Reusability of existing structural steel

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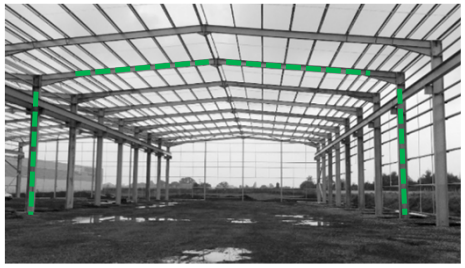
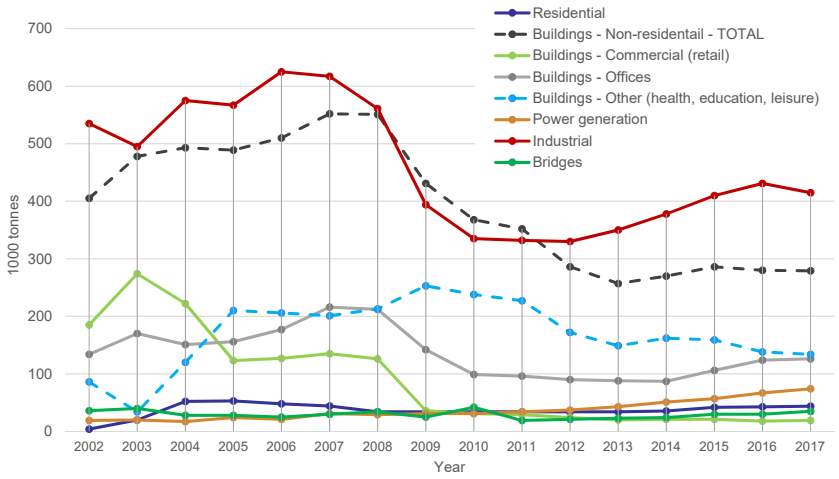
Why single-storey buildings?

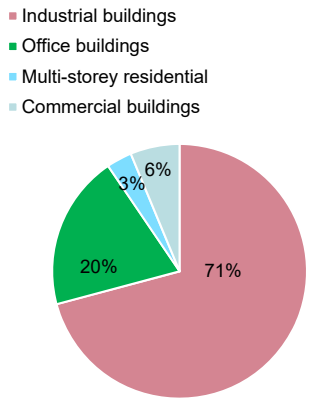
Particularly attractive for reclaiming and reusing structural steel:

- Use **dry and lean construction** systems that facilitate the deconstruction system (structural members are visually exposed);
- **Building layers easily detachable**;
- Have a **repetitive structural approach**, allowing good standardisation possibilities; opportunity to reclaim a significant number of members with the same cross section;
- Considerable member length on it's original form – **long spans** (free of major modifications);
- Members are **easily accessible** at relatively safe working heights;
- Are **readily disassembled** and can be **easily reassembled;**
- Each building component is **simple to document;**



Why single-storey buildings?





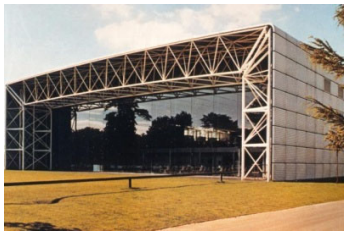
UK 2018

Hot rolled and fabricated profiles

FIGURES CREDITS: World Steel Association, European Steel Association, Primary Interviews, Grand View Research; SCI

Structural level of reuse

Constituent product (individual members)

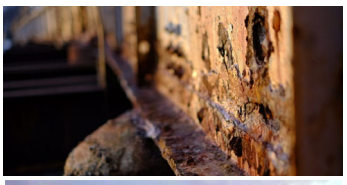


Structural component (truss system, cladding panel, etc.)

Whole structure or part of it

Scope of steel reuse

- All members to be reused should come from a **building** structure constructed after **1970;**
- **"Building" because groups of members can be easily pointed out,** based on cross section and structural application (say columns, rafters, bracings), minimizing testing costs;
- **1970 as a benchmark for current Eurocode design** rules and for tests used to specify those rules (buckling curves rely on testes from 1969-1989); material properties similar to the ones we use today;
- **Damage-free building structures**, i.e. structural members that have not been subjected to extreme-event limit state, e.g. large-scale earthquake, fire, fatigue etc.;
- Members to be reused shall **not have areas of accelerated localised corrosion** (> 5% thickness lost);
- Welded/built-up members of members with welded splices: **welds need to be tested** according to the execution standard (EN1090-2);



Most relevant barriers for reuse

1. The reclaimed material satisfies the **performance requirements**, which are the essential mechanical, physical, dimensional, chemical (CEV) and/or other relevant properties of steel **to ensure their adequacy to be used in structural design to EN 1993 (Adequacy assessment)**;

2. The salvaged material meets the **quality requirements** from nominal specifications to **ensure their reliability** to be used in the structural design to EN 1993 **(Reliability assessment)**;

3. Relevant material properties (and fabrication procedures if needed) need to be known and documented to **achieve CE marking (documentation & certification)**

Product conformity, quality and traceability

To which specific product standard was the material manufactured to? (say EN 10025-2 or EN10210)

- Check for **product conformity, quality and traceability**:
  - If **mill certificate/documentations is available**, it is **possible to trace back the reclaimed steel** and check if:
    - the steel meets the relevant material requirements
    - the steel meets all reliability requirements for design to EN 1993

    Note: this can be the case of a steelwork manufacturer by a non-EU standard
  - **Otherwise**, the **steelwork needs to be tested to justify material properties** and show it meets all the **reliability requirements** according to Eurocodes 3 design

    Note: it is expected that the steelwork available to be reclaimed will fall into this category.

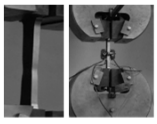
Material performance requirements – CE Marking

- Adequacy assessment for steelwork with no documentation – EN 1090 clause 5.1

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, 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.

Hardness testing

XRF spectrometer (Chemical analysis)

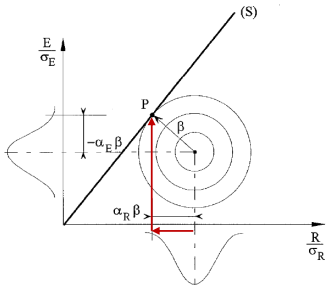


Tensile testing

Material quality assurance requirements

- Reliability assessment for steelwork with no documentation :
  - Use guidelines from RFCS *Safebrictile* project
  - Ensure that the required level or reliability by EN1990 is achieved while using EN1993 partial factors

Steel grade	Yield strength (N/mm²)		Ultimate strength (N/mm²)			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



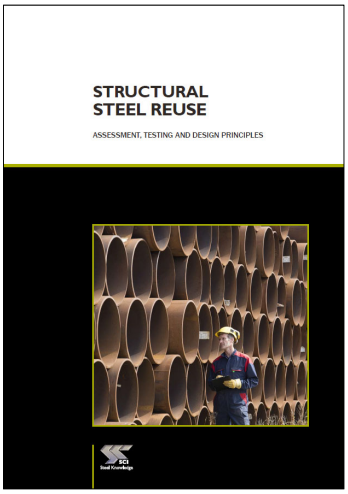
Eurocode 3 material partial factors rely on the fact that the mean values for yield and tensile strength are higher than the characteristic value. This is why we have a partial safety factors equal to 1 according to most of the European national annexes. While documenting reclaimed steel, this "overstrength" needs to be justified to allow reclaimed steel to be used in structural design to EN 1993.

Classification of reclaimed steel

- Reclaimed steelwork classes

	Class A	Class B	Class C
Classification	Original material test certificates are available and constitute evidence of conformity with the relevant product standard	Original material test certificates are not available. Comprehensive testing protocol is applied.	Original material test certificates are not available. Most conservative steel grade in accordance with structure age and location is adopted.
Adequacy assessment	**Optional minimal testing** Original material documentation used for the adequacy assessment. If required, minimum NDT can be carried out to confirm material provenance.	**Comprehensive testing** Reclaimed steel is tested for the adequacy assessment. All required material characteristics are justified according to EN1090-2 section 5.1 shall be justified and declared.	***No adequacy assessment***
Reliability assessment	**Original certification** Original inspection documents are available and it is possible to trace back the material and ensure that it meets the relevant product standards	**Material re-certified** Reclaimed steel is tested and it is demonstrated that it meets all reliability requirements (frequency of testing to be specified in the protocol)	***No reliability assessment***

Sampling and material testing – SCI P427



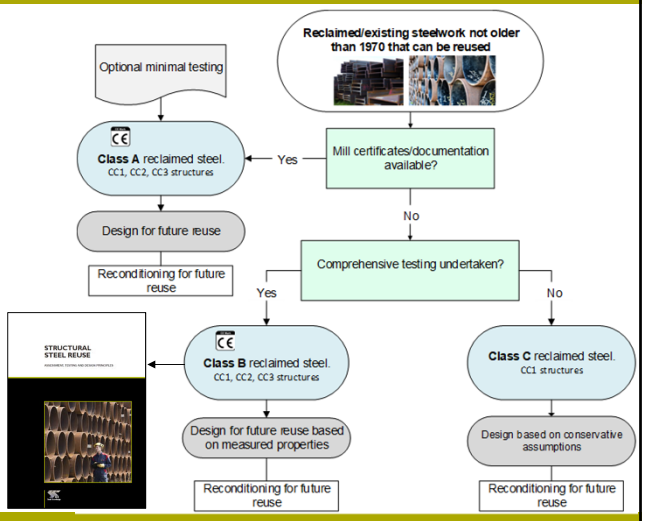
1. **Categorise structural members by <u>groups</u>** (from the same building), e.g. according to size, structural function (beam columns, bracing); 20 tonnes is the maximum group weight – similar to current EN10025 requirement;
2. **100% Non-destructive testing (NDT)** for each group (hardness & spectrometer) in combination with limited **Destructive testing (DT)**;
3. **Sampling for DT:** Regions of reduced stress to minimise the effects of reduced area, e.g. flange tips at beam ends for simply supported beams; detailed testing procedures provided and how to evaluate results;
4. **Destructive testing** for each group to confirm mechanical and chemical properties of reclaimed steel (**<u>Class B</u>**);
   - **<u>CC1 and CC2: one coupon</u>** from each test unit;
   - **<u>CC3: three coupons</u>** from each test unit;
5. **Guidance about how to handle test data provided**, ensuring that appropriate uncertainties from the test procedures are accounted for;

Sampling, material testing and geometric tolerances

- Testing protocol for reclaimed steel

	Reclaimed steel work		
	Class A	**Class B**	**Class C**
Programme of material testing	Optional	Mandatory	—
Non-destructive testing	10% (randomly)	100%	(CEV if steel to be welded)
Destructive testing (per test unit, 20 tonnes)	—	• 1 test (coupon for tensile and CEV) for CC1 • 3 tests (coupons for tensile and CEV) randomly selected for CC3	—

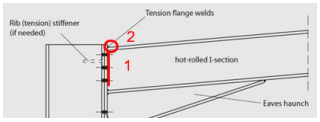
- Geometric tolerances according to EN1090-2 need to be assessed and documented.

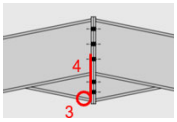


Adequacy of fabrication procedures – CE Marking

- Adequacy assessment for steelwork with no documentation – Welds
  - Visual inspection of 100% of the welds is mandatory; testing according to EN 1090-2 as a minimum requirement;
  - Following percentages of connection to be tested are recommended:

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%



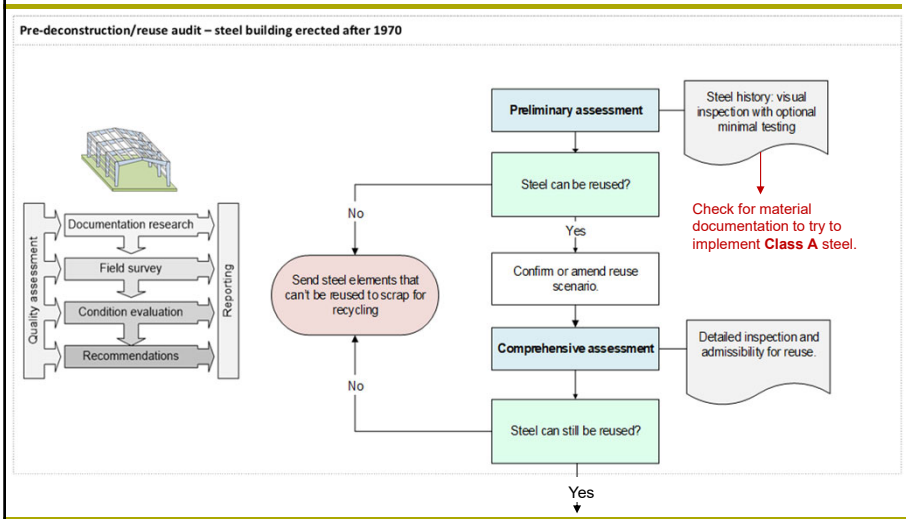


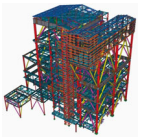
Portal framed structure with pinned bases subjected to gravity loading:

1. Eaves connections: between the beam web and the end plate;
2. Eaves connections: welds between the top flange and the end plate;
3. Apex connection: welds between the bottom flange and the end plate;
4. Apex connection: welds between the web and the end plate;

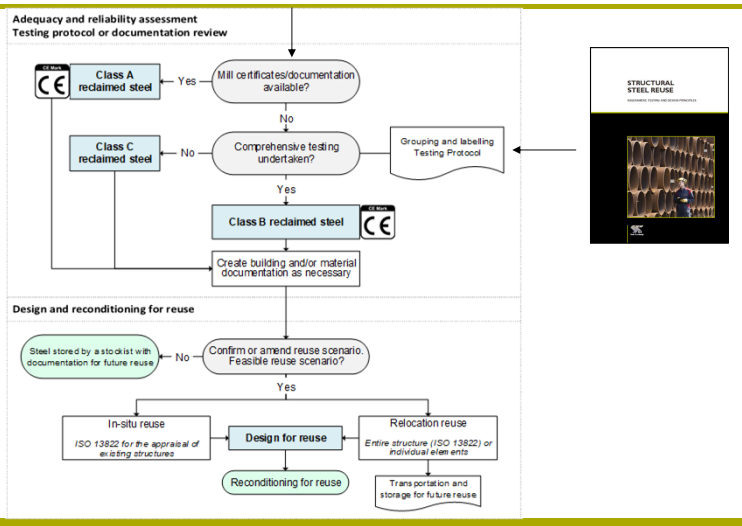
Each one of these welds represent a possible test sample.
50 rafters from 25 frames (200 critical connections).
30 welds should be tested by non-destructive tests (NDT).
These 30 welds should be selected randomly from the critical welds identified.
Every weld to be tested should ideally be selected from a different element.

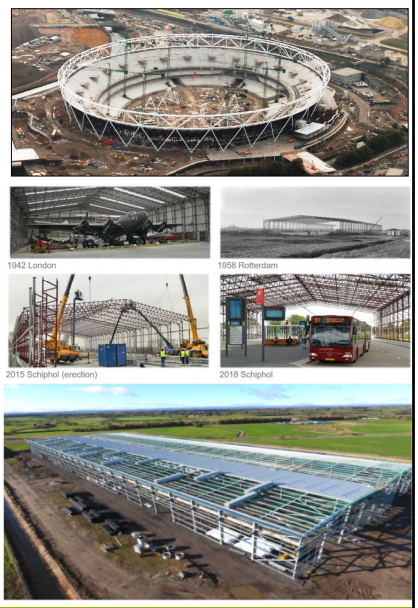
Assessment



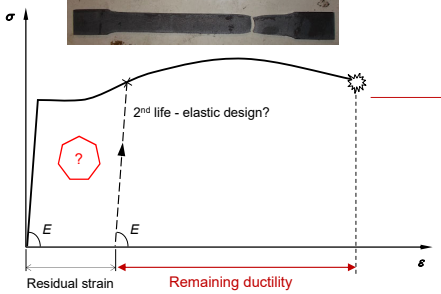


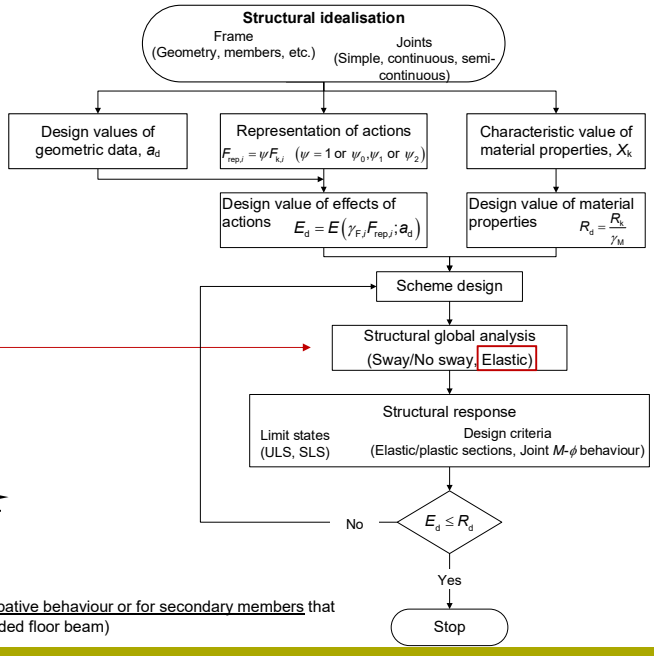
Testing





Design overview





Global plastic analysis is **not** recommended while using reclaimed steel;
Applications with seismic action are restricted to structures with a low dissipative behaviour or for secondary members that take no part for horizontal stiffness and stability of the building (e.g., pin-ended floor beam)

Design overview

Partial factors for resistance:

- Reclaimed steel members are expected to perform as intended for new steel, without accounting for any material property changes (these do not deteriorate with time, as long as there is no fatigue); no concerns with cross sectional resistances.

- Although steel members have to meet the **geometric tolerances from EN 1090-2, cross-sectional imperfections and member imperfections (mainly due to imprecisions during the geometric assessment) may still affect the member buckling resistance**; increase reliability to account for such uncertainty; see SCI P427 for more detail; Values for UK practice are:

$$\gamma_{M0} = 1.0 \qquad \gamma_{M1,mod} = \mathbf{1.15} \qquad \gamma_{M2} = 1.1$$

Design overview

Partial factors for actions:

- It is common practice to lower the required safety level when evaluating and upgrading an **existing structure**, as long as the **human safety levels are not exceeded → shorter design life**

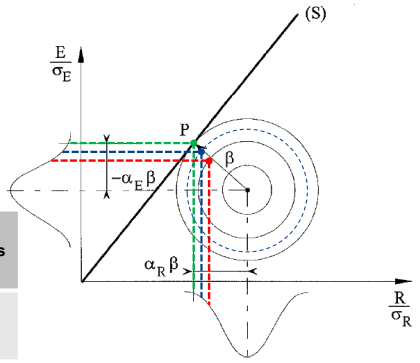
- If need be, assume a **shorter design life for designs with reclaimed steel, say 15-30 years**, and compensate for the lower partial factors by a **high level of quality management and control/inspection** (only recommended for scenarios where the **whole structure is relocated or for existing structures**)

- For reuse of existing steelwork on **new structures, standard reliability levels according to Eurocode 0 are recommended**; adjusting members/frames spacing of number of buckling restraints may be used to allow for reclaimed steel reuse;

Design overview

Partial factors for actions:

- **Shorter design life**, say 15 to 30 years (not 50 as usual):
  50 years → $\beta = 3.8$
  15-30 years → $\beta = 3.3$ → K_{FI} =0.90
  Minimum for human Safety → $\beta = 2.5$ (ISO 13822)



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_{FI} = 0.9)	Eq. 6.10 (not 6.10a and 6.10b)	1.215 $G_{k,j,sup}$	1.0 $G_{k,j,inf}$	1.35 $Q_{k,1}$	1.35 $\Psi_{0,i}$ $Q_{k,i}$

- Equivalent to say that an **Utilization Factor of** ~1.11, say **1.10, is acceptable for in situ reuse of existing buildings or for relocations**;

Testing and Design procedures overview

Property/procedure	Reclaimed steelwork class		
	Class A (with documentation)	**Class B (no documentation)**	**Class C (no assessment)**
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; $k_{\gamma Mi}$ – The material partial factor is adjusted with a factor $k_{\gamma Mi}$. $\gamma_{Mi,mod}$ is obtained by $K_{\gamma Mi}$ x γ_{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.

Final remarks

1. Steel buildings, in particular single storey buildings, can be easily dismantled and their elements reclaimed; large quantities of the same cross section with a considerable length free of modifications;
2. Steel is a high reusable material; properties don't deteriorate over time; there are opportunities for re-fabricating reclaimed steel as done for new steel;
3. Most issues can be overcome: justify material properties; documentation to CE marking
4. Design to EN 1993:
   - Restriction to elastic global analysis; no application to primary structural systems for seismic design, unless the structure is classified as low dissipative structure;
   - Reliability: use $\gamma_{M1,mod}$=1.15 and possibility of using lower partial factors for actions for existing building or relocations;

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