number, barcode, QR code or RFID) so that the original building, building location and location of each component will be known.

If adequate documentation is not available, drawings and eventually a 3D BIM model can be produced (depending on the reuse scenario for the reclaimed steelwork). This is clearly not the case if individual elements are intended to be reclaimed for future reuse applications.

If any structural element is classified as non-reusable in the current condition, it can be repaired/refurbished or sent for recycling.

After the comprehensive assessment, only reusable elements are grouped (see section 6.1) and made available for testing (if required). The necessity of testing is related to the available documentation and the future reuse scenario. Based on the reclaimed steel classification (A, B or C), appropriate testing procedures shall be implemented according to Section 7. Testing procedures described in Section 7 shall be used (if required) to justify the material properties.

5.4 Data collection and documentation

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

Design and inspection documents contain important information that can be used for a thorough assessment of the existing structure. It shall be verified that the documents are correct and, in that context, that they are updated to include information of any previous intervention on the structure.

Other evidence, such as the occurrence of significant earthquake events, fires, significant snow/wind loads, changes in soil conditions, corrosion, and misuse of the structure, shall be recorded and documented.

Building owner, designers, fabricators and on-site contractors, and neighbours can be contacted to collect available information.

The process should try to provide answers to the following topics:

- Collect drawings, CAD drawings, 3D models, mill certificates, photographic evidence etc. for the as-build structure;
- Collect information about the design such as calculation notes, loading history, etc.;
- Records of interventions (e.g. expansions, modification, etc.);
- Records from any possible incident in the building/area: fire, earthquakes, etc.;
- Inspection and maintenance records;
- Date and place of construction of the original building;
- Building owner's manual (O&M manual);
- Identify fabricator, erector, designers, architects and other actors.

The following data should be recorded from the existing structure and steelwork in a report:

- 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/anecdotal information;
- A preliminary listing of the steel members;
- A preliminary inspection of the members for damage, obvious repairs, significant corrosion, etc.;
- Any evidence of plasticity.

5.5 Inspection requirements undertaken by the stockholder

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 – EN1090-2);
- Any significant loss of section;
- Signs of damage, or plastic strain.

The stockholder shall keep records of the data collected from the assessment of the existing steelwork.

5.6 Commentary about EN 1998-3

Among current European design recommendations, EN 1998-3 [90] is one of the few normative references that addresses the assessment of existing structures. The guidance is rather general, and intended essentially for an assessment of earthquake resistance of structures. In addition, safety issues arising from other loads should be addressed. Following, a commentary about the procedure proposed in EN 1998-3 is provided.

In order to substantiated the admissible analysis method and estimate the confidence factor, EN1998-3 establishes three knowledge levels about the inspected structure, based on the amount and quality of information/documentation available and performed tests. This section is intended to provide specific guidance for steel structures. The three levels are presented in Table 3.1 of EN 1998-3 (see - Table 5.4).

Table 5.4. Knowledge levels and corresponding methods of analysis (EN1998-3).

| Knowledge Level | Geometry | Details | Materials | Analysis | CF |
|-----------------|--|--|--|----------|-------------------|
| KL1 | From original outline construction drawings with sample visual survey <i>or</i> from full survey | Simulated design in accordance with relevant practice <i>and</i> from limited in-situ inspection | Default values in accordance with standards of the time of construction <i>and</i> from limited in-situ testing | LF- MRS | CF _{KL1} |
| KL2 | | From incomplete original detailed construction drawings with limited in-situ inspection <i>or</i> from extended in-situ inspection | From original design specifications with limited in-situ testing <i>or</i> from extended in-situ testing | All | CF _{KL2} |
| KL3 | | From original detailed construction drawings with limited in-situ inspection <i>or</i> from comprehensive in-situ inspection | From original test reports with limited in-situ testing <i>or</i> from comprehensive in-situ testing | All | CF _{KL3} |

NOTE The values ascribed to the confidence factors to be used in a country may be found in its National Annex. The recommended values are CF_{KL1} = 1,35, CF_{KL2} = 1,20 and CF_{KL3} = 1,00.

The Knowledge Levels (KL) are established considering the available information about the structure, concerning the topics of: **geometry, details and materials**.

Based on the achieved Knowledge Level (KL), the confidence factors CF is selected, which is intended to increase the safety of the design process. To determine material properties for capacities for comparison with demand in safety verification, the mean values obtained from in-situ tests and additional sources of information, shall be divided by the confidence factor (CF). Hence, in direct safety verifications the strength is reduced by CF. Conversely, for properties to be used in calculation of the force capacity of ductile components, with the purpose of establishing a failure hierarchy between brittle and ductile components, the mean value of materials shall be multiplied by the confidence factor (CF). Hence, for the purpose of failure hierarchy the strength of the weaker element is increased by CF. The value of CF is only equal to 1 for a Knowledge level 3 (KL3), for which detailed information about geometry, details and materials are required.

The assessment and testing programmes recommended in this protocol are in agreement with the KL3. Therefore, the factor CF would, in this case, be equal to 1. For KL2 and KL3, the confidence factors would be 1.20 and 1.35 respectively.

For a knowledge level 3 (KL3), the following requirements are specified:

- i) Geometry: *“the overall structural geometry and member sizes are known either (a) from a comprehensive survey or (b) from the complete set of outline construction drawings used for both the original construction and any subsequent modifications. In case (b), a sufficient sample of both overall geometry and member sizes should be checked on site; if there are significant discrepancies from the outline construction drawings, a fuller dimensional survey is required.”*
- ii) Details: *“the structural details are known either from comprehensive in-situ inspection or from a complete set of detailed construction drawings. In the latter case, limited in-situ inspections in the most critical elements should be performed to check that the available information corresponds to the actual situation.”* This procedure would be relevant for a reuse scenario where the building is entirely reused, or for the cases where the connections are intended to be reused based on the information from the construction drawings.
- iii) Materials: *“information on the mechanical properties of the construction materials is available either from comprehensive in-situ testing or from original test reports. In this latter case, limited in-situ testing should be performed.”* The comprehensive testing is represented by the protocol proposed in section 7 for Class B reclaimed steel. The limited testing can be related to the testing procedure described on section 7 for Class A steel.

EN 1998-3 recommends the percentages of inspected details and tested elements according to *Table 5.5*.

Table 5.5. Minimum requirements for inspection and testing according to EN1998-3. Values per floor.

| | Inspection (of details) | Testing (of materials) |
|---------------------------------|--|----------------------------|
| | For each type of primary element (beam, column, wall): | |
| Level of inspection and testing | Percentage of elements that are checked for details | Material samples per floor |
| Limited | 20 | 1 |
| Extended | 50 | 2 |
| Comprehensive | 80 | 3 |

EN 1998-3 3.4.3.1 states that non-destructive testing can be used but not in isolation. This consideration is fulfilled for Class B steel (related to the proposed comprehensive testing procedure), for which no material documentation is available.

For the inspection of details, the percentages of elements to be inspected based on Table 5.3 are in agreement with the recommendation to achieve KL3 knowledge level (*Table 5.5*).

As stated in the defined scope of this protocol, the use of reclaimed structural steel elements in a primary seismic structural system is not recommended. For other cases, for example, when the assessment of an existing building is undertaken, at least one destructive test is recommended per type of primary element per floor for a CC2 structure. For CC3 structures, three destructive tests are recommended per type of primary element per floor.

Further guidance for seismic applications, can be found in the following references:

- AISC 342 [77];
- ASCE/SEI 41-17 [78].

6. Responsibilities of the holder of stock

The organisation holding the reclaimed steel stock has important responsibilities in relation to 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 Annex B.

6.1 Member grouping – test unit

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.).
- Local stiffeners are not considered as detrimental for grouping.

If steelwork originally manufactured to an alternative specification/product standard (other than the EN standards), 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 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 test results for yield strength, ultimate strength and elongation;
- Non-destructive and destructive tests to determine the chemical composition and 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 EN 1090-2 section 5.1.

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 this protocol.

7. Test programmes

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 listing of the data to be recorded is given in Annex C.

Details of the testing requirements are presented in Annex E to Annex H, as shown in *Table 7.1*.

Table 7.1. *Testing requirements*

| Characteristic to be determined | Annex |
|--|---------|
| Yield strength, ultimate strength and elongation | Annex E |
| Impact toughness (if required) | Annex F |
| Product analysis to determine CEV | Annex G |
| Section dimensions and member straightness | Annex H |

The different testing procedures are:

- Minimal testing;
- Comprehensive testing.

Minimal testing is not intended to determine unknown material characteristics, but instead to make sure that the available documentation matches the related steelwork. Comprehensive testing is intended to re-certify the reclaimed steel according to EN1090-2 section 5.1.

The minimal testing requirements can be applied to Class A steel but is not mandatory. Comprehensive testing is related to Class B structural reclaimed steelwork, allowing for re-certification and consequent CE marking of the steelwork.

A summary of the recommended testing procedures is shown in *Table 7.2*.

Table 7.2. *Testing procedures*

| Type of material testing | Steel class | Documentation | Purpose | Relevant Annexes |
|--------------------------|-------------|---------------|---|--------------------------------|
| Minimal | Class A | Available | Confirm traceability of materials | E.3, G.2 |
| Comprehensive | Class B | Not-available | Re-certification of the reclaimed steel | E.3, E.7, G.2, G.3 H.1, H.3 |

7.2 Minimal testing

Minimal testing is intended for the cases where material documentation is available (Class A steel) or to perform a preliminary assessment of existing steelwork. Minimal testing can also be used as part of a preliminary assessment as described in section 5.3.2.

The optional minimal testing is intended to confirm that a certain existing material documentation is related to a certain group of steel elements. Only non-destructive tests are recommended. A summary of the minimal testing procedure is presented in *Table 7.3*.

It should be noted that this procedure is intended to “new” steelwork for which documentation is available.

Table 7.3. *Recommendations for minimal testing*

| Characteristic to be determined | Type of testing | Percentage of elements to be tested | Annex |
|---------------------------------|-----------------|--|-------|
| Tensile and yield strength | Non-destructive | 10% - with a minimum of 3 tests per group. | E.3 |
| Chemical composition (CEV) | Non-destructive | | G.2 |

7.3 Comprehensive testing

The recommendations for comprehensive testing 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 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 7.4 relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition to Consequence class.

Table 7.4. Testing approach related to Consequence class [68].

| Consequence class | NDT to establish yield strength, ultimate strength and CEV | Minimum number of DT to establish yield strength, ultimate strength and CEV and elongation | Acceptance approach |
|-------------------|--|--|---|
| CC1 | All members to be subject to non-destructive tests | 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) |

7.4 Identification, inspection documents and traceability

Clause 5.2 in EN 1090-2 states that: “The properties of supplied constituent products shall be documented in a way that enables them to be compared to the specified properties. Their conformity with the relevant product standard shall be checked in accordance with CI 12.2.”

Inspection documents previously/also known as mill or test certificates, are supplied with all new rolled steel sections and plate supplied to the steelwork contractor. EN 10204 [72] defines the different types of inspection documents that include Type 2.1, 2.2, 3.1 and 3.2 certificates.

An important distinction exists between specific and non-specific inspection certificates.

- **Non-specific inspection** is defined (in EN 10204) as inspection carried out by the manufacturer in accordance with his own procedures to assess whether products defined by the same product specification and made by the same manufacturing process, are in compliance with the requirements of the order or not. Types 2.1 and 2.2 are based on non-specific inspection. The products inspected are not necessarily the products actually supplied.
- **Specific inspection** is defined as inspection carried out, before delivery, according to the product specification, on the products to be supplied or on test units of which the products supplied are part, in order to verify that these products are in compliance with the requirements of the order. Type 3.1 and 3.2 inspection documents are based on specific inspection. A type 3.2 certificate means that products were tested by a third-party accredited entity.

The type of inspection document required for (new) hot-rolled structural steels is set out in Table B.1 in EN 10025-1. Only the steel manufacturer can provide an inspection document to EN 10204. However, clause 12.2.1 of EN 1090-2 states that:

“Documents supplied with constituent products in accordance with the requirements of Clause 5 shall be checked to verify that the information on the products supplied matches those in the component specification. These documents include inspection certificates, test reports, declaration of compliance as relevant for plates, sections, hollow sections, welding consumables, mechanical fasteners, studs etc.”.

Test reports and declarations of compliance can be provided by the stockholder, not just by the original manufacturer. EN 1090-2 also gives requirements for inspection documents for metallic products in Table 1. It is clear that if the inspection is intended to guarantee a minimum characteristic yield strength, an inspection document 3.1 is needed as a minimum requirement.

For reclaimed steel, as group characteristics are justified for the group of reclaimed elements itself, the documentation provided by the stockholder will provide the same level of reliability of a 3.1 or 3.2 certificate. If destructive tests are performed by an external accredited laboratory, a document equivalent to a certificate 3.2 can potentially be issued.

Clause 5.2 in EN 1090-2 states that: “For EXC3 and EXC4, constituent products shall be traceable at all stages from receipt to hand over after incorporation in the works. This traceability may be based on records for batches of product allocated to a common production process, unless traceability for each individual constituent product is specified. For EXC2, EXC3 and EXC4, if differing grades and/or qualities of constituent products are in circulation together, each individual constituent product shall be designated with a mark that identifies its grade and its quality. Methods of marking shall be

in accordance with that for components given in 6.2 (EN1090-2). If marking is required, unmarked constituent products shall be treated as nonconforming product.”.

The distinction between Execution Class 2 and 3 is important in the context of traceability and identification of steel products. Note that EXC2 is the most common execution class for most buildings.

CI 6.2 in EN 1090-2 addresses identification of steel components and states: “At all stages of manufacturing each piece or package of similar pieces of steel components shall be identifiable by a suitable system. Identification may be achieved as appropriate by batching or by the shape and the size of the component or by the use of durable and distinguishing marks applied in a way not producing damage. Chiselled notches are not permitted.”.

To deal with reclaimed steel, it is essential that the stockist implement an efficient component tracing system and digital records for each individual member and group. More information about data records and traceability can be found in Annex C.

8. Fabrication issues

8.1 General comments

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

8.2 Existing coatings on reclaimed steelwork

In most situations, it is envisaged that any existing coatings on reclaimed steelwork should 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 its existing corrosion protection is contemplated, 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 their specification is uniquely linked to the original member. For both of these reasons, no reliance should be placed on existing fire protection coatings.

For the cases where the existing coating system needs to be removed, the following international standards may be used:

- EN ISO 8501: Visual assessment of surface cleanliness [41];
- EN ISO 8502: Tests for the assessment of surface cleanliness [42];
- EN ISO 8503: Surface roughness characteristics of blast-cleaned steel substrates [43];
- EN ISO 8504: Surface preparation methods [44].

The coating system shall be defined according to EN ISO 12944-2 [39] and EN ISO 12944-5 [40].

For the evaluation of degradation of coatings, ISO 4628 which is divided into 9 parts, can be used:

- ISO 4628-1: Part 1: General introduction and defect designation system [79]
- ISO 4628-2: Part 2: Assessment of degree of blistering [80]
- ISO 4628-3: Part 3: Assessment of degree of rusting [81]
- ISO 4628-4: Part 4: Assessment of degree of cracking [82]
- ISO 4628-5: Part 5: Assessment of degree of flaking [83]
- ISO 4628-6: Part 6: Assessment of degree of chalking by tape method [84]
- ISO 4628-7: Part 7: Assessment of degree of chalking by velvet method [85]
- ISO 4628-8: Part 8: Assessment of degree of delamination and corrosion around a scribe [86]
- ISO 4628-10: Part 10: Assessment of degree of filiform corrosion [87]

8.3 Reclaimed members with corrosion

High levels of corrosion are not accepted as geometric properties of the cross section may be compromised. However, small levels of localized corrosion may be accepted if the geometric properties of the cross section are not diminished more than 5% of the minimum thicknesses specified by the product standard of manufacturers tables [32]. The 5% allowance shall be added to geometric tolerances.

For other cases, where corrosion reduces considerably the thickness of a plate, measured thicknesses may be used for structural design purposes.

The evaluation of the effects of corrosion shall be measured after appropriate surface treatment according to EN ISO 12944-4 [46].

8.4 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 EN 1993-1-1 and EN 1993-1-8 [45] 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 the 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.

8.5 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 testing.

The steel grade of connecting plates and other fittings should be assessed by non-destructive tests following the recommendations in Appendix C. 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 EN 1090-2 (Table 24) should be applied to reclaimed steel elements. Visual inspection of 100% of the welds is mandatory.

Bearing in mind that values from Table 24 of EN 1090-2 are seen as a minimum, the following minimum number of connections to be tested may be also considered:

Table 8.1. *Suggested minimum percentage of welds to be tested [47].*

| Total number of connections | Number of connections to be tested | Total % |
|-----------------------------|------------------------------------|---------|
| 6 | 3 (minimum) | 50% |
| 10 | 4 | 40% |
| 15 | 5 | 33% |
| 20 | 6 | 30% |
| 30 | 8 | 27% |
| 40 | 10 | 25% |
| 50 | 12 | 24% |
| 75 | 16 | 21% |
| 100 | 20 | 20% |
| 200 | 30 | 15% |
| 300 | 40 | 13% |
| 500 | 60 | 12% |
| 1000 | 100 | 10% |
| 2000 | 150 | 8% |

Example:

Consider a group of haunched rafters from a portal framed structure with pinned bases subjected to gravity loading. Four types of critical welds may be identified (see Figure 8.1):

1. Welds between the beam web and the end plate on eaves connections;
2. Eaves connections: welds between the top flange of the rafter and the end plate;
3. Apex connection: welds between of the bottom flange of the rafter/haunch and the end plate;
4. Welds between the haunch/beam web and the end plate on apex connections.

Each one of these welds represent a possible test sample. To test 15% of the welds, from a test unit with 50 rafters from 25 frames (200 critical connections, see Table 8.1), 30 welds should be tested (that respects a minimum of 30 welds inspected). These 30 welds should be selected randomly from the critical welds identified in connections 1, 2, 3 or 4 above. Every weld to be tested should ideally be selected from different elements.

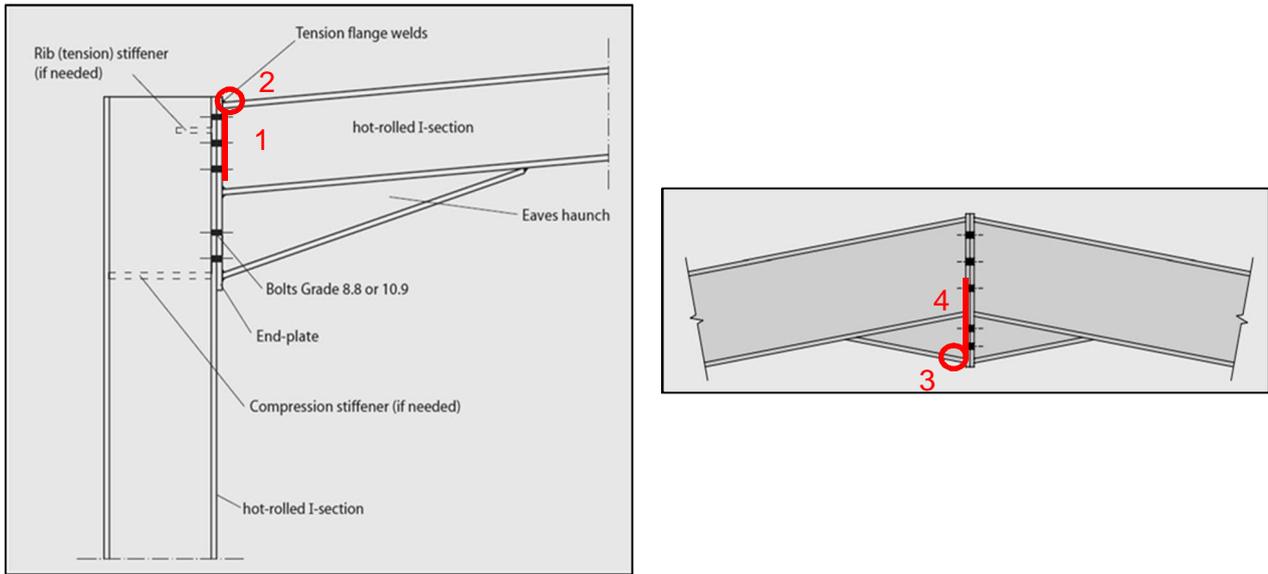


Figure 8.1 – Examples of critical weld details that can be tested.

References

- [1] EN 1090-1:2009+A1:2011. Execution of steel structures and aluminium structures. Requirements for conformity assessment of structural components, BSI;
- [2] EN 1993-1-1:2005+A1:2014. Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings, BSI;
- [3] EN 1090-2:2018. Execution of steel structures and aluminium structures Technical requirements for steel structures, BSI;
- [4] EN 1990:2002+A1:2005. Eurocode. Basis of structural design, BSI;
- [5] PD CEN ISO/TR 15608:2017. Welding. Guidelines for a metallic material grouping system, BSI;
- [6] EN 1993-1-10:2005. Eurocode 3. Design of steel structures. Material toughness and through-thickness properties, BSI;
- [7] EN 10365:2017. Hot rolled steel channels, I and H sections. Dimensions and masses, BSI;
- [8] EN 10034:1993. Structural steel I and H sections. Tolerances on shape and dimensions, BSI;
- [9] EN 10024:1995. Hot rolled taper flange I sections. Tolerances on shape and dimensions, BSI;
- [10] EN 10279:2000. Hot rolled steel channels. Tolerances on shape, dimension and mass, BSI;
- [11] EN 10056-1:2017. Structural steel equal and unequal leg angles. Dimensions, BSI;
- [12] EN 10056-2:1993. Specification for structural steel equal and unequal angles. Tolerances on shape and dimensions, BSI;
- [13] EN 10055:1996. Hot rolled steel equal flange tees with radiused root and toes. Dimensions and tolerances on shape and dimensions, BSI;
- [14] EN 10029:2010. Hot-rolled steel plates 3 mm thick or above. Tolerances on dimensions and shape, BSI;
- [15] EN 10051:2010. Continuously hot-rolled strip and plate/sheet cut from wide strip of non-alloy and alloy steels. Tolerances on dimensions and shape, BSI;
- [16] EN 10017:2004. Steel rod for drawing and/or cold rolling. Dimensions and tolerances, BSI;
- [17] EN 10058:2018. Hot rolled flat steel bars and steel wide flats for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
- [18] EN 10059:2003. Hot rolled square steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
- [19] EN 10060:2003. Hot rolled round steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
- [20] EN 10061:2003. Hot rolled hexagon steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
- [21] EN 10210-2:2019. Hot finished steel structural hollow sections. Tolerances, dimensions and sectional properties, BSI;
- [22] EN 10219-2:2019. Cold formed welded steel structural hollow sections. Tolerances, dimensions and sectional properties, BSI;
- [23] EN 10219-1:2006. Cold formed welded structural hollow sections of non-alloy and fine grain steels. Technical delivery requirements
- [24] EN 10210-1:2006. Hot finished structural hollow sections of non-alloy and fine grain steels. Technical delivery requirements, BSI;
- [25] EN 10025-2:2019. Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, BSI;
- [26] EN 10025-3:2019. Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels, BSI;

- [27] EN 10025-4:2019. Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels, BSI;
- [28] BS 15:1948. Structural steel, BSI;
- [29] BS 4360-2:1969. Specification for weldable structural steels metric units, BSI;
- [30] SCI P419 Brittle fracture selection of steel sub-grade to EN 1993-1-10;
- [31] PD 6695-1-10 Recommendations for the design of structures to BS EN 1993-1-0, BSI, 2009;
- [32] SIA 269/3:2011. Existing structures – Steel structures, SIA Zurich.
- [33] National Structural Steelwork Specification, BCSA Publication No. 57, 1st edition, 1989;
- [34] BS 449-2:1969. Specification for the use of structural steel in building. Metric units, BSI;
- [35] SIA 263:2013. Construction en acier, SIA Zurich;
- [36] European Commission, EU Construction & Demolition Waste Management Protocol, September 2016
- [37] European Commission, Guidelines for the waste audits before demolition and renovation works of buildings, May 2018,
- [38] Kamrath, P., Sansom, M., Ungureanu, V., Hradil, P., Safe and efficient deconstruction, Deliverable D2.1 of PROGRESS project, May 2020.
- [39] EN ISO 12944-2:2017. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Classification of environments, BSI;
- [40] EN ISO 12944-5:2018. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Protective paint systems, BSI;
- [41] EN ISO 8501, Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Parts 1 to 4, BSI;
- [42] EN ISO 8502, Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Parts 1 to 12, BSI;
- [43] EN ISO 8503, Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Parts 1 to, BSI;
- [44] EN ISO 8504, Preparation of steel substrates before application of paints and related products. Surface preparation methods. Parts 1 to 3, BSI;
- [45] EN 1993-1-8:2005. Eurocode 3. Design of steel structures. Design of joints, BSI;
- [46] EN ISO 12944-4:2017. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Types of surface and surface preparation, BSI;
- [47] FEMA 352:2000. Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings; Federal Emergency Management Agency USA.
- [48] EN ISO 19650-1:2018. Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling.
- [49] EN 17412. Building Information Modelling. Level of Information Need. Concepts and principles. Part 1: Concepts and principles;
- [50] EN ISO 6507-1:2018. Metallic materials. Vickers hardness test. Test method, BSI.
- [51] EN ISO 6507; all parts. Metallic materials. Vickers hardness test, BSI.
- [52] EN ISO 6508; all parts. Metallic materials. Rockwell hardness test, BSI.
- [53] EN ISO 6505; all parts. Metallic materials. Brinell hardness test, BSI.
- [54] An Evaluation of Mechanical Properties with the Hardness of Building Steel Structural Members for Reuse by NDT Masanori Fujita * and Keiichi Kuki; Metals 2016;
- [55] EN ISO 377:2017. Steel and steel products. Location and preparation of samples and test pieces for mechanical testing, BSI.
- [56] EN ISO 6892-1:2016. Metallic materials. Tensile testing. Method of test at room temperature, BSI.

- [57] EN ISO 148-1:2016. Metallic materials. Charpy pendulum impact test. Test method, BSI.
- [58] EN ISO 14284:2002. Steel and iron. Sampling and preparation of samples for the determination of chemical composition, BSI.
- [59] SCI P138 – “Appraisal of existing Iron and Steel Structures”, M. Bussell, 1997.
- [60] BCSA - “Historical structural steelwork handbook”, Publication 11/84, W. Bates, 1984.
- [61] EN 10025-1:2004; Hot rolled products of structural steels. General technical delivery conditions, BSI.
- [62] EN 10025-2:2019; Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, BSI.
- [63] EN 10025-3:2019; Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels, BSI.
- [64] EN 10025-4:2019; Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels, BSI.
- [65] Standardisation of safety assessment procedures across brittle to ductile failure modes (SAFEBRITTLE) RFCS project RFSR-CT-2013-00023;
- [66] EN ISO 18265:2013 Metallic materials. Conversion of hardness values, BSI.
- [67] Pavlina, E.J., Van Tyne, C.J.; Correlation of Yield Strength and Tensile Strength with Hardness for Steels; ASM International; JMEPEG (2008) 17:888–893;
- [68] SCI P427 – Structural Steel Reuse: assessment, testing and design principles, The Steel Construction Institute, 2019;
- [69] BS EN ISO 9001 – Quality management systems. Requirements; 2015, BSI.
- [70] ISO 19011 – Guidelines for auditing management systems; 2018, BSI.
- [71] BS EN ISO 9712 – Non-destructive testing. Qualification and certification of NDT personnel, 2012, BSI.
- [72] BS EN 10204; Metallic products. Types of inspection documents, 2004;
- [73] BS 2645-2:1956; Tests for use in the approval of welders. Manual metal arc and oxy-acetylene welding of mild steel and low alloy steel pipelines and pipe assemblies, BSI;
- [74] Gulvanessian H, Calgar JA, Holický M (2012). Designer’s guide to Eurocode: basis of structural design EN 1990, ICE Publishing, Thomas Telford, London (2nd edition).
- [75] Steenbergen RDJM, Vrouwenvelder ACWM (2010). Safety philosophy for existing structures and partial factors for traffic loads on bridges, Heron 55(2), 123-140.
- [76] Matthews S (2012). Structural appraisal of existing buildings, including for a material change of use, Part 3: Structural appraisal procedures, BRE-DG 366, Building Research Establishment, UK.
- [77] AISC 342 – 2019 (draft): “Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings”
- [78] ASCE/SEI 41-17 – 2017: “Seismic Evaluation and Retrofit of Existing Buildings”
- [79] BS EN ISO 4628-1:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. General introduction and designation system;
- [80] BS EN ISO 4628-2:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of blistering, BSI;
- [81] BS EN ISO 4628-3:2016, Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of rusting, BSI;

- [82] BS EN ISO 4628-4:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of cracking, BSI;
- [83] BS EN ISO 4628-5:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of flaking, BSI;
- [84] BS EN ISO 4628-6:2011; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of chalking by tape method, BSI;
- [85] BS EN ISO 4628-7:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of chalking by velvet method, BSI;
- [86] BS EN ISO 4628-8:2012; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of delamination and corrosion around a scribe or other artificial defect, BSI;
- [87] BS EN ISO 4628-10:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of filiform corrosion;
- [88] PROGRESS: Provisions for greater steel reuse; Research Fund for Coal and Steel Grant agreement No: 747847; Deliverable 2.1; Safe and efficient deconstruction, 2019;
- [89] PROGRESS: Provisions for greater steel reuse; Research Fund for Coal and Steel Grant agreement No: 747847; Deliverable 3.1; Summary of design practices for reusable buildings and products, 2019;
- [90] BS EN 1998-3:2005; Eurocode 8. Design of structures for earthquake resistance. Assessment and retrofitting of buildings;
- [91] *BS EN ISO 19650-1:2018*; Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling; BSI.
- [92] *BS EN ISO 19650-2:2018*; Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling; BSI.
- [93] prEN 17412 – Building information modelling – Level of information needed – concepts and principles;
- [94] prEN ISO 23387-1 Building Information Modelling (BIM) — Data templates for construction objects used in the life cycle of any built asset — Concepts and principles;
- [95] ISO/DIS 20887 – Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles requirements and guidance.
- [96] ISO 19272:2015; Low alloyed steel — Determination of C, Si, Mn, P, S, Cr, Ni, Al, Ti and Cu - Glow discharge optical emission spectrometry (routine method); BSI, 2015.
- [97] BS EN 13018:2016 Non-destructive testing. Visual testing. General principles; BSI;
- [98] BS EN ISO 13385-1:2019; Geometrical product specifications (GPS). Dimensional measuring equipment. Design and metrological characteristics of callipers; BSI;
- [99] BS EN ISO 13385-2:2011; Geometrical product specifications (GPS). Dimensional measuring equipment. Calliper depth gauges. Design and metrological characteristics, BSI;
- [100] BS EN ISO 3452-1:2013; Non-destructive testing. Penetrant testing. General principles; BSI;
- [101] BS EN ISO 23277:2015; Non-destructive testing of welds. Penetrant testing. Acceptance levels;
- [102] BS EN ISO 15549:2019; Non-destructive testing. Eddy current testing. General principles, BSI;

- [103] BS EN ISO 17643:2015; Non-destructive testing of welds. Eddy current examination of welds by complex plane analysis, BSI;
- [104] BS EN ISO 17640:2018 Non-destructive testing of welds. Ultrasonic testing. Techniques, testing levels, and assessment
- [105] BS EN ISO 17636; all parts; Non-destructive testing of welds. Radiographic testing. X- and gamma-ray techniques, BSI;
- [106] BS EN ISO 17638:2016 Non-destructive testing of welds. Magnetic particle testing
- [107] BS ISO 19272:2015; Low alloyed steel. Determination of C, Si, Mn, P, S, Cr, Ni, Al, Ti and Cu. Glow discharge optical emission spectrometry (routine method), BSI;
- [108] BS EN 1090-4:2018; Execution of steel structures and aluminium structures. Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications, BSI;
- [109] BS EN 10346:2015; continuously hot-dip coated steel flat products for cold forming. Technical delivery conditions, BSI;
- [110] BS EN 10143:2006; continuously hot-dip coated steel sheet and strip. Tolerances on dimensions and shape;
- [111] BS EN 13523-1:2017; Coil coated metals. Test methods. Film thickness, BSI;
- [112] BS EN 13523-6:2002; Coil coated metals. Test methods. Adhesion after indentation, BSI;
- [113] BS EN 13523-7:2014; Coil coated metals. Test methods. Resistance to cracking on bending (T-bend test), BSI;
- [114] ASTM E112 – 13; Standard Test Methods for Determining Average Grain Size;
- [115] CWA 15627:2007; Small punch test method for metallic materials, BSI;
- [116] BS EN 1993-1-3:2006; Eurocode 3. Design of steel structures. General rules. Supplementary rules for cold-formed members and sheeting, BSI;
- [117] CHETTOE, C.S., DAVEY, N. and MITCHELL, G.R. The strength of cast-iron girder bridges Journal of the Institution of Civil Engineers, 1943 to 44 22 (8), 243 to 307;
- [118] TWELVETREES, W.N. Structural iron and steel Fourdrinier, 1900;
- [119] ANGUS, H.T. Cast iron: physical and engineering properties (2nd edition) Butterworth, 1976;
- [120] BS EN ISO 17637:2016; Non-destructive testing of welds. Visual testing of fusion-welded joints, BSI.
- [121] DD ENV 1993-1-1:1992; Eurocode 3. Design of steel structures. General rules and rules for buildings (together with United Kingdom National Application Document), BSI;
- [122] JRC - New European Technical Rules for the Assessment and Retrofitting of Existing Structures; 2015;
- [123] Assessment criteria for Existing Structures; Nico P.M. Scholten; Prof. Ton C.W.M. Vrouwenvelder; Structural Engineering International 1/2010.
- [124] ISO 13822:2010, Bases for design of structures - Assessment of existing structures;
- [125] ISO/IEC 17025 Testing and calibration laboratories, 2017;
- [126] BS EN 1561:2011; Founding. Grey cast irons, BSI.
- [127] <https://www.ym.fi/download/noname/%7BBDABB0AD-55DB-4B66-8F8C-AA6141A7B4E5%7D/153256>; Circular Economy in the Construction Sector - Council Conclusions (adopted 28 November 2019); General Secretariat of the Council On: 28 November 2019; Brussels, 28 November 2019
- [128] CWA 17316: 2018; Smart CE marking for construction products; CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels;
- [129] Dorman Long & CO Ltd (1964). Handbook for constructional engineers, Fanfare Press Ltd, London, UK.
- [130] The British Constructional Steelwork Association (1994). National structural steelwork specification for building construction, 3th Ed., 203, London, UK
- [131] BS 4 Part 1;1962. Specification for structural steel section; Part 1: Hot Rolled sections;
- [132] <https://www.youtube.com/watch?v=NCORhUAfgcY;>

- [133] BS EN 14509:2013; Self-supporting double skin metal faced insulating panels. Factory made products;
- [134] CEN – European Committee for Standardisation (2004). EN 1998 Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings (incorporating CEN corrigenda July 2009, Jan. 2011, and March 2013, and CEN amendment A1:2013), Brussels, Belgium.
- [135] SAMCO Final Report 2006 F08b Guideline for Structural Health Monitoring F08b Guideline for Structural Health Monitoring Dir. u. Prof. Dr. W. Rücker, Dipl.-Ing. F. Hille, Dipl.-Ing. R. Rohrmann Federal Institute of Materials Research and Testing (BAM), Division VII.2 Buildings and Structures Unter den Eichen 87, 12205 Berlin, Germany;
- [136] Probabilistic Model Code, Parts 1 to 4, Basis of design, Load and resistance models, Examples, JCSS, 2001-2002.
- [137] JRC - New European Technical Rules for the Assessment and Retrofitting of Existing Structures. Prospect for CEN Guidance, 2015.
- [138] JRC - Assessment of Existing Steel Structures: Recommendations for Estimation of Remaining Fatigue Life; B. Kühn, M. Lukić, A. Nussbaumer, H.-P. Günther, R. Helmerich, S. Herion, M.H. Kolstein, S. Walbridge, B. Androic, O. Dijkstra, Ö. Bucak; Joint Report Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250) Editors: G. Sedlacek, F. Bijlaard, M. Gérardin, A. Pinto and S. Dimova Background documents in support to the implementation, harmonization and further development of the Eurocodes; 2008.
- [139] Innovative methods for the assessment of existing structures, Dimitris Diamantidis, University of Applied Sciences in Regensburg, Faculty of Civil Engineering Milan Holický, Czech Technical University in Prague, Klokner Institute, 2013.
- [140] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 1 Requirements for structural appraisal; Stewart Mathews; 2012;
- [141] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 2 Preparing for structural appraisal; Stewart Mathews; 2012;
- [142] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 3 Structural appraisal procedures; Stewart Mathews; 2012;
- [143] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 4 Additional considerations and information sources; 2012;
- [144] Appraisal of Existing Structures, Institution of Structural Engineers, 2010;
- [145] NEN 8700 - Assessment of existing structures in case of reconstruction and disapproval – Basic Rules, 2011;
- [146] NEN 8701 Assessment of existing structures in case of reconstruction and disapproval – Actions, 2011;
- [147] Eurocodes and structural safety of the existing buildings – considering the publication of the Dutch NEN 8700, Dr. Nico P.M. Scholten (Expertcenter Regulations in Building); Prof. Ton C.W.M. Vrouwenvelder (TNO Built Environment and Geosciences); 4th International Conference CIVIL ENGINEERING`13 Proceedings Part II Building and renovation, 2013.
- [148] Assessment criteria for Existing Structures; Nico P.M. Scholten (Expert center Regulations in Building); Prof. Ton C.W.M. Vrouwenvelder (TNO Built Environment and Geosciences); Structural Engineering International 1/2010.
- [149] Allen D E. Limit states criteria for structural evaluation of existing buildings. Canadian Journal of Civil Engineering, 1991, 18 (6) 995–1004.
- [150] Diamantidis D and Bazzuro P. Safety acceptance criteria for existing structures. Workshop on 'Risk Acceptance and Risk Communication', Stanford University, US, March 2007.

- [151] Steenbergen R D J M and Vrouwenvelder A C W M. Safety philosophy for existing structures and partial factors for traffic loads on bridges. *Heron*, 2010, 55 (2) 123–140.
- [152] Joint Committee on Structural Safety (JCSS). Probabilistic assessment of existing structures, RILEM Report 32, edited by D Diamantidis. Cachan, France, RILEM Publications s.a.r.l., 2001.
- [153] JCSS, Background documentation Eurocode 1 ENV Part 1: Basis of Design, ECCS, Report No 94, 1996.
- [154] BRE Report 511 “Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loading” defines revised performance requirements (updating those given in MHLG Circulars 62/68 and 71/ 68) and provides technical guidance on structural appraisal procedures that may be employed.
- [155] DMRB - “Design Manual for Roads and Bridges” standards: Volume 0 (Introduction and General Requirements), Volume 1 (Highway Structures: Approval Procedures and General Design), Volume 2 (Highway Structures: Design (Substructures and Special Structures), Materials) and Volume 3 Highway Structures: Inspection and Maintenance).
<http://www.standardsforhighways.co.uk/ha/standards/dmrb/index.htm>
- [156] Reliability analysis for structural design; Milan Holický, Sun Press, 2009;
- [157] Commentary and worked examples to EN 1993-1-10 “Material toughness and through thickness properties“ and other toughness oriented rules in EN 1993; G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard Joint Report Joint Report Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250) Editors: M. Gérardin, A. Pinto and S. Dimova Background documents in support to the implementation, harmonization and further development of the Eurocodes;
- [158] STAS 767/0-88 (1988). Steel Structures. General technical requirements for quality of non-industrial, industrial and agricultural buildings. Romanian Institute for Standardization (including the previous version STAS 767/0-77);
- [159] C150-99 (1999). Code for the quality of welded steel joints in civil, industrial and agricultural constructions, MLPAT – Ministry for Public Works and Territorial Administration (including the previous versions C150-84 and C150-72).
- [160] Guideline for Structural Condition Assessment of Existing Buildings, ASCE Standard Guideline, SEI/ASCE 11-99;
- [161] Guideline SIA 462:1994 Assessment of the structural safety of existing buildings, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 1994;
- [162] Basics for assessment of existing structures (Milan Holický, Editor), Klokner Institute, Czech Technical University in Prague, 2013.
- [163] REAE - Regulamento de Estruturas de Aço para Edifícios - Decreto n.º 46160, Diário do Governo n.º 15/1965, Série I de 1965-01-19, 1965.

Annex A Design recommendation for Classes A & B reclaimed steel

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 $\gamma_{M1} = 1.10$ was initially proposed, with values of $\gamma_{M0} = 1.00$ for major axis bending and $\gamma_{M0} = 1.10$ for minor axis bending. The introduction of a different approach for lateral torsional buckling curves allowed the reduction from $\gamma_{M1} = 1.10$ to $\gamma_{M1} = 1.00$. Later, it was proposed that by considering strain hardening, it was possible to justify the use of $\gamma_{M0} = 1.00$ 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 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 today. 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 EN 1990). The recommendation for $\gamma_{M1,mod}$ (for all steel grades) is based on principles expressed in EN 1990 with a conservative assumption for the partial factor associated with the uncertainty of the resistance model ($\gamma_{Rd} = 1.15$).

The recommended value of $\gamma_{M1,mod}$ for Class B reclaimed steel (or Class A reclaimed steel previously erected) 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 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.

For the cases where in situ reuse is applied, i.e., steelwork is not disassembled and re-erected, the value of $k_{\gamma_{M1}} = 1$ is recommended for steelwork erected after 1970.

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 EN 1993-1-1. The cross-sectional resistance depends on dimensional characteristics and material strength, which have both been verified/justified 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.

The recommended values of $k_{\gamma_{M1}}$ should be used for Consequence class 1 structures such as agricultural buildings. It is recommended that the factor $K_{F1} = 0.90$ (see EN 1990 Table B3) is applied to all partial factors if designing a Consequence class 1 structure using reclaimed steel.

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 EN 1990 allows designers to apply the factor $K_{F1} = 1.10$ 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 EN 1990) as an alternative to the K_{F1} factor.

Annex B Design recommendation for Class C reclaimed steel

B.1 Introduction

For the cases where CE marking is not mandatory, conservative assumptions about the material properties may be used for the analysis and design. However, this approach is only recommended for Consequence class 1 structures (CC1). The conservative material properties provided in Table B.1 may be used.

Table B.1 – Recommended material properties for non-tested structural steel.

| Material | Period of erection | f_y [N/mm ²] | f_u [N/mm ²] | G [N/mm ²] | E [N/mm ²] | ϵ_{uk} [%] | v | ρ [kg/m ³] | α_T [10 ⁻⁶ /°C] |
|-----------------|--------------------|-------------------------------|-------------------------------|---------------------------|---------------------------|------------------------|------|--------------------------------|--------------------------------------|
| Steel – Members | Erected after 1970 | 235 | 360 | 81000 | 210000 | 25 | 0.30 | 7850 | 10 |
| Steel – Welds | Erected after 1970 | - | 360 | - | - | - | - | - | - |

These values are proposed based on historical steel and iron data provided in Annex J.

Based on the building's age and location, local standards may be used to set the conservative value for yield strength. Check Annex I for details about withdrawn European product standards.

The visual appearance of old steel is described in Annex J.3.

B.2 The value of γ_{M1}

Please check section A.2.

B.3 The values of γ_{M0} and γ_{M2}

Please check section A.3.

B.4 Connections

If no testing is undertaken (Class C steel), the reuse scenario must ideally avoid welding procedures. Moment resisting connections are also not recommended as they usually require welding.

For the cases where welding procedures are mandatory, a value for the CEV of 0.51 may be assumed (this value is a reference from BS 4360 from 1969 [29]).

Non-destructive tests are recommended to assess the value of CEV.

B.5 Consequence class 1 structures

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

Annex C Data records and information

C.1 Data records

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

Building information:

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

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 determined 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 (assumed).
- The product standard used to infer the relevant material properties shall be stated (*e.g.* EN 10025 or 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.*).

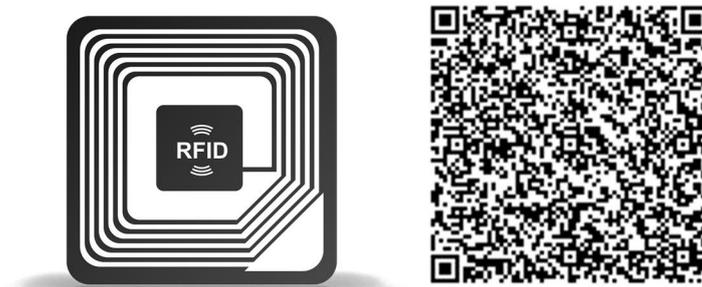
Annex A from the deliverable D2.1 also gives recommendations for the data that should be recorded.

CWA 17316 [128] provides guidance for smart CE marking for construction products, mainly proposing an efficient way to trade and exchange information. CWA 17316 may be used to store the relevant information in a format that facilitates exchange between project actors and between stockholders and those actors.

C.2 Component tracking and digital information

A physical component tracking is often implemented during fabrication and erection processes. However, the component tracking is often lost and not preserved during the life time of the building. It is advised that a form of physical component tracking must be preserved during the lifetime of the building, linked with a digital model where the relevant building and member information can be kept. This measure will facilitate the application of reclaimed steelwork without the need for further testing.

Bar codes, QR codes or Radio frequency identification (RFI) provide an efficient and reliable method of component tracking. This technology can be used as a digital passport for each reclaimed member. It is also possible to store the relevant information needed for future life cycles in a simple QR code, bar code or RFID.



Annexes Figure 1. Examples of component tracking with RFID and QR codes.

The level of information that a 3D BIM model needs to accommodate is a responsibility of all project actors. The ISO standards BS EN ISO 19650-1 [91] and BS EN ISO 19650-2 [92] introduced the concept of level of information need (LOIN), for which is suggested that each project actor must define the relevant information to be stored for the purpose of the element on a specific project. Within the scope of the project, the concept will be discussed from a structural engineering point of view.

The following standards offer some general guidance to specify the LOIN of an element:

- prEN 17412 [93];
- prEN ISO 23387-1 [94];
- ISO/DIS 20887 [95].

However, these standards are rather general for the concept of LOIN. For the definition of LOIN, the actor should try to answer question related to the object such as “who”, “why”, “how”, “when” or relevant numerical quantities for a specific purpose. The process can be performed for topics such as responsibilities, material/product properties/characteristics and geometry, reusability, sustainability, health and safety, costs, structural analysis outcome, appearance/coating, on-site position, labelling, ID, linked documentation, etc.

Following, key concepts from a structural engineering point of view will be presented. These concepts are also generic and are only intended to point out a way forward for the procedure. The following categories for the information that can be stored are proposed:

Table C.2 Proposed information categories for the definition of the LOIN: general definition.

| | |
|---|---|
| Context | For each life cycle: the context/time where/when the structural member has been used; |
| Project actors | For each life cycle: actors involved from relevant disciplines; |
| Purpose | For each life cycle: the purposes of the member; |
| Identification | For each life cycle: the identity of the structural steel member and its traceability to the digital information; |
| Structural design | For each life cycle: relevant design conditions and design outcome for the building and element; |
| Fabrication & erection | For each life cycle: records from fabrication and procedures and the quality of those procedures; |
| Provenance & characteristics | Full traceability of the member material, including records and certificates; |

Table C.3 Proposed information categories for the definition of the LOIN: detail

| | |
|------------------------------|---|
| Context | For each life cycle: project name and description, site name and address, construction date, etc. |
| Project actors | For each life cycle: architects, engineers, contractors, etc. |
| Purpose | Features such as load bearing, structural function (beam, column bracing), condition (permanent, temporary), etc. |
| Identification | For each life cycle: member unique identification number, location (say floor number, bloc number, building), and other relevant visual property (such as colour); Member ID, section serial size |
| Structural design | Building behaviour factor for seismic design, fire rating, critical temperature, fire protection thickness, UF (utilization factor), studs detailing (spacing, height, number/section, material, etc.), floor frequency, deflection (total and imposed), project loading (say total floor permanent and imposed loads), wind action (peak pressure), snow load, type of connections (say pinned, fixed or assumed elastic stiffness), etc. |
| Fabrication & erection | For each life cycle: fabrication company, fabrication date, standard for fabrication quality (say EN1090-2), any relevant fabrication records, erection company, erection date, any other relevant erection record; |
| Provenance & characteristics | <p><u>New steel</u>: producer, mill certificate identification/number/ID, material product standard (say EN10025-2 or EN10210-1), delivery condition according to EN 10204, steel grade and sub grade, through thickness quality (Z), heat treatment delivery condition, geometry product standards (say EN 10365 and EN 10034);</p> <p><u>Reclaimed steel</u>: entity responsible for the re-certification (stockholder), reference standard (say EN10025-2 or EN10219-1), grade and subgrade, all necessary properties according to EN 1090-2 section 5.1 (measured/determined values), reference to the stockholder internal re-certification document number, element product standards (say EN 10365 and EN 10034), straightness according to EN 1009-2;</p> |

The following information may be used as a reference for reclaimed elements in a BIM model (example of a reclaimed steel member being reused on a second life cycle):

Table C.4 Key items for reuse while defined the level of information needed of a model.

| Item | Commentary |
|--|--|
| Steel origin | "Reclaimed-UK" or "New-UK" |
| Date of first erection | 1975 |
| Local of first erection | Leeds |
| Steel Fabricator first erection | "Fabricator 1" |
| Structural design first application | "Consultants 1" |
| Date of second erection | 2019 |
| Local of second erection | London |
| Structural design second application | "Consultants 2" |
| Steel Fabricator second erection | "Fabricator 2" |
| Fabricator ID from second erection | "CL01" |
| Stockholder/manufacturer | This item can represent also the steel producer for new steel. |
| Stockholder/manufacturer certificate number | This item can represent also the material certificate number from the producer for new steel. |
| Steel grade and subgrade | "S355JR", Exact wording as in the material standard. |
| Material in compliance with the standard | "EN10025-2" – This may not be applicable; for example, if the minimum elongation according to the code is not justified. Alternative would be EN1090-2 5.1 |
| Design yield strength (N/mm ²) | 355 |
| Design tensile strength (N/mm ²) | 470 |
| Recorded yield strength (N/mm ²) | 405 |
| Recorded tensile strength (N/mm ²) | 520 |
| Recorded elongation at failure (%) | 23 |
| Measured Carbon Equivalent Value (CEV) | 0.45 |
| Profile size | IPE500, or as in the product standard. |
| Section Dimensions | "EN 10365", or another relevant standard |
| Section Tolerances | "EN 10034", or another relevant standard |

Guidance form CWA 17316 may be used to facilitate the exchange information.

Some data from table C.5 can also be seen as important data to be store in a QR code for example as a permanent physical component tracking.

Table C.5 Proposed information to be stored on a permanent physical component tracking.

| Item | Commentary |
|---|--|
| Steel Origin Locale | Reclaimed-UK |
| Steel Origin Date | 1975 |
| Steel Fabricator (current application) | Fabricator name |
| Fabricator ID | C10 |
| Structural design (current application) | Consultant name |
| Stockholder | Stockholder name |
| Stockholder certificate number | Report/certificate number |
| Steel grade and subgrade | S355JR |
| Material in compliance with the standard | EN1090-2 cl. 5.1 |
| Design yield strength (N/mm ²) | 355 |
| Design tensile strength (N/mm ²) | 470 |
| Measured yield strength (N/mm ²) | 405 |
| Measured tensile strength (N/mm ²) | 520 |
| Measured elongation at failure (%) | 23 |
| Measured Carbon Equivalent Value (CEV) | 0.45 |
| Profile size | IPE500 |
| Section Dimensions | EN 10365 |
| Section Tolerances | EN 10034 |
| <p><i>Example of a real possible QR code for component tracking:</i></p>  <p>https://www.the-qr-code-generator.com/</p> | <p>Origin: Reclaimed-UK Steel Age: 1975 ID: C10 Fabricator: Name Designer: Name Stockholder: Name Stockholder Certificate: AA001 Steel Designation: S355JR Material Standard: EN1090-2 cl. 5.1 Design yield (MPA): 355 Design tensile (MPA): 470 Measured Yield (MPA): 405 Measured Tensile (MPA): 520 Measured Elongation (%): 23 Measured CEV: 0.45 Profile: IPE500 Dimensions: EN 10365 Tolerances: EN 10034</p> |

Annex D Review of inspection and testing techniques

D.1 Inspection techniques

The inspection techniques appropriate to this protocol are summarised in the table below. These simple techniques will assist in the determination of the general condition of the structure and help define a suitable sampling and testing procedure. In practice, this is combined with detailed measurements. The following information can be gathered:

- The age of the structure and any modifications or repairs,
- Materials with which the structure has been built or modified,
- The geometry and structural configuration of the building, size of members and details of the joints.

In the case of reuse of the entire primary structure, the inspection of the building includes further detail. The section dimensions of components at critical locations should be measured. Dimensions of joints and their connectors should be recorded, including weld sizes. Inspection of all welds needs to be carried out. Additionally, for all critical parts, the resistance of which are related to geometric imperfections, detailed measurement of deviations should be made in accordance with EN 1090-2.

Table D.6 Inspection techniques

| Technique | Description | Comments/Value |
|------------------------|--|--|
| Visual inspection | Examination for corrosion, cracks, deformities, damage, etc. | Essential. General assessment of the physical condition of the structure. Will not reveal fine or subsurface cracks. General provisions are given in EN 13018 [97]. |
| Field survey | Geometrical survey of positions and sizes of members and details. | Essential in absence of drawings, and to (i) check for modifications and repairs, (ii) determine the cross-section dimensions, straightness, verticality, deformation and deflection of members. |
| Dimensional inspection | Measurements using Vernier callipers, micrometres, three-dimensional laser scanning, ultrasonic measurements, etc. | Essential in absence of original structural drawings. Geometric data collection, size of members. For equipment and tools see e.g. EN ISO 13385-1 [98] and EN ISO 13385-2 [99]. |

D.2 Non-destructive and minimum invasive testing for material properties

Non-destructive hardness testing is suitable for estimating the ultimate tensile strength of the steel. The table below summarizes some of the alternative non-destructive techniques that can be used to assess the properties of reclaimed steel.

Table D.7 Potential NDT techniques

| Technique | Description | Comments/Value |
|----------------------------------|---|--|
| Hardness testing | Diameter of imprint measured when hardened steel ball is pressed against a smooth surface with known force. | Provides hardness number, e.g. Vickers according to ISO 6507 [51] hardness, which is a guide to yield and ultimate strength of the material. Vickers test method is stated on EN 1090-2. Other alternatives are Rockwell ISO 6508 [52] and Brinell ISO 6505 [53] test methods. |
| Positive metal identification | Uses X-ray Fluorescence and optical emission spectrometry to establish the metallic alloy composition, and grade identification by reading the quantities by percentage of its elements. | Essential for characterisation of weldability of steel structural members, as a function of the carbon equivalent. Provides additional information on the type and associated physical properties of steel and about its alloying materials. ISO 19272 [104]. |
| Instrumented indentation testing | Instrumented indentation apparatus uses similar technique as hardness test with measured load and penetration in repeated loading and unloading cycles. | Output of the indentation test includes stress-strain relationship, elastic modulus, hardness and stiffness. |
| Small punch testing | Small punch test uses ceramic ball pressed against the face of small circular specimen (diameter 8 mm, thickness 0.5 mm). The stress-strain relationship is then derived from the measured load versus ball displacement. | Calculation according to prEN 15627 can be used to predict yield and tensile strength of the steel. The equivalent stress-strain relationship of the tensile coupon may be obtained by more advanced Finite Element Modelling. |

D.3 Non-destructive testing of welds

NDT is generally carried out by operating equipment close to, against or fixed to the surface of the structure, and has a major advantage that it does not damage the structure, and eliminates the need for destructive sampling, and subsequent laboratory testing. The table below sets out some of the techniques that can be used during the examination phase. NDT techniques can be useful to locate and/or size defects.

Table D.8 Potential NDT techniques

| Technique | Description | Comments/Value |
|---------------------------------|---|--|
| Visual inspection | Covers the visual examination of fusion welds in metallic materials. The examination is normally performed on welds in the as-welded condition but exceptionally, the examination may be carried out at other stages during the welding process. | Ensures minimum quality control for every welded connection. BS EN 17637 [120]. |
| Penetrant testing | Dye highlight surface breaking cracks. | Indicates surface cracks in members not otherwise visible to the naked eye, approximately 25 µm. Surface defects may be accurately detected. EN ISO 3452-1 [100] gives the general principles for this technique. For welds, see EN ISO 23277 [101] |
| Eddy current welding inspection | Eddy current methods are used for non-destructively locating and characterising discontinuities in magnetic or nonmagnetic electrically conducting materials. | Essential to detect surface and near-surface cracks. Only applicable to simple geometries. Will not detect sub-surface embedded defects. General principles are given in EN ISO 15549 [102] and for welds see EN ISO 17643 [103]. |
| Ultrasonic testing | Transducer converts electrical energy into ultra-high frequency sound waves which are reflected by defects and recorded. | Suitable for detecting embedded planar defects, including cracks, lack of fusion of welds, lamellar tearing, hydrogen cracking. EN 17640 [104]. |
| Magnetic particle inspection | Magnetic particle inspection uses magnetisation of questionable cross sections in electrically conductive materials. For visualization of the magnetic field, a suspension usually with fluorescent steel splinters is used. | This inspection method can be used for detection of surface cracks in ferromagnetic materials only. Cracks in nonmagnetic material or in sandwiched elements cannot be detected. The method can be applied as quality control of precise setting of drilled holes to stop active fatigue cracks. EN 17638 [106] can be pointed out as a reference. |
| Radiographic inspection | Radiographic inspection (x-ray, γ-ray, e.g. with Iridium source) is applied to detect cracks and flaws in built-up sections to evaluate sandwiched members. The radiographic source is located on one side of the built-up element, the radiosensitive film, detector or digital storage unit on the other side of the inspected cross section. | The radiographic or γ-ray inspection is the only method with validated feasibility during laboratory tests and on-site for detection of internal failure or of cracks in the middle of sandwiched elements. EN ISO 17636 [105] can be pointed out as a reference. |

D.4 Destructive testing for material properties

DT techniques require retrieving small samples from the existing structure. Potential DT techniques are identified in the table below. Samples for testing are extracted by cutting or drilling. It is important to consider the likely value of the test results in relation to possible damage to the structure, e.g. embrittlement following heating when sample is removed by flame cutting, and whether indirect methods might be appropriate. Mechanical and metallurgical properties can usually be established from laboratory testing on the same sample. Information about obtaining samples from steel can be found in relevant standards, e.g. for steel see EN 10025.

Table D.9 Potential DT techniques

| Technique | Description | Comments/Value |
|-------------------------------|---|---|
| Tensile testing | Tensile tests on meaningful samples providing yield and ultimate tensile strength, modulus of elasticity, uniform elongation, and elongation at failure. | For test details see EN ISO 6892-1 [56] |
| Chemical composition analysis | Testing for carbon, silicon, manganese, sulphur, and phosphorus. | Essential for material identification and to check the weldability of the steel as a function of the carbon equivalent, as well as the impurity levels. Tests are carried out on drilling swarf or scrapings Provides further information on the type and associated physical properties of steel. See EN ISO 14284 [58]. |
| Small punch testing | The stress-strain relationship can be also obtained by small-punch test of small sample. | Small punch testing is standardised but the method should be calibrated against the tensile tests of full-size specimen, see CWA 15627 [115]. |
| Charpy impact test | Brittleness and notch ductility at a range of temperatures determined by measuring the energy required to fracture a standard U- or V-notched sample with a blow from a pendulum. | Desirable. Allows characterisation of the steel sub-grade when material certificates are not available. For test details see EN ISO 148-1 [57]. Impact toughness can be also tested on sub-sized specimen and the results recalculated to match the behaviour of the full-sized tests. |
| Metallography | Determination of the average grain size | Determination of internal structure of the material by microscopic examination of a sample with one flat surface. See ASTM E 112 [114]. |

Annex E Testing: strength and elongation – reliability assessment

E.1 Introduction

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.

E.2 Measured strength and assumed steel grade – reliability assessment

The results of non-destructive and destructive tests should be compared with the values presented in Table E.10 in order to determine the steel grade. The values in Table E.11 have been developed from reference [65]. Minimum values are established by reducing the mean value by 1.64 times the standard deviation for each steel grade.

Table E.10 Steel grade identified from test results [65].

| Steel grade | Yield strength (N/mm ²) | | Ultimate strength (N/mm ²) | | | Standard |
|-------------|-------------------------------------|------|--|------|---------------------|---------------------------|
| | Minimum | Mean | Minimum | Mean | f_u / f_y mean | |
| 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 | 594 | 1.12 | EN 10025-3/4; EN 10219 |

The values in Table E.9 are appropriate for steel with thicknesses between 3 mm and 60 mm.

The minimum values were obtained by reducing 1.64 standard deviation from the mean value. The following material characteristics were considered:

Table E.11 Steel grade data according to reference [65].

| Steel grade | Yield Strength | | Tensile Strength | |
|-------------|-----------------------------|-------|-----------------------------|-------|
| | Mean X characteristic value | COV | Mean X characteristic value | COV |
| S235 | 1.25 | 0.055 | 1.20 | 0.050 |
| S275 | 1.25 | 0.055 | 1.20 | 0.050 |
| S355 | 1.20 | 0.050 | 1.15 | 0.040 |
| S460 | 1.15 | 0.045 | 1.10 | 0.035 |

Every element within a group must comply with the minimum yield strength from Table E.10 in order for the associated grade to be assumed.

By assuming the minimum yield and tensile strength values from Table E.10, the adequate reliability levels are met when designing with the Eurocodes. It is noted that one must not consider characteristic measured values from tests for structural design. This means that for a test programme that justifies minimum characteristic values of 391 and 505 N/mm² for yield and tensile strength respectively, the designer must consider that the material (according to EN10025-2) has a yield strength of 355 N/mm² and 470 N/mm² for tensile strength (for plate thicknesses between 3 and 100mm).

E.3 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 that is considered sufficiently accurate to define 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 EN 1990 to determine the representative value for the whole group. Once the hardness value for the group has been determined, the yield strength and ultimate strength should be calculated and compared with Table E.10 to define the steel grade.

E.4 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 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 EN 1990 for “ V_x unknown”, presented as Table E.12.

Table E.12 Values of k_n for the 5% characteristic value (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 |

An ultrasonic hardness test can be used as testing method. Vickers hardness test according to EN ISO 6507 [50] is one of the available options.

E.5 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 (rounded conservatively from reference [54]):

$$f_y = 2.70 H_v - 71$$

$$f_u = 2.50 H_v + 100$$

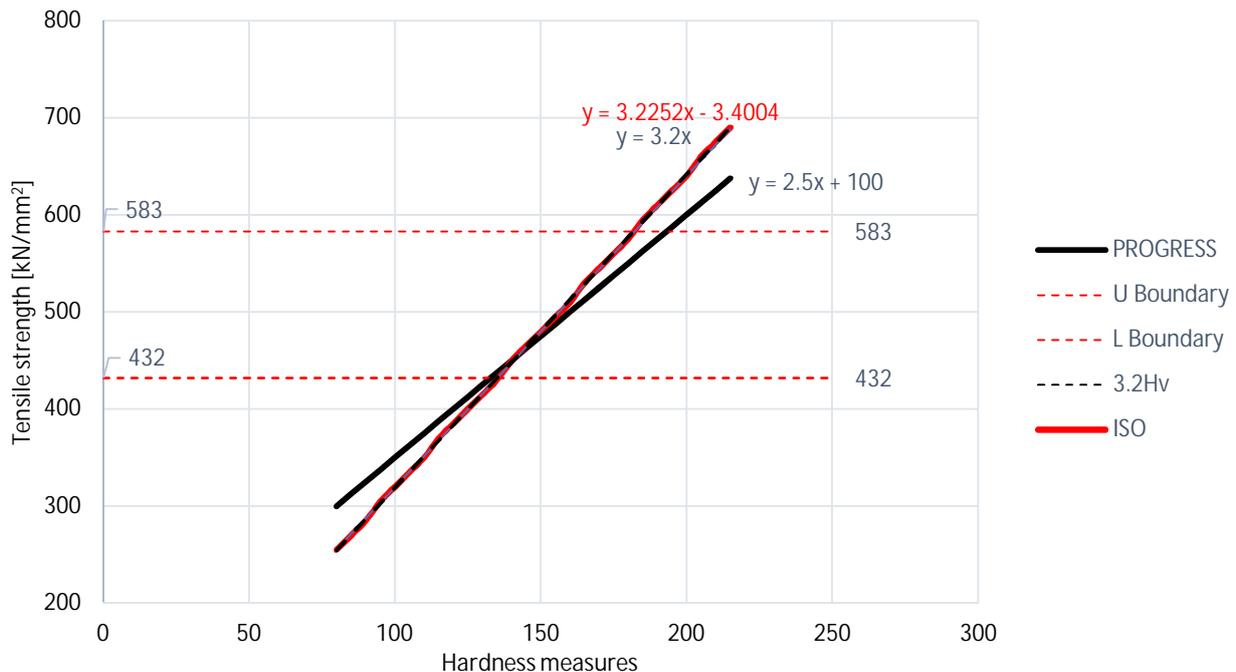
where:

H_v is the Vickers hardness value for the group;

f_y is the yield strength

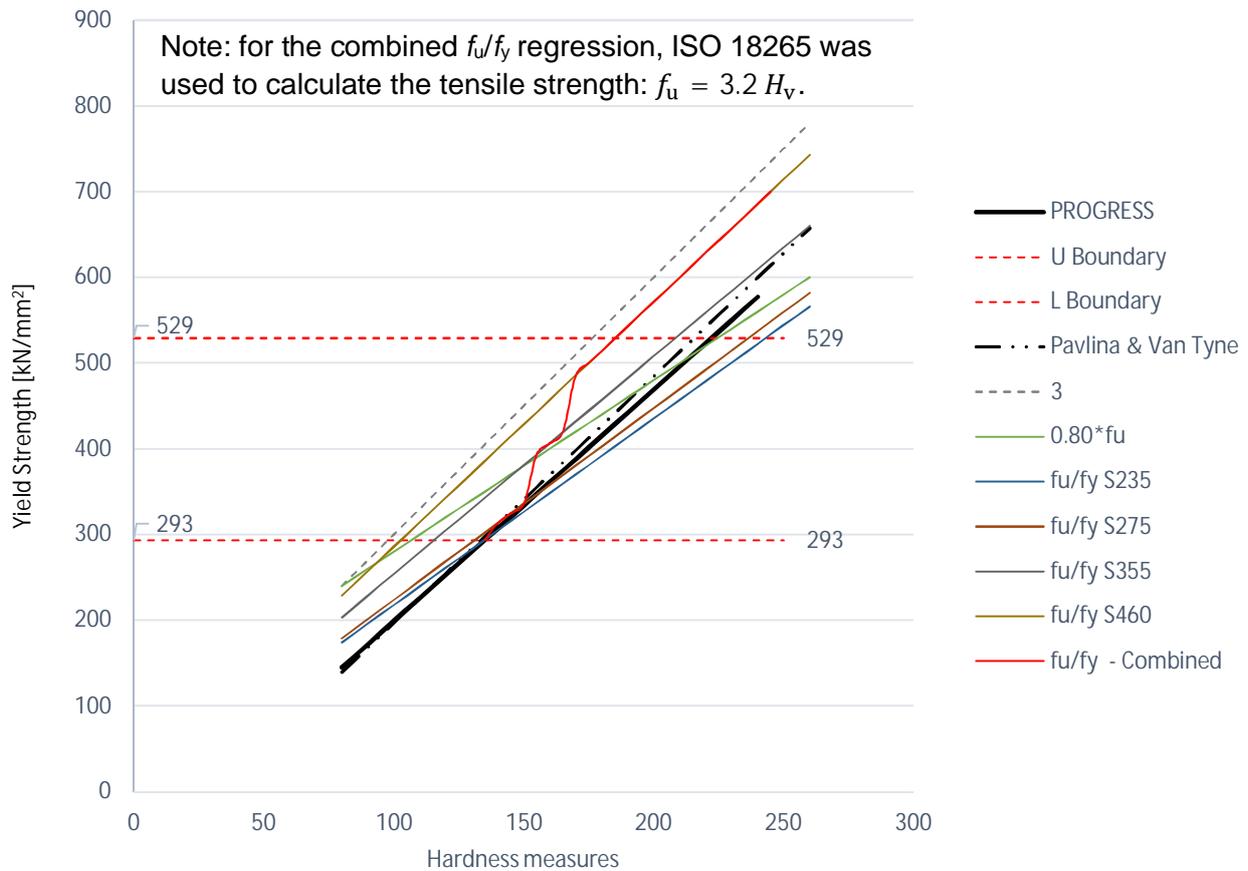
f_u is the ultimate strength

EN ISO 18265 [66] can also be used to estimate ultimate strength based on hardness values. The rule from ISO 18265 can be approximately represented by: $f_u = 3.2 H_v$. This method tends to be less conservative than the one proposed above for the range of tensile strengths to be tested.



Annexes Figure 2. Comparison between correlation for tensile strength and hardness measures.

There is no standard method to calculate the yield strength from hardness measures. However, some references can be found in literature. As a rule of thumb, a ratio of 3 between yield strength and hardness measures can be found. Others report that keeping a ratio of 0.8 between yield and tensile strength is reasonable. Reference [67] proposes a linear regression as follows: $f_y = 2.876 H_v - 90.7$. Bearing in mind the data from section E.2, the mean relationships between tensile and yield strength can be used as benchmarks to assess the proposed method. A combined regression is presented in Figure 3 below where data from S235, S275, S355 and S460 is used. It can be shown that the proposed method is reasonable in comparison with literature and steel data from section E.2.



Annexes Figure 3. Comparison between correlation for yield strength and hardness measures.

Correction factors need to be applied according to EN ISO 6507-1 [50] for curved surfaces.

E.6 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 $k_n = 1.76$ (from Table E.12)

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

If $H_v = 160.6$, then:

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

and:

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

According to Table E.10 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.

E.7 Destructive tensile tests: non-statistical and statistical testing regimes

E.7.1 General guidance for destructive testing

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

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

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

The tensile destructive tests shall be performed according to EN ISO 6892-1 [56]. As a reference, test sample locations may be defined according to ISO 377 [55]. Guidance from the relevant product standard may be also followed, for examples, EN10025 or EN10219.

The declared yield strength, tensile strength and elongation should be based on the results of the destructive tests, not on the non-destructive tests. The declared yield strength and tensile 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.

As a remark, it should be noticed that if a reclaimed element does not comply with a certain product standard, such as EN 10025-2, the element can still be used as long as the relevant material properties are declared, as requested by EN1090-2 section 5.1. As an example, if the elongation at failure measured by a destructive test does not comply with the minimum values from EN10025-2 for a specific steel grade, but if the measured elongation is such that the minimum values from EN 1993-1-1 for elastic global analysis are fulfilled, the reclaimed steel can still be reused.

E.7.2 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 E.3. 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.

E.7.3 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 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 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 EN 1990 for “ V_x known”, presented as Table E.13.

Table E.13 Values of k_n for the 5% characteristic value (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 (and proposed for publication in the revised version of EN 1993-1-1).

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

Annex F Testing: impact toughness - adequacy assessment

F.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 EN 10025-1, six samples are required for testing purposes, taken from locations identified in Annex A of EN 10025-1.

For every 20 tonnes in a batch, one set of tests (six samples) from one single member should be used to determine the Charpy value for all members in that batch. The Charpy test should be performed according to EN ISO 148-1 [57].

Annex G Testing: chemical composition - adequacy assessment

G.1 Introduction

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

G.2 Non-destructive tests to determine 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.

The chemical composition may be assessed according to BS ISO 19272 [96].

G.3 Destructive tests to determine chemical composition

The chemical composition of the steel can be determined 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 7.4*), no statistical analysis should be undertaken.

The chemical composition may be assessed according to EN ISO 14284 [58].

Annex H Inspection: geometric tolerances - adequacy assessment

H.1 General guidance

Geometric properties and tolerances can be verified by adequate methods such as laser scanning, LIDAR or photogrammetry. LIDAR (Light Detection and Ranging technique) is a surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. LIDAR is sometimes called 3D laser scanning, a special combination of a 3D scanning and laser scanning.

H.2 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 2.2*), the measured dimensions should be used to determine the cross-sectional properties.

H.3 Bow imperfections (lack of straightness)

The straightness of every member, in both axes, should be measured and compared with the permitted deviations in EN 1090-2. Members falling outside the permitted deviations should be straightened as part of the fabrication process. See also section 4.9.2.

Annex I Withdrawn product standards

The product standards presented in the next sections may be of interest for re-certifying the reclaimed steel based on building age and location. This is also intended to map existing documentation with current product standards such as EN 10025.

I.1 European overview

Table I.14 Withdrawn European product standards.

| Designation according to EN 10025-2:2004 | Equivalent former designations in | | | | | | | | | | |
|--|-------------------------------------|----------------------------|---------------------------------|---------------------------------|-------------------------------------|-------------------------------|-----------------------------|-----------------------------------|--------------------------------------|------------------------------|---------------------------------|
| | According to EN 10025:1990 +A1:1993 | According to EN 10025:1990 | Germany according to DIN 17 100 | France according to NF A 35-501 | United Kingdom according to BS 4360 | Spain according to UNE 36-080 | Italy according to UNI 7070 | Belgium according to NBN A 21-101 | Sweden according to SS 14 to NP 1729 | Portugal according to M 3116 | Norway according to steel grade |
| S185 | 1.0035 | S185 | St 33 | A 33 | A 310-D | Fe 320 | A 320 | Fe 310-0 | St 320 | | |
| | | S235JR | St 37-2 | E 24-2 | | Fe 360 B | AE 235-B | Fe 360-B | | | NS 12 120 |
| | | S235JRG1 | USI 37-2 | | AE 235 B-FU | | | | | | NS 12 122 |
| S235JR | 1.0038 | S235JRG2 | RSI 37-2 | E 24-3 | 40 B | Fe 360 BFN | AE 235 B-FN | | | | NS 12 123 |
| S235J0 | 1.0114 | S235J0 | St 37-3 U | | 40 C | Fe 360 C | AE 235 C | Fe 360-C | | | NS 12 124 |
| ^a | | S235J2G3 | St 37-3 N | E 24-4 | 40 D | Fe 360 D1 | AE 235 D | Fe 360-D | | | NS 12 124 |
| S235J2 | 1.0117 | S235J2G4 | -- | | | Fe 360 D2 | | | | | |
| S275JR | 1.0044 | S275JR | St 44-2 | E 28-2 | 43 B | Fe 430 B | AE 275 B | Fe 430-B | | | NS 12 142 |
| S275J0 | 1.0143 | S275J0 | St 44-3 U | E 28-3 | 43 C | Fe 430 C | AE 275 C | Fe 430-C | | | NS 12 143 |
| ^a | | S275J2G3 | St 44-3 N | E 28-4 | 43 D | Fe 430 D1 | AE 275 D | Fe 430-D | | | NS 12 143 |
| S275J2 | 1.0145 | S275J2G4 | -- | | | Fe 430 D2 | | | | | |
| S355JR | 1.0045 | S355JR | -- | E 36-2 | 50 B | Fe 510 B | AE 355 B | Fe 510-B | | | |
| S355J0 | 1.0553 | S355J0 | St 52-3 U | E 36-3 | 50 C | Fe 510 C | AE 355 C | Fe 510-C | | | NS 12 153 |
| ^a | | S355J2G3 | St 52-3 N | | 50 D | Fe 510 D1 | AE 355 D | Fe 510-D | | | NS 12 153 |
| S355J2 | 1.0577 | S355J2G4 | -- | E 36-4 | 50 DD | Fe 510 D2 | | | | | |
| ^a | | S355K2G3 | -- | | | Fe 510 DD1 | | | | | |
| S355K2 | 1.0596 | S355K2G4 | -- | | | Fe 510 DD2 | AE 355-DD | Fe 510-DD | | | |
| S450J0 | 1.0590 | | | | 55C | | | | | | |
| E295 | 1.0050 | E295 | St 50-2 | A 50-2 | A 490 | Fe 490 | A 490-2 | Fe 490-2 | | | |
| E335 | 1.0060 | E335 | St 60-2 | A 60-2 | A 590 | Fe 590 | A 590-2 | Fe 590-2 | | | |
| E360 | 1.0070 | E360 | St 70-2 | A 70-2 | A 690 | Fe 690 | A 690-2 | Fe 690-2 | | | |

^a When a product is delivered in the N condition +N shall be added to the designation (see 4.2.2).

I.2 UK overview

Table I.15 Historical British Standards covering the specification of UK structural steel.

| BS | Date | Title |
|------------|------------------------|---|
| BS15 | 1906, 1912, 1930, 1936 | Standard Specification for Structural Steel for Bridges and General Building Construction |
| CF(15)7376 | 1941 | War Emergency revision to BS15 |
| BS15 | 1948 | Structural steel |
| BS15 | 1961 | Mild Steel for General Structural Purposes |
| BS546 | 1934 | High Tensile Structural Steel for Bridges and General Building Construction |
| 968 | 1941 | (War emergency standard) High Tensile (Fusion Welding Quality) Structural Steel for Bridges and General Building Purposes |
| 968 | 1962 | High Tensile (Fusion Welding Quality) Structural Steel for Bridges or General Building Purposes |
| BS 4360 | 1968, 1972, 1979 | Weldable Structural Steels |
| 1 | 1901 | First attempt to standardise steel sections |
| 4 | 1904 | Structural steel sections |
| 449 | 1932, 1959 | Use of structural steel in buildings |
| CP 113 | 1948 | The structural use of steel in buildings |
| 4360 | 1968 | Weldable structural steels (superseded 15 and 968) |

From 1903, when British Standard 4 was first issued, all the tables in the various historical handbooks, refer to British Standard Sections, though at various times since 1903 some steel sections have been imported and used which do not conform to British Standards. The most notable of these are Broad Flange Beams rolled on the continent of Europe.

In 1972 British Standard 4848 Part 4 (Metric Equal and Unequal angles) was issued. These metric sizes replace the imperial sizes in British Standard 4. Details of metric angles and their properties are contained in the Constrado publication "Structural Steelwork Handbook - Metric Angles to BS4848 Part 4 1972" published in 1973.

The second major development was the issue of British Standard 4 Part 1 in 1980. This updated previous issues of BS4 to correct minor inaccuracies and to cover the properties of Universal Beams, which (as at 1980) all have parallel flanges. Again, all the details given in BS4 Part 1 1980 are

included in the BCSA/Constrado publication "Structural Steelwork Handbook - Sections to BS4 Part 1".

For steel design, 5950, which succeeded 449 in 1985, uses partial safety factors to cover variations in material quality, structural performance and applied loads. A material factor (γ_m) of 1.0 has been adopted for structural steel. As far as loading is concerned, the make-up of the partial load factor is as described in Section 4.6.3 of BS5959. The structural performance factor, γ_{f3} , takes account of rolling tolerances on the steel, together with inaccuracies of design, fabrication and erection.

Where welding is to be undertaken on an existing structure, as part of repair or strengthening, it is necessary to check that the original material is of a suitable composition and condition. 5135, now withdrawn, contains a useful formula for establishing the weldability of steel in terms of a 'carbon equivalent' value taking account of other elements present including manganese. It will often be worthwhile to seek specialist advice on weldability and welding techniques, particularly for older steel which may contain higher levels of sulphur and phosphorus than is permitted in more recent steel specifications.

Annex J Assessment and design of old metallic materials

J.1 General considerations

The focus of this protocol is “modern” steelwork, produced and erected after 1970. However, in this annex provisions for assessing and design with older materials are provided. This section is also intended to justify the consistency of the proposed testing protocol. For instance, questions may arise about why when using non-statistical testing, the elongation is justified by one representative destructive test. However, it is clear that there is no actual concern in the minimum requirements to design according to Eurocode 3 based on available data for old materials presented in this section.

Often the evidence from visual inspection and dating will, with experience, be conclusive in identifying cast, wrought iron or steel. However, testing procedures from previous annexes are recommended to confirm the material provenance.

J.2 Overview of old materials characteristics and main period of use

As a reference, a summary of the material characteristics based on the period of use can be found below. This may be a way forward for structural metallic materials erected before 1970.

Table J.16 Characteristic values of old structural steel and iron – adapted from [32]

| Material | Period of use ¹⁾ | f_{yk} ²⁾ [N/mm ²] | f_{uk} ²⁾ [N/mm ²] | G [N/mm ²] | E_k ²⁾ [N/mm ²] | ϵ_{uk} ²⁾ [%] | v | ρ [kg/m ³] | α_T [10 ⁻⁶ /°C] | f_y/f_u |
|--------------------------|-----------------------------|--|--|---------------------------|---|--------------------------------------|--------------------|--------------------------------|--------------------------------------|-----------|
| Cast iron ³⁾ | Before 1900 | 70-200 ⁴⁾ | 120-600 | 29000 | 78000 | <0.8 | 0.26 ⁵⁾ | 7250 | 10 | 1.71 |
| Wrought iron | 1850-1900 | 220 | 320 | 77000 | 200000 | 15 | 0.30 | 7800 | 10 | 1.45 |
| Mild rimmed iron | 1890-1900 | 220 | 320 | 77000 | 200000 | 25 | 0.30 | 7800 | 10 | 1.45 |
| | 1900-1940 | 235 | 335 | 81000 | 210000 | 25 | 0.30 | 7800 | 10 | 1.42 |
| Mild steel | 1925-1969 | 235 | 360 | 81000 | 210000 | 25 | 0.30 | 7850 | 10 | 1.53 |
| Connections: | | | | | | | | | | |
| Welds | 1900-1924 | - | 300 | - | - | - | - | - | - | - |
| | 1925-1969 | - | 360 | - | - | - | - | - | - | - |
| | From 1970 | - | +360 ⁶⁾ | - | - | - | - | - | - | - |
| Rivets: wrought iron | 1850-1900 | - | 320 | - | - | 18 | - | - | - | - |
| Rivets: Mild rimmed iron | 1890-1940 | - | 320 | - | - | 28 | - | - | - | - |
| Rivets: Mild steel | From 1925 | - | 350 | - | - | 30 | - | - | - | - |

1) Main phase of manufacture; 2) Parallel to the direction of rolling; characteristic value; elongation at failure; 3) Cast iron with lamellar graphite in accordance with EN 1561 [126]; 4) Conventional value of 0.1% ultimate strain, since cast iron has no yield range; 5) Average value for different type of cast iron; 6) At least equal to the base material.

It is unlikely that steels with a characteristic yield strength lower than 235 N/mm² are found before 1970. Further guidance about old materials may be found in: SCI P138 – “Appraisal of existing Iron and Steel Structures” and BCSA - “Historical structural steelwork handbook”.

For design with old materials, SIA 269/3 [32] may be used as a reference.

J.3 Visual characteristics of cast and wrought iron, and steel

Table J.17 Visual characteristics of cast and wrought iron, and steel – 1/2 [59]

| Visual characteristic | Grey cast iron | Wrought iron | Steel |
|---------------------------------|--|--|---|
| Surface texture (uncorroded) | ‘Gritting’ or pitted from mould Possible ‘blowholes’ Possible straight lines or ‘steps’ from junction of half moulds (e.g. diametrically opposite along axis of hollow circular column) | Smooth | Smooth Possible millscale |
| Surface texture (corroded) | Uniformly rough; ‘powdery’ rather than ‘flaky’ | Possible ‘delamination’, with rust layers flaking off like puff pastry (flat sections) or triangular wedges (rods) - see Figure 6.3 | Possible ‘delamination’ as for wrought iron, usually on flat sections only |
| Fracture surface | Crystalline, bright (new) or grey (old) | Fibrous (crystalline if fatigue failure) | Slightly fibrous or striated (crystalline if fatigue failure) |
| Element cross-sectional profile | Typically ‘chunky’ with relatively thick sections, often ornate or complex profile (fluted or plain hollow circular or cruciform columns, ,I,I or polygonal beam sections) | ‘Crisp’ profile, typically ●, ,I,L,T, or Z section or compound riveted section; joists and channels usually thicker than steel members | Thin ‘crisp’ profile, typically ●, ,I,U,L, or T section, solid or hollow circular or rectangular columns, or compound riveted or welded section |
| Corners of element | External corners sharp, typically 90°; re-entrant corners rounded | Outer flange corners sharp, often less than 90°; ‘toe’ and ‘root’ corners rounded | As wrought iron, except for recent I-sections (sharp 90° external corners) |
| Flange section | Rectangular, or polygonal in beams with typically larger tension flange and small or absent compression flange (see Figure 3.2) Flange width or thickness may vary along element (largest at midspan) | Usually tapered flanges on I-sections, thickest at web; equal flange sizes Constant flange section along element | As wrought iron, except for recent I-sections (which have parallel flanges) Constant flange section along element |

Table J.18 Visual characteristics of cast and wrought iron, and steel – 2/2 [59]

| Visual characteristic | Grey cast iron | Wrought iron | Steel |
|-----------------------------|---|--|--|
| Element elevational profile | Usually varies along length; beams often have 'fish-belly or 'hump-backed' web profile and integral web stiffeners; columns often have ornate Classical heads with spigots and extended ledges or 'tables' supporting beams, baseplates and intermediate stiffeners; other elements often ornate and complex Beams and columns may have intermittent openings in web | Constant along length unless compound beam(s) or plate girder when web profile may vary (plate girders only) and flange plates increase in number and size towards midspan Openings in web usually stiffened (if original) by L or T framing on all sides | As wrought iron; recent plate girders may have web and flange plates of various thicknesses and depths butt-welded together As wrought-iron, also castellated and cellular beams in recent construction |
| Section size | Large beams (over say 10 m) often cast in sections, bolted together at flanged junctions | I-sections up to 20 inches (508 mm) deep, occasionally slightly more; deeper sections invariably built-up riveted plate girders; columns built-up from I-section, angles, and plates; small tees and channels | I-sections up to 3 feet (914 mm) deep; solid circular columns up to 1 foot (305 mm) diameter; hollow tubular columns up to around 18 inches (457 mm) side length |
| Connection methods | Typically bolts (often square-headed); beams often tied together at column heads by wrought iron 'shrink rings' fitted around cast-on beam lugs | Rivets for all built-up sections; bolts (often square-headed); flats, bars and rods sometimes hammer-welded together in older structures; cotters and wedges for tie-rods | Rivets (up to 1950s); bolts in clearance holes (earlier square, later hexagonal heads); welding (20th century); close tolerance bolts (since First World War); high strength friction grip bolts (since 1950s) |
| Identification on element | Maker's name and location often cast onto element (e.g. on web of beam, in plaque at foot of column); occasionally load capacity also indicated | Rarely, at intervals on rolled sections; cast iron plaque sometimes attached to major elements (bridges, roof structures) | Often, at intervals on rolled sections; BS 15 used to require that "every piece of steel shall bear the maker's name or trade mark" (excepting bars and small pieces) while BS 548 (high tensile steel) required this plus "the letters H.T." (to distinguish it from mild steel). |

J.4 UK overview of old materials characteristics and main period of use

Table J.19 shows the main periods of structural use of iron and steel in the UK. With this data, it can be pointed out that the reclaimed metallic elements from the construction industry in the XX century are likely to be mild steel or modern steel. In a transition period between 1880 and 1900, composite elements made of wrought iron and mild steel were common.

Table J.20 Main periods of the structural use of cast and wrought iron, and steel in the UK [59]

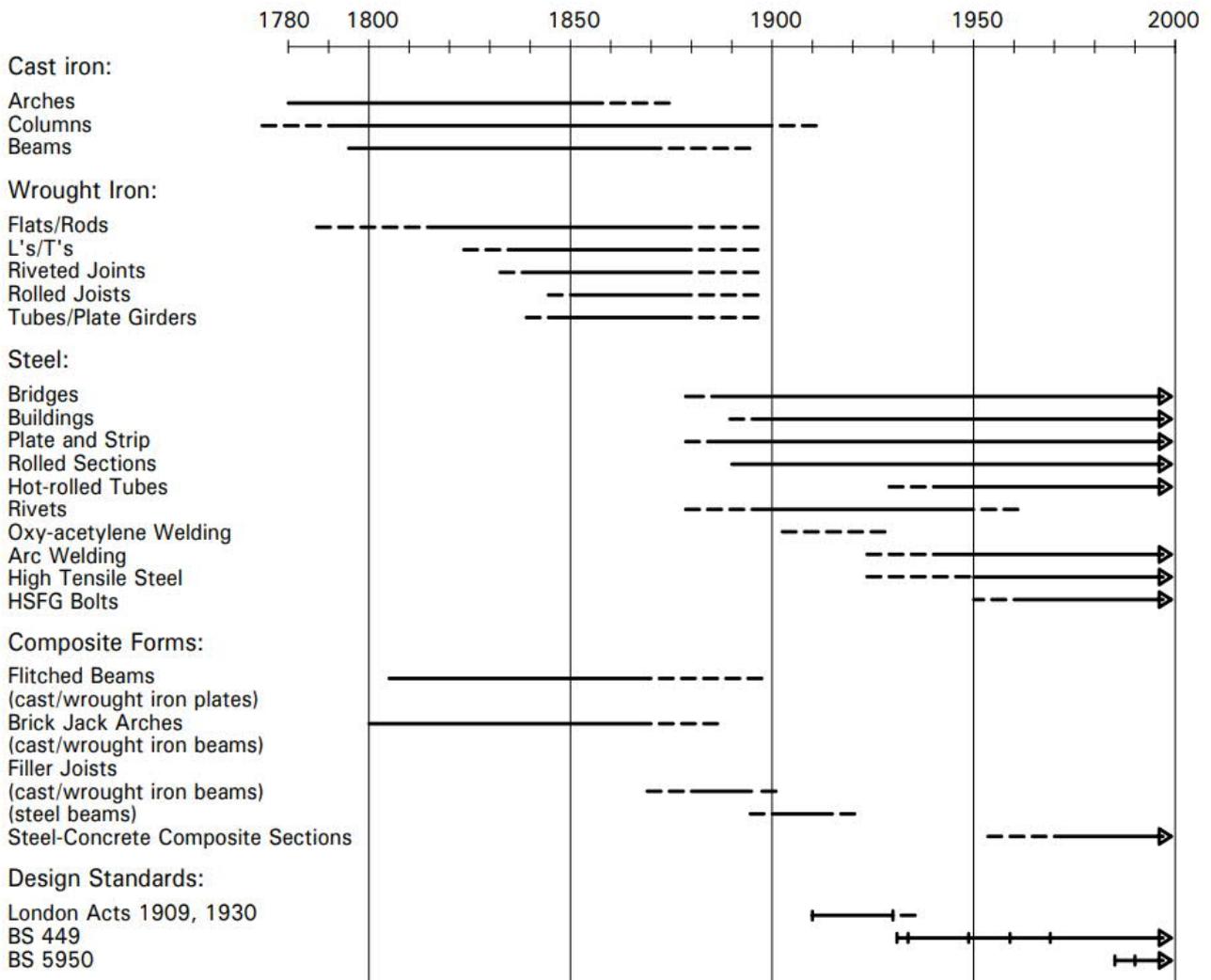


Table J.21 Typical properties of structural grey cast iron [59]

| Property (values in N/mm ² unless noted) | Typical values (or range of values) | Notes |
|--|--|---|
| Ultimate tensile strength: Lowest Mean Highest | 65-100 123 150-280 | Results from various authorities ⁽²²⁾ and various section sizes; typical strain at failure 0.5-0.75% ⁽³⁷⁾ |
| Flexural tensile strength (modulus of rupture): Rectangular bars not exceeding 1 inch (25.4 mm) wide Rectangular bars 3 inches (76.2 mm) wide Round bars 1 inch (25.4mm diameter) Round bars 2 inches (50.8 mm) diameter I-beams of various section sizes Bridge beams | 315 208 355 309 116-232 116-134 | Typical values from Ref. 22 " " " " " " " " " " " " " " " " Ref. 21 |
| Ultimate compressive strength | 587-772 | Ref. 22; squat specimens |
| Ultimate shear strength | Not less than UTS | Ref. 22 |
| Young's modulus (kN/mm ²) Tension Compression | 66-94 84-91 | Cast iron is neither isotropic nor linear-elastic, and these are secant modulus values from Ref. 22; modulus falls with increasing stress |
| Modern grade 150 grey cast iron | 69-103 | Ref. 37 |

Ref. 21 – [117]

Ref. 22 – [118]

Ref 37 – [119]

Table J.22 Tensile strengths of modern grey cast iron (from 1452:1990) [59]

| Grade and minimum tensile strength of separately cast sample (N/mm ²) | Casting section thickness (mm) | Expected tensile strength of sample from casting (N/mm ²) | Expected tensile strength of cast-on sample (N/mm ²) |
|---|--------------------------------|---|--|
| 100 | 2.5-10 | 120 | * |
| | 10-20 | 90 | * |
| 150 | 2.5-10 | 155 | * |
| | 10-20 | 130 | * |
| | 20-40 | 110 | 120 |
| | 40-80 | 95 | 110 |
| | 80-150 | 80 | 100 |
| | 150-300 | * | 90 |
| 180 | 2.5-10 | 185 | * |
| | 10-20 | 160 | * |
| | 20-40 | 135 | 150 |
| | 40-80 | 115 | 135 |
| | 80-50 | 100 | 125 |
| | 150-300 | * | 100 |
| 200 | 2.5-10 | 205 | * |
| | 10-20 | 180 | * |
| | 20-40 | 155 | 170 |
| | 40-80 | 130 | 150 |
| | 80-150 | 115 | 140 |
| | 150-300 | * | 130 |

* Not quoted

Table J.23 Typical properties of structural wrought iron (UK) [59]

| Property (values in N/mm ² unless noted) | Typical value (or range of values) | Notes |
|---|------------------------------------|---|
| Ultimate tensile strength (and flexural tensile strength) | 278-593 | Ref.22; values are for tension parallel to direction of working i.e. parallel to slag strands - UTS normal to this direction is about two-thirds to three-quarters of these values; UTS is increased by cold-working, with substantial reduction in ductility |
| | 309-386 | BS 51:1939 ⁽⁴⁰⁾ , now withdrawn |
| Ultimate compressive strength | 247-309 | Ref.22 |
| Ultimate shear strength | At least two-thirds of UTS | Ref.22 |
| Young's modulus (kN/mm ²) | 154-220 | Ref.22 |
| Elastic limit | 154-408 | Ref.22; higher values are achieved by cold-working, with a substantial reduction in ductility |
| Elongation at failure (%) | 7-21 | Ref.22; other sources give ranges of 4-36%(sic) depending on degree of working |
| Poisson's ratio | 0.25 | Ref.22 |

Ref. 22 – [118]

Table J.24 Typical properties of structural steel before 1906 (UK) [59]

| Property (values in N/mm² unless noted) | Typical value (or range of values) |
|---|---|
| Ultimate tensile and compressive strength | 386-494 |
| Ultimate shear strength | Three-quarters of UTS |
| Young's modulus (kN/mm ²) | 200-205 |
| Elastic limit | 278-309 |
| Elongation at failure (%) | 18-20 |
| Poisson's ratio | 0.26-0.34 |

Table J.25 Properties of structural steel prescribed by British Standards since 1906 until 1968 (UK)

| Property (values in N/mm² unless noted) | Typical value (or range of values) | Notes |
|---|---|---|
| Ultimate tensile strength: | | |
| BS 15: 1906 | 432-494 | BS 15 covered mild steel |
| BS 15: 1912-1941 | 432-509 | |
| BS 15: 1948-1961 | | |
| Rivet bar | 386-463 | |
| Other | 432-509 | |
| BS 548: 1934-1942 | | |
| Rivet bar | 463-540 | BS 548 covered high tensile steel |
| Other | 571-664 | |
| BS 968: 1941 | As BS 548: 1934 | BS 968 covered weldable high tensile steel |
| BS 968: 1943 | 509-633 | |
| BS 968: 1962 | 494-602 | |
| Yield strength: | | |
| BS 15: 1948-1961 | 225-235 | No change in UTS. No requirements for rivet bar; values depended on steel thickness, being lower for thicker sections |
| BS 15: 1961-1968 | 230-250 | |
| BS 548: 1934-1942 | 293-355 | |
| BS 968: 1941 | As BS 548: 1934 | |
| BS 968: 1943 | 293-324 | |
| BS 968: 1962 | 340-355 | |
| Elongation at failure (%): | | |
| BS 15: 1906-1941 | | |
| Rivet bar | 25 (min.) | |
| Other | 20 (min.) | |
| BS 15: 1948-1961 | | |
| Rivet bar | 26-30 | Cold bend test |
| Other | 16-24 | |
| BS 548: 1934-1942 | | |
| Rivet bar | 22-27 | |
| Other | 14-18 | |
| BS 968: 1941-1943 | | |
| Plates | 14-18 | |
| Sections and bars | 14-22 | |
| BS 968: 1962 | | |
| Standard test pieces | 15-23 | |

Annex K Evaluation procedure for reuse of sandwich panels

| | |
|--|--|
| <p>General</p> | <p>Here is given rules for evaluation of potential for reusing sandwich panels, dismantled after being in use for a considerable amount of years. The reason for dismantling the panels should be a change of the use of the building, not a failure in the panels. For the evaluation of safety aspects for reuse, the rules in EN 1990 (safety factors) and rules in harmonized product standard EN 14509 [133] for type testing essential properties are used. Type testing is used in EN 14509 as name for the testing where the declared values for all essential characteristics are done and following rules in EN 14509. A basic requirement for a limited amount of testing is that the name of manufacturer is known and a copy of original declared values (values given by the manufacturer) is known. This might limit the use of reduced testing program for panels older than 25 years, because of the lack of common known rules, unless they have been produced under national type approvals with an existing type testing and third-party control. For other cases a full testing program following rules in EN 14509 is recommended.</p> |
| <p>Main evaluation criterion</p> | <p>The evaluation of potential to reuse sandwich panels are:</p> <ul style="list-style-type: none"> -Architectural or aesthetical based -Performance based; evaluation of essential properties as in EN 14509 |
| <p>Aesthetical aspects</p> | <p>For this purpose, color change of the surface or damages in surface is visually observed</p> |
| <p>Mechanical strength and safety</p> | <p>The mechanical panel properties to be declared and to be determined based on Type Testing are according to EN 14509:</p> <ul style="list-style-type: none"> -wrinkling strength, -shear strength and shear module, -creep coefficient (for permanent loads only) -compression strength and compression module; -tensile strength and tensile module, -durability properties -tolerances <p>For further processing the reference level of mechanical properties are the values declared by the manufacturer at the time of delivery of the panels. This reference level is further called as zero level.</p> <p>The evaluation of the possible degradation of the panel mechanical properties is first evaluated by comparing the level of cross panel tensile strength to the zero level. If considerable degradation (over 10 % lower characteristic value compared to the declared value) is noticed, the panel shear strength and compression strength is tested. The characteristic value of the panel shear strength, determined on panels sampled from the panels</p> |

| | |
|-------------------------------------|--|
| | <p>dismounted is the value used for design when reusing the panels. The other properties used by design are</p> <ul style="list-style-type: none"> -The mean value of the shear module measured from the panels to be reused. -For wrinkling strength and compression strength and module the originally declared values are reduced with the ratio of the characteristic shear strength to the originally declared shear strength. This procedure is evaluated to be conservative as the experience is that the ageing is affecting mostly cross panel tensile strength and panel shear strength. Results from testing dismantled panels at the end of 90'ies indicate that the ageing rate of wrinkling strength is approximatively the half of the ageing in shear strength. <p>The level of material safety factors is suggested to be the same as determined based on original type tests. In principle a lower level could be possible as the expected life time of the panels to be reused is lower than when originally installed. As there is little knowledge on this behavior today, the original material safety values are suggested to be used.</p> <p>It is suggested to test samples taken from dismantled panels for testing cross panel tensile strength as specified in EN 14509 chapter A.1. The number of samples should be at least 3, preferable 10. The density of the samples is measured from samples taken close to the samples for tensile strength.</p> |
| <p>Tensile strength and density</p> | <p>The characteristic value of tensile strength is compared to originally declared value. If there is degradation in the level of less than 10 %, the panels can be reused using the originally declared properties for all mechanical strength properties. If the degradation is more than 10 % a set of samples for testing shear strength and module and compression strength and module should be taken. At least 3 samples each should be taken, preferably 5 for shear and 10 for compression tests.</p> |
| <p>Shear strength</p> | <p>The shear strength and shear module are tested for the samples taken from the dismantled panels. If the degradation in tensile strength is not more than 10%, one shear test is performed. The test result shall be at least the same as the declared value. The full scale of tests is performed if the cross panel tensile strength has degradation more than 10 % compared to original declared tensile strength. The characteristic value is calculated for the shear strength. This value is used for the design of the panels to be reused.</p> |
| <p>Compression strength</p> | <p>The compression strength is tested for the samples taken from the dismantled panels. The tests are performed if the cross panel tensile strength has degradation more than 10 % compared to original declared tensile strength. The characteristic value is calculated for the compression strength. This value is used for the design of the panels to be reused.</p> |

| | |
|--|--|
| <p>Bending moment/Wrinkling strength</p> | <p>For the bending moment or wrinkling strength, the originally declared value can be used if the tensile strength has degradation less than 10 %. If the degradation is higher either the wrinkling strength is reduced with the same ratio as the shear strength is in comparison to the originally declared shear strength, or the wrinkling strength is tested for panels sampled from the dismantled panels. The characteristic value of test results is then used in design when reusing the panels.</p> |
| <p>Material safety factors</p> | <p>The material safety values determined by the original type testing is used. Alternatively, the safety values determined from the tests on dismantled panels can be used calculated as given in EN 14509 chapter A.16.</p> |
| <p>Durability properties</p> | <p>Need of repeating testing of durability is actual only if there is degradation of tensile strength more than 10 %. In that case only the short-term durability testing (14 days, see EN 14509 Annex B, clause B.2.4, for all other core types than mineral wool and 7 days for mineral wool core, see EN 14509 Annex B, clause B.3.4) shall be done. For panels with core of mineral wool the degradation shall be less than 15 % and for all other types less than 17 %.</p> |
| <p>Tolerances</p> | <p>The tolerances are visually inspected and if deviation noticed checked that the panels are fit for reuse</p> |
| <p>Thermal behavior</p> | <p><u>PU panels</u>: If there is reduction in closed cells ratio (see ISO 4590) for PU is decreased with 10%, the thermal conductivity shall be retested and a new design value shall be determined (EN 14509, clause A.10).</p> |
| <p>Fire safety</p> | <p>Only panels with core materials with fire retardants shall be retested for the small flame behavior. This is to check that the effect of fire retardants is still active. Otherwise a reclassification might be needed. The panels are fit for use where fulfilling the requirements in the project for reuse.</p> |

| | |
|---|---|
| <p>Summary on evaluation procedure for reuse of sandwich panels. For more information on testing see EN 14509. Mechanical strength Testing cross panel tensile strength 3 samples a minimum (EN 14509, A.1): Calculate characteristic result for tensile strength Testing one sample for shear strength (EN 14509, A.3 or A.4)</p> | |
| <p>Evaluation: Tensile strength $\geq 0,9^*$ Declared value of Tensile strength and Shear strength \geq Declared value of Shear strength</p> | <p>If YES; No further testing. All declared values for mechanical strength can be used</p> <p>If NO; New declared values to be determined with a test program according to EN 14509 for -Tensile strength -Compression strength -Shear strength The wrinkling strength is reduced with same amount that shear strength is reduced.</p> |
| <p>Durability</p> | |
| <p>Tensile strength $\geq 0,9^*$ Declared value of Tensile strength</p> | <p>If YES; No further testing; panels are fit for use</p> <p>If NO; <u>Miwo panels:</u> The 7 days testing (see EN 14509 clause B.3.4) is to be done. The reduction in tensile strength after ageing shall not exceed 15 % of the mean value of the tensile strength in ambient temperature <u>For all other panel type</u> the procedure in EN 14509 Annex B.2 is followed so that the panels are tested 14 days in the temperature as described in B.2.4. The reduction in tensile strength after ageing shall not exceed 17% of the mean value of the tensile strength in ambient temperature</p> |
| <p>Tolerances; damages evaluated by visual inspection</p> | <p>If no serious damages or faults found; Panel can be reused</p> <p>If serious damages are found causing weakness in strength, in insulation behavior or tightness of joints then those panels are rejected</p> |
| <p>Moisture content</p> | <p>If no notable wetness of core material found the panels can be reused</p> |
| <p>Thermal behavior</p> | |
| <p>For PU panels: Closed cell ratio $\geq 0,9^*$ closed cell ratio by type testing and change in density less than 10 %</p> | <p>If YES; no further testing; original thermal conductivity value can be used</p> <p>If NO; new test for determining thermal conductivity is to be done following rules in EN 14509 chapter A.10.</p> |

| | |
|-------------|---|
| Fire safety | Small flame tests (see EN 14509 clause C.1.2) to be done with core material including fire retardants. The classification is checked and if needed reclassified. The panels are fit for use where fulfilling the requirements in the project for reuse. |
|-------------|---|

Annex L Evaluation procedure for the reuse of light gauge steelwork

L.1 General considerations

The success rate of reclaiming secondary light gauge steelwork is likely to be much lower in comparison with primary hot rolled steelwork. This is due to the fact that cladding is usually fixed with a considerable number of connectors. However, in this section, recommendation for sampling and testing procedures for light gauge elements are proposed.

L.2 CE marking of reclaimed light gauge cold formed elements

L.2.1 CE marking

The re-certification of non-constituent light gauge cold formed elements is allowed by clause 5.1 of EN1090-4 [108]. It is stated that *“If constituent products that are not covered by the standards listed in Clause 5.3 are to be used their properties shall be specified”*. The following properties were identified as required for an appropriate product recertification:

1. Yield strength or 0,2 %-proof strength ($R_{eH}/R_{p0,2}$);
2. Tensile strength (R_m);
3. Elongation after fracture A80 mm in %;
4. Bend radius to thickness ratio, if relevant;
5. Adhesion of metallic coating;
6. Tolerances on dimensions and shape, including minimal thickness;

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

7. A maximum limit for the carbon equivalent of the steel, or;
8. A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated.

L.2.2 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 EN 1090.

In addition to careful control of the fabrication process, material properties must be declared according to EN 1090-4 clause 5.1. When using reclaimed steel, this is the stockholder's responsibility.

L.2.3 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.

The requirements of EN 1090-4 and the testing regime for reclaimed steelwork are discussed in Section L.2.4.

L.2.4 Material properties to be declared for reclaimed cold formed steelwork

The test regime for cold formed steelwork is intended to allow the necessary material properties according to EN 1090-4 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 L.26.

Table L.26 Proposed material properties to be declared – based on EN 1090-4

| Item | Property | To be declared | Procedure |
|--|---|---|---|
| 1 | Yield strength or 0,2 %-proof strength ($R_{eH}/R_{p0,2}$) | Yes | Determined by destructive tests. |
| 2 | Tensile strength (R_m) | Yes | Determined by destructive tests. |
| 3 | Elongation after fracture A80 mm in %; | Yes | Determined by destructive tests. |
| 4 | Tolerances on dimensions and shape, including minimal thickness | Yes | Based on dimensional survey. |
| 5 | Bend radius to thickness ratio, if relevant | If required | If required, determined by destructive tests. |
| 6 | Metallic coating composition, designation and layer mass and thickness | Yes | If required, determined by non-destructive or destructive tests and visual inspection |
| 7 | Adhesion of metallic coating | Yes | Based on visual inspection |
| In addition, if the steel is to be welded, its weldability shall be declared as follows: | | | |
| Item | Property | To be declared | Procedure |
| 8 | A maximum limit for the carbon equivalent of the steel, or; | If required (usually not required as welding procedures are often not used) | Maximum to be declared from manufacturer's test certificates. |
| 9 | A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated | | Determined by non-destructive and destructive tests. |

Section L.2.5 provides a commentary on each material property that must be declared.

L.2.5 Commentary on the required properties

Yield strength & Tensile strength

The same conclusions from section 2.5.1 of this document are applicable.

It is not expected that cold formed light gauge elements erected before 1970 suitable for reuse can be found.

According to EN 10346 [109], the tensile tests shall be performed without coating, in the test direction given in Tables 7 to 11 and section 7.2.5.2 of the same standard.

Elongation after fracture

The same conclusions from section 2.5.2 of this document are applicable.

According to EN 10346, the tensile tests shall be performed without coating, in the test direction given in Tables 7 to 11 and section 7.2.5.2 of the same standard.

Geometric tolerances and limitations

The geometric tolerances on dimensional shape shall comply with EN 10143 [110].

EN 1993-1-3 [116] specifies minimum thicknesses for cold formed elements.

The following limits must be respected:

- For sheeting and members: $0.45\text{mm} \leq t_{\text{cor}} \leq 1.5\text{mm}$
- Connections: $0.45\text{mm} \leq t_{\text{cor}} \leq 4\text{mm}$

Where t_{cor} is the plate thickness without any coating material.

According to EN 1993-1-3 section (2), if thicker or thinner materials are used, the load bearing resistance need to be determined by a design assisted by testing.

According to EN 1090-4, the following minimum thicknesses shall apply:

Profile steel sheets:

Decking: $t_{\text{N}} \geq 0.75 \text{ mm}$

Roof coverings: $t_{\text{N}} \geq 0.50 \text{ mm}$

Floors: $t_{\text{N}} \geq 0.75\text{mm}$

Walls and wall claddings:

Outer skin: $t_{\text{N}} \geq 0.50 \text{ mm}$

Single skin or inner skin: $t_{\text{N}} \geq 0.50 \text{ mm}$

Liner trays: $t_{\text{N}} \geq 0.75\text{mm}$

Structural members:

Purlin: $t_N \geq 0.88 \text{ mm}$

Spacer profiles in roofs and walls: $t_N \geq 0.75 \text{ mm}$

Edge stiffening profiles: $t_N \geq 1.00 \text{ mm}$

Edge trims: $t_N \geq 0.75 \text{ mm}$

Restraint members: $t_N \geq 0.88 \text{ mm}$

t_N is the nominal thickness of the element (with the coating system).

In addition to the referred requirements, EN1090-2 and EN1090-4 tolerances must be respected.

Bend radius to thickness ratio

As the reclaimed steelwork is already bent, there is no need to specify this property. A visual inspection to assess possible cracks and the adhesion of metallic coating nearby the bend region shall be undertaken for each reclaimed element.

Metallic coating composition, designation and layer mass

The composition of the metallic coating needs to be specified according to EN 10346. Section 3 from EN 10346 specifies the key chemical components for each coating type. All members must be tested by non-destructive test procedures.

| Coating type | Description EN 10346 section 3 | Characteristics EN 10346 section 3 | Appearance EN10346 section 7.4 |
|--------------|--|--|--|
| Z | application of a zinc coating by immersing the prepared strip in a molten bath of zinc | The zinc content is at least 99%. | Normal spangle (N): The finish is obtained when the zinc coating is left to solidify normally. Either no spangle or zinc crystals of different sizes and brightness appear depending on the galvanizing conditions. The quality of the coating is not affected by this. If a pronounced spangle is desired, this shall be indicated specially at the time of enquiry and order. Minimized spangle (M): The finish is obtained by influencing the solidification process in a specific way. The surface will have reduced spangles, in some cases, not visible to the unaided eye. The finish may be ordered if the normal spangle does not satisfy the surface appearance requirements. |
| ZF | application of a zinc-iron coating by immersing the prepared strip in a molten bath of zinc and a subsequent annealing | The zinc content of the bath is at least 99%. The annealing produces an iron-zinc coating with an iron content of normally 8 % to 12 %. | The regular zinc-iron alloy coating results from heat treatment in which iron diffuses through the zinc. The surface has a uniform matt grey appearance. |
| ZA | application of a zinc-aluminium coating by immersing the prepared strip in a molten bath of zinc-aluminium | The composition of the bath is approximately 5% aluminium, small amounts of mischmetal and the balance zinc. | The coating finish has a metallic lustre that is the result of unrestricted growth of the zinc-aluminium crystals during normal solidification. Crystals of different sizes and brightness may appear depending on the manufacturing conditions. The quality of the coating is not affected by this. |
| ZM | application of a zinc-magnesium coating by immersing the prepared strip in a molten bath of zinc-aluminium-magnesium | The composition of the bath is sum of aluminium and magnesium from 1,5 % to 8 %, containing minimum of 0,2 % magnesium and the balance zinc. | Due to the normal solidification of the coating, the surface has a uniform metallic appearance and may be slightly matt to bright. It may also show variations in appearance and a tendency to darkening. |
| AZ | application of an aluminium-zinc coating by immersing the prepared strip in a molten bath of aluminium-zinc-silicon | The composition of the bath is 55% of aluminium, 1,6% of silicon and the balance zinc. | The products are supplied with a normal spangle. Normal spangle is a coating finish, having a metallic lustre, which is the result of unrestricted growth of the aluminium-zinc crystals during normal solidification. If a pronounced spangle is desired, this shall be indicated specially at the time of enquiry and order. |
| AS | application of an aluminium-silicon coating by immersing the prepared strip in a molten bath of aluminium-silicon | The composition of the bath is 8 % to 11 % silicon and the balance aluminium. | Deviating from other hot-dip coated products, a relatively pronounced (Al-Fe-Si) alloy layer is formed over the base material during hot-dip coating. This shall be taken into account for further processing. If a maximum value for the mass of this layer is required, this shall be especially agreed upon at the time of enquiry and order. The test method is described in Annex C of EN 10346. |

For the coating layer weight assessment, section 7.3 from EN 10346 must be considered. The single spot minimum coating mass value may be used to assess the actual coating designation according to EN 10346 section 7.3.

For coating thickness assessment, recommendation from EN10346 section 7 shall be applied.

EN 13523-1 [111], Coil coated metals — Test methods — Part 1: Film thickness.

Adhesion of metallic coating

For many purposes, the adhesion test has the objective of detecting any adhesion less than “perfect”. For such a test, one uses any means available to attempt to separate the coating from the substrate. This may be prying, hammering, bending, beating, heating, sawing, grinding, pulling, scribing, chiselling, or a combination of such methods. If the coating peels, flakes, or lifts from the substrate, the adhesion is less than perfect.

Existing steelwork was already bent. Therefore, visual inspection for assess this. There shall be no cracks at the bended areas visible by the naked eye (EN1090-4 section 6.1).

Relevant standards for bending tests:

EN 13523-6 [112], Coil coated metals — Test methods — Part 6: Adhesion after indentation (cupping test) EN 13523-7 [113], Coil coated metals — Test methods — Part 7: Resistance to cracking on bending

EN 10346 section 7.10 specifies that adhesion of the coating shall be testing by using “an appropriate method”, referring that the selection of the method is “left to the discretion of the manufacturer”.

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. For cold forming products, EN 10346 may be used, where in table 2 of the same standard the chemical composition for steels for construction is presented. Table 6 of EN 10346 presents permissible deviations of the product analysis are provided.

The intent of this declaration is to enable the carbon equivalent value (CEV) to be calculated, which is a key measure of weldability.

L.3 Design recommendations

The design recommendations from section 4 shall be considered.

For Class C reclaimed steelwork, as a wide range of steel grades are likely to be available, it is not recommended to assumed a yield and tensile strengths of more than 120 MPa and 260 MPa respectively. See EN 10346 section 7 and EN 1993-1-3 section 3 for more detail.

L.4 Assessment of reclaimed steelwork

Recommendation specified in section 5 are also applicable for cold formed light gauge elements.

L.5 Responsibilities of the holder of stock

Recommendation specified in section 6 are also applicable for cold formed light gauge elements.

The additional material properties described in section L.2.4 shall be specified. Annex C recommendation shall be adapted to cover the required properties for light gauge cold formed elements.

L.6 Test programme – comprehensive testing

The recommendations for comprehensive testing procedure (testing 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. Purlins and side rails and other type of elements shall be treated separately for each type of profile cross-section (as individual groups) with a maximum of 4 tonnes.

Non-statistical testing is not recommended for reclaimed cold formed steel elements.

Statistical testing requires destructive testing to assess material characteristics in accordance with EN 1990. Statistical testing exceeds the requirements for 'new' steel specified in the product Standard.

The table below relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition (if needed) according to the building Consequence Class.

Table L.27 – Testing approach related to Consequence class for cold formed light gauge steel

| 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 if required; usually not required as welding procedures are often not used with cold formed elements). | 3 | Statistical for yield strength, ultimate strength and elongation (maximum value of CEV) |
| CC2 | | 5 | Statistical for yield strength, ultimate strength and elongation (maximum value of CEV) |
| CC3 | | 7 | Statistical for yield strength, ultimate strength and elongation (maximum value of CEV) |

The use of hardness test to assess the likely steel grade for light gauge cold formed elements is possible according to ISO 6507-1 [50]. Appropriate considerations for the test force according to Annex A of ISO 6507-1 must be considered. To undertake hardness measure, coating system need to be removed. The testing area needs to be repaired by a zinc-rich spray.

Samples for destructive tests shall be collected from the profile webs, as far away as possible of any bent part. The coupons here can be simple strips of 250x20mm collected from different elements.

L.7 Fabrication issues

Light gauge cold formed elements are likely to be welding free. However, the disassembly process may cause damage to the steelwork. Problems with existing coating systems are not expected. However, the steelwork aging certainly reduced the coating mass (which will be affected by building/steelwork exposure environment). This means that coating mass for the subsequent life cycles are reduced, reducing the durability of the coating system. It is expected that the testing protocol will define the remaining/available coating mass for the reclaimed cold-formed steelwork.

L.8 Reliability assessment for light gauge cold formed elements

There is no available comprehensive data from tests to use as a reference to perform the reliability assessment of cold formed reclaimed steelwork. From the product standard, the data in table L.30 can be obtained for the characteristic values of yield and tensile strengths for the different steel grades according to EN 10346. The proposed minimum values for yield and tensile strength to be used for the reliability assessment are presented in table L.28.

Table L.28 Steel grade according to EN 10346.

| Steel grade | f_y [N/mm ²] | f_u [N/mm ²] | f_u/f_y | Elongation % |
|-------------|----------------------------|----------------------------|-----------|--------------|
| 220 | 220 | 300 | 1.36 | 20 |
| 250 | 250 | 330 | 1.32 | 19 |
| 280 | 280 | 360 | 1.29 | 18 |
| 320 | 320 | 390 | 1.22 | 17 |
| 350 | 350 | 420 | 1.20 | 16 |
| 390 | 390 | 460 | 1.18 | 16 |
| 420 | 420 | 480 | 1.14 | 15 |
| 450 | 450 | 510 | 1.13 | 14 |

Data from 46 tensile tests was collected from several resources. Mean values and coefficient of variation were calculated for each steel grade. The results used to produce table L.30 were derived from the values presented in table L.29. As buckling curves don't depend of the yield strength for cold formed elements, average values for mean strength (yield and tensile) and coefficient of variation are proposed for all steel grades up to S450.

Table L.29 Tensile test data

| Steel Grade | f_{yk} | | | | f_{uk} | | | |
|----------------|----------------|--------------|---------------|--------------|----------------|--------------|---------------|--------------|
| | Mean | Ratio | Sdev | COV | Mean | Ratio | Sdev | COV |
| S280 | 295.975 | 1.057 | 6.012 | 0.020 | 392.451 | 1.090 | 16.341 | 0.042 |
| S320 | 328.667 | 1.027 | 4.163 | 0.013 | 431.667 | 1.107 | 8.505 | 0.020 |
| S350 | 406.427 | 1.161 | 26.332 | 0.065 | 471.315 | 1.122 | 27.846 | 0.059 |
| S450 | 470.208 | 1.045 | 21.436 | 0.046 | 560.961 | 1.100 | 47.804 | 0.085 |
| Average | 375.319 | 1.073 | 14.486 | 0.036 | 464.098 | 1.105 | 25.124 | 0.051 |

Table L.30 Proposed values for the reliability assessment of cold formed elements to EN 10346.

| Steel grade | Yield Strength | | | | | Tensile Strength | | | | | |
|-------------|-------------------------------|------------------------|------|----------------------|----------------------|-------------------------------|----------------------|------|----------------------|----------------------|---------------------|
| | f_y [N/mm ²] | Mean | COV | Min | Mean | f_u [N/mm ²] | Mean | COV | Min | Mean | f_u / f_y mean |
| | | X characteristic value | | [N/mm ²] | [N/mm ²] | | [N/mm ²] | | [N/mm ²] | [N/mm ²] | |
| 220 | 220 | 1.100 | 0.04 | 226 | 242 | 300 | 1.10 | 0.05 | 303 | 330 | 1.364 |
| 250 | 250 | 1.100 | 0.04 | 257 | 275 | 330 | 1.10 | 0.05 | 333 | 363 | 1.320 |
| 280 | 280 | 1.100 | 0.04 | 288 | 308 | 360 | 1.10 | 0.05 | 364 | 396 | 1.286 |
| 320 | 320 | 1.100 | 0.04 | 329 | 352 | 390 | 1.10 | 0.05 | 394 | 429 | 1.219 |
| 350 | 350 | 1.100 | 0.04 | 360 | 385 | 420 | 1.10 | 0.05 | 424 | 462 | 1.200 |
| 390 | 390 | 1.100 | 0.04 | 401 | 429 | 460 | 1.10 | 0.05 | 465 | 506 | 1.179 |
| 420 | 420 | 1.100 | 0.04 | 432 | 462 | 480 | 1.10 | 0.05 | 485 | 528 | 1.143 |
| 450 | 450 | 1.100 | 0.04 | 463 | 495 | 510 | 1.10 | 0.05 | 515 | 561 | 1.133 |