Good practices in design for reuse

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28/05/2020

SCI Steel Knowledge

European Commission

Research Fund for Coal & Steel

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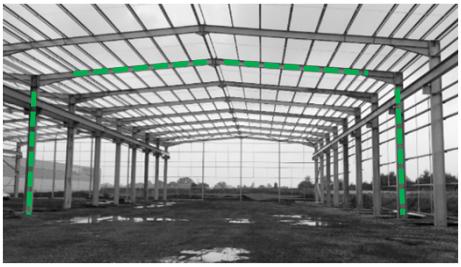
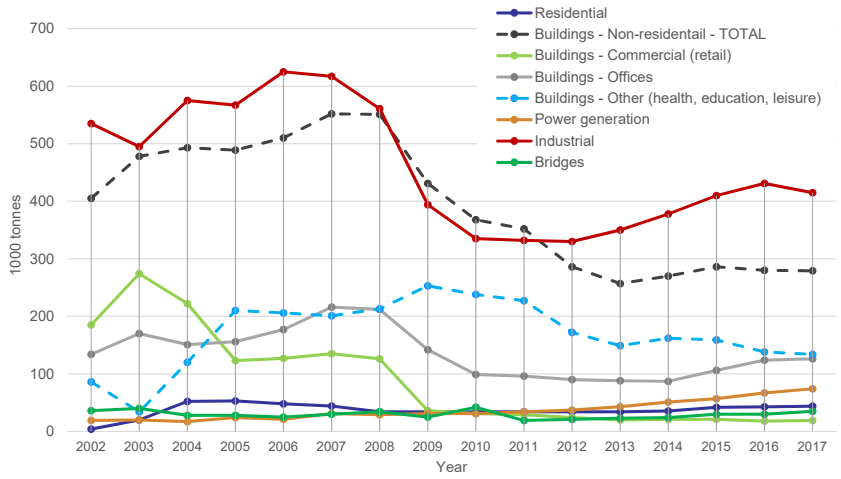
Why single-storey buildings?

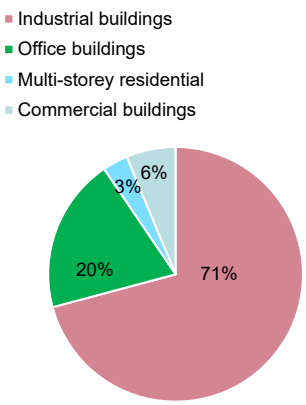
Particularly attractive for reclaiming and reusing structural steel:

- Use **dry and lean construction** systems that facilitate the deconstruction process (members are visually exposed);
- Most of the **building layers are easily detachable**;
- Have a **repetitive structural approach;** significant number of members with the same cross section;
- Considerable member length on it's original form – **long spans** (members free of major modifications);
- Members are **easily accessible**;
- 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

Reuse of existing steelwork

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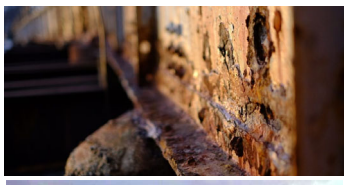
Scope of steel reuse

- 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);



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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)**


CE

01234

Any Co Ltd, PO Box 21, B-1050

03

01234-CPD-00234

EN 10025-1

Hot rolled structural steel products.

Intended uses: Building constructions or civil engineering.

Tolerances on dimensions and shape: Plate EN 10029 Class A

Elongation

Tensile strength

Yield strength : Steel S355J0 – EN 10025-2

Impact strength

Weldability

Durability: No performance determined

Regulated substance: No performance determined

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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 manufactured 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 most of steelwork available to be reclaimed will fall into this category.

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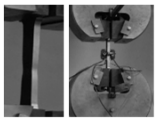
Material performance requirements – CE Marking

- 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

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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*

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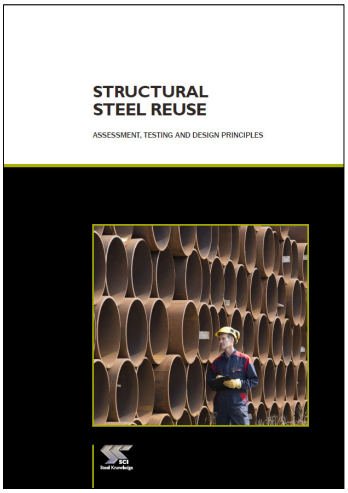
Sampling and material testing – SCI P427



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;

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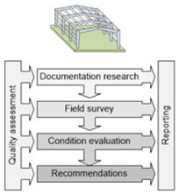
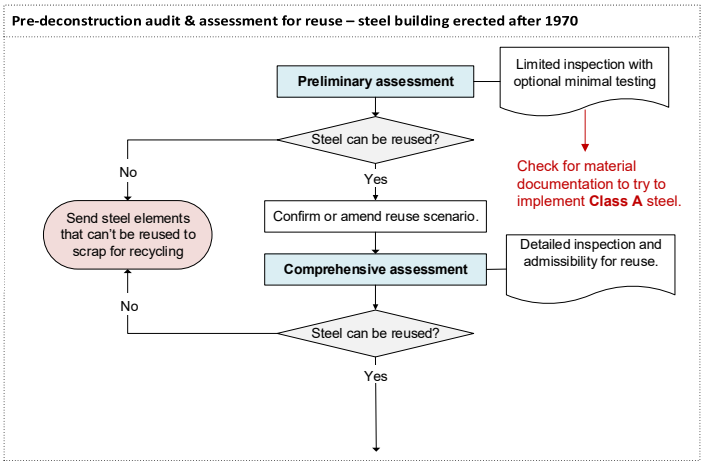
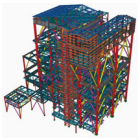
Assessment







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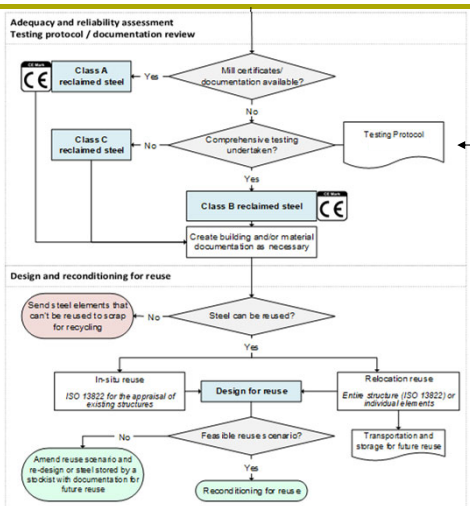
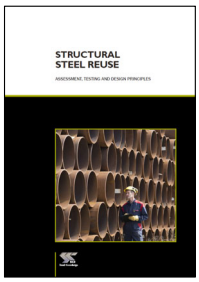
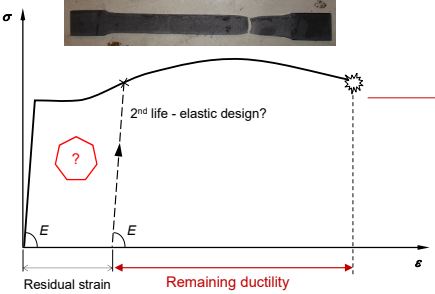
Testing and design

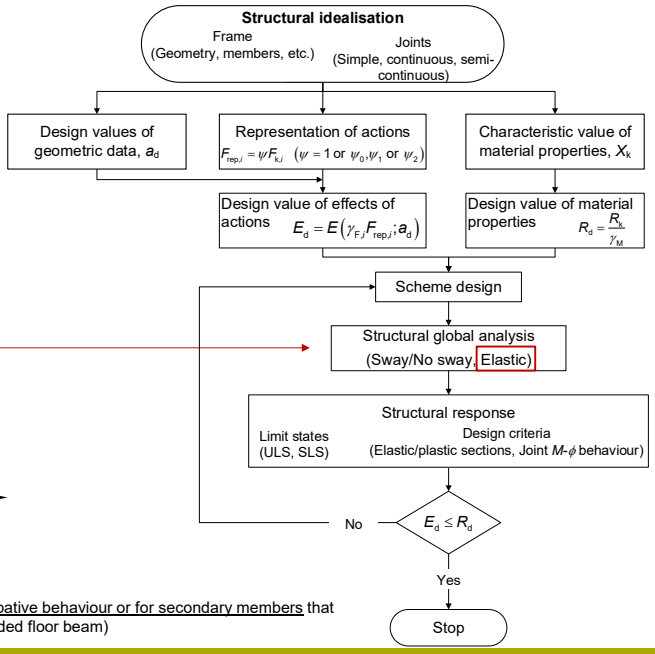




SCI P427

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

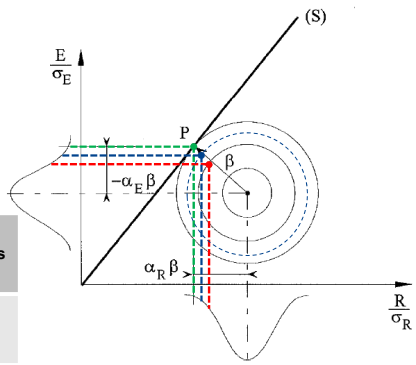
Partial factors for actions:

- **Shorter design life**, say 15 to 30 years (not 50 as usual):

  50 years → β = 3.8

  15-30 years → β = 3.3 → K_{FI} =0.90

  Minimum for human Safety → β = 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**;

New buildings: design for reuse

Single storey buildings overview

- Structural systems: portal frames

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Single storey buildings overview

- Structural systems: trussed solutions (longer spans; heavier loads)

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Single storey buildings overview

- SCI Publications: best practice for portals and connections

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Key concepts for steel reuse

- Standardization (building geometry, detailing, etc.)
- Reduce number of interfaces (number of building layers)
- Reduce number of components (members; connections)
- Design for adaptability and relocation
- Design and detailing for construction, deconstruction and transportation

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Reduce interfaces

- Avoid secondary structure (if possible) – long span cladding

Long span roof claddings (Finland)

Long span roof claddings (Finland)

Deep decking system (Portugal)

FIGURES CREDITS: https://www.ruukki.com/; http://www.afaconsult.com/;

Good practices in design for reuse

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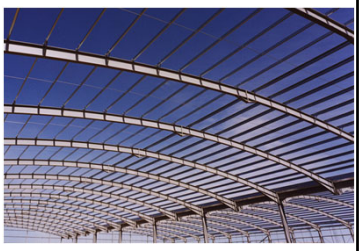
Reduce number of diferente components and materials

- Fewer robust members
- Reduce number of different cross-sections
- Reduce number of materials (steel-grades, subgrades)



FIGURES CREDITS: https://www.steelconstruction.info

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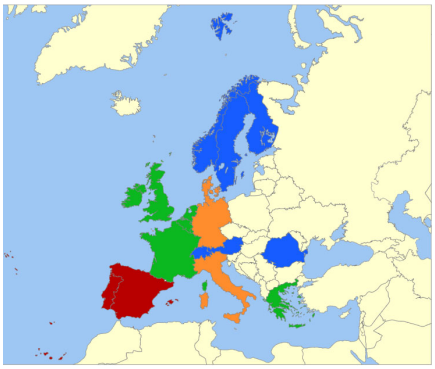
Design for adaptability and relocation

- Environmental loads: snow

Country	s_k (kN/m^2)			Class
	Min.[a)]	Country average[b)]	Min. European value	
Finland	2.00	2.75	2.00	S1
France	0.45	**0.65**	**0.70**	S3
Germany	0.45	0.85	1.00	S2
Ireland	0.40	**0.55**	**0.70**	S3
Italy	0.60	1.00	1.00	S2
The Netherlands	0.70	**0.70**	**0.70**	S3
Norway	1.50	3.50	2.00	S1
Portugal	0.10	0.30	0.40	S4
Romania	1.50	2.00	2.00	S1
Spain	0.30	0.40	0.40	S4
Sweden	1.50	2.50	2.00	S1
United Kingdom	0.45	**0.65**	**0.70**	S3

a) Assuming the average altitude for the less critical zone of the country
b) Assuming the average altitude for the zone representing most area of the country



European snow load classes

FIGURES CREDITS: Progress

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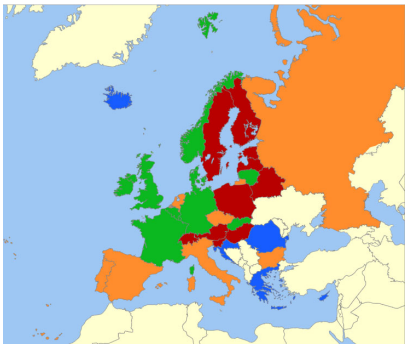
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Design for adaptability and relocation

- Environmental loads: wind

Country	$V_{b,0,min}$ [m/s]	$V_{b,0,max}$ [m/s]	$V_{b,0,mean}$ [m/s]	Class - Mean	$V_{b,0,class}$ [m/s]	$q_{b,0,class}$ [kN/m²]
Austria	17.6	28.3	21	W4	23	0.55
Belarus	22.0	24.0	22	W4	23	0.61
Belgium	23.0	26.0	24	W3	26	0.72
Bulgaria	24.0	35.8	27	W2	28	0.91
Croatia	20.0	48.0	29	W1	> 28	1.05
Cyprus	24.0	40.0	29	W1	> 28	1.05
Czech Republic	22.5	36.0	27	W2	28	0.91
Denmark	24.0	27.0	25	W3	26	0.78
Estonia	21.0	21.0	21	W4	23	0.55
Finland	21.0	26.0	22*	W4	23	0.61
France	22.0	28.0	24*	W3	26	0.72
Germany	22.5	30.0	25*	W3	26	0.78
Greece	27.0	33.0	29	W1	> 28	1.05
Hungary	23.6	23.6	23	W4	23	0.66
Iceland	36.0	36.0	36	W1	> 28	1.62
Ireland	25.0	28.0	26	W3	26	0.85
Italy	25.0	31.0	27*	W2	28	0.91
Latvia	21.0	27.0	23	W4	23	0.66
Lithuania	24.0	32.0	26	W3	26	0.85
Luxemburg	24.0	24.0	24	W3	26	0.72
Netherlands	24.5	29.5	27*	W2	28	0.91
Norway	22.0	31.0	25	W3	26	0.78
Poland	22.0	26.0	23	W4	23	0.66
Portugal	27.0	30.0	27*	W2	28	0.91
Romania	27.0	35.0	31*	W1	> 28	1.20
Russia	19.6	43.6	27	W2	28	0.91
Slovakia	24.0	26.0	24	W3	26	0.72
Slovenia	20.0	30.0	23	W4	23	0.66
Spain	26.0	29.0	27*	W2	28	0.91
Sweden	21.0	26.0	22	W4	23	0.61
Switzerland	20.0	24.0	21	W4	23	0.55
United Kingdom	22.0	32.0	25*	W3	26	0.78

* - According to the most usual value defined with the national annex. Other results obtained with a weighted average: (2* $V_{b,0,min}$ + $V_{b,0,max}$)/3. Class W1: 23 m/s; Class W2: 26 m/s; Class W3; 28 m/s; Class W4 >28 m/s



European wind load classes

CREDITS: Progress

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Design for adaptability and relocation

- Environmental loads: snow

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[a] Assuming the average altitude for the less critical zone of the country
[b] Assuming the average altitude for the zone representing most area of the country

FIGURES CREDITS: Progress

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Design for adaptability and relocation

- Design outcome:
  - Standard section sizes (avoid tapered/welded sections)
  - Spare capacity may be available; document the spare capacity
- Design according to Eurocode 3:
  - Elastic global analysis is recommended
  - SLS stress checks to be performed
  - $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ (allowing for future relocations)
  - γ_{M0} and γ_{M2}: values from the appropriate NA to be used

CREDITS: Progress; SCI

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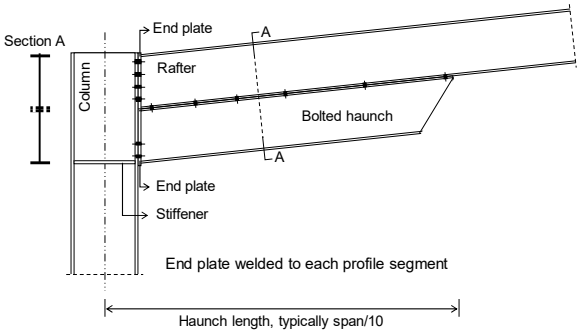
Design and detailing for deconstruction and reuse

- Detailing principles for reuse:
  - Reduce the number of connections and connectors (simple connections);
  - Use bolts/screws instead of other solutions (specially with cladding); reduce welding;
  - Detail for easy access of connections;
  - Repetitive detailing (modular/standard);
  - Avoid permanent attachments (floor systems are critical).

CREDITS: Progress; SCI

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: bolted haunch

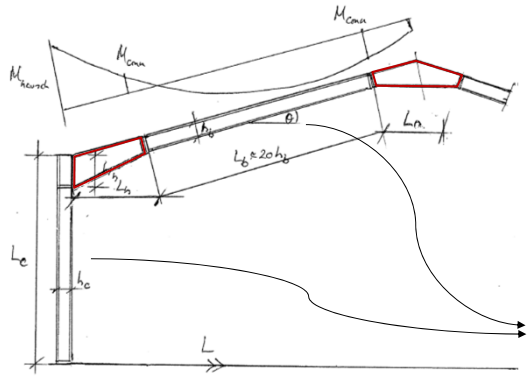


Alternative to use intermittent welds between rafter and haunch.

FIGURES CREDITS: https://www.northlincsstructures.com/;

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: standard (expendable) components



- Fabricated haunch segments 2no) of length $L_h \approx 0.1L$ to 0.12L, where L is the overall span of the portal frame
- Fabricated apex segment (1no) of length $L_a \approx 0.1L$.
- Beams (2no) of length, $L_b = 20h_b$, where h_b is the beam depth.
- Columns (2no) of overall length, $L_c = 20h_c$, where h_c is the column depth.

$L = 2\,(L_b + L_h)\cos\theta + L_a$
where θ is the slope of the rafter to the horizontal = 6°

FIGURES CREDITS: Progress; Ruukki

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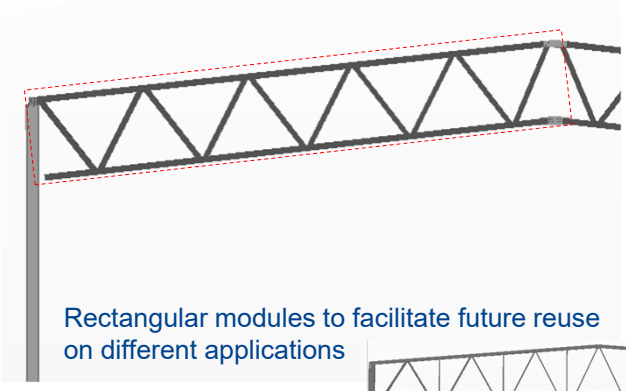
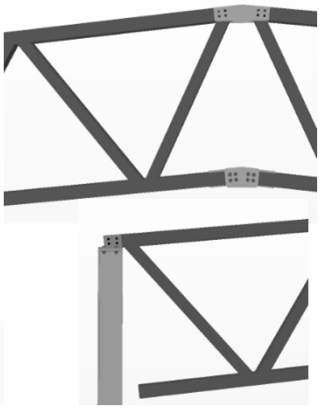
Design and detailing for deconstruction and reuse

- Detailing principles for reuse: standard components



Rectangular modules to facilitate future reuse on different applications



FIGURES CREDITS: Progress; Ruukki

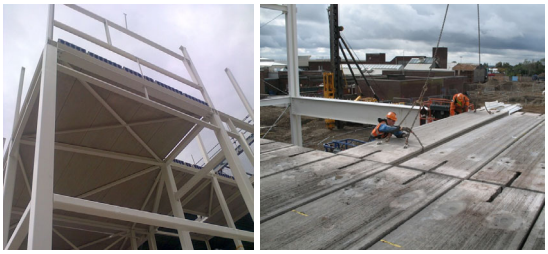
PROGRESS 2017-2020 PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: mezzanines

CLT floor system

Precast concrete units



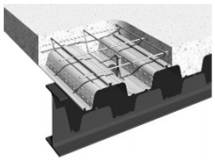
FIGURES CREDITS: https://www.kloecknermetalsuk.com

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: mezzanines

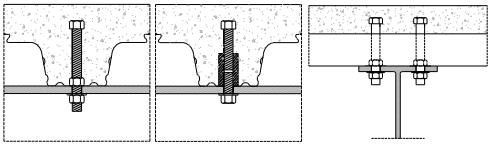
Demountable composite floor system

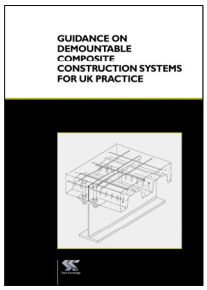


Welded shear studs

vs

Bolts





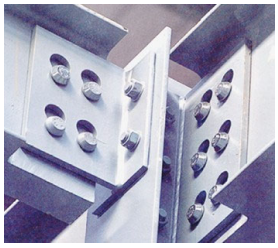
SCI P428: https://portal.steel-sci.com/shop.html?sku=P428

FIGURES CREDITS: REDUCE: Research Fund for Coal and Steel, Grant agreement No: 710040; Figure on the left: https://www.tatasteelconstruction.com

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

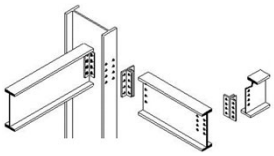
Design and detailing for deconstruction and reuse

- Detailing principles for reuse: design for deconstruction & reuse

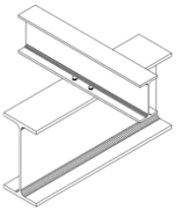


Quicon system

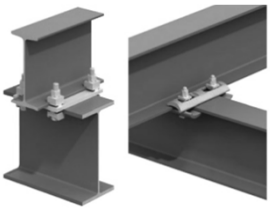
Hollo Bolts and Blind Bolts (hollow sections)



Cleated connections



Hot rolled bolted purlins



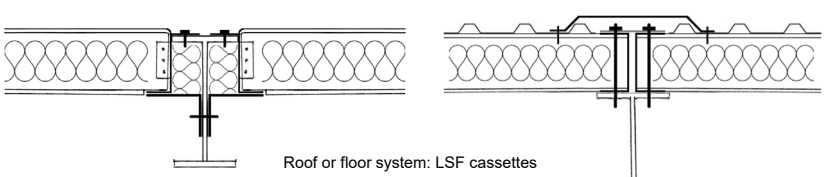
Clamped connections for purlins

FIGURES CREDITS: SCI; http://www.lindapter.com (right)

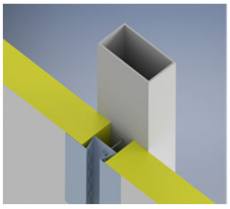
PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

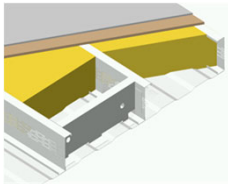
Design and detailing for deconstruction and reuse

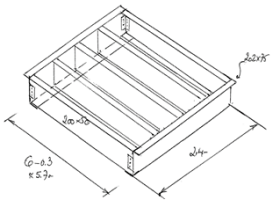
- Detailing principles for reuse: long span cladding cladding

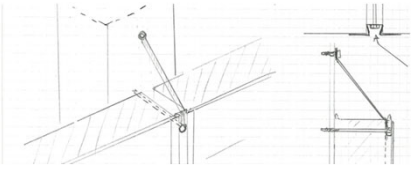


Roof or floor system: LSF cassettes









FIGURES CREDITS: SCI; Ruukki, RWTH

Clamped façade systems

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: long span cladding cladding

Heathrow Terminal 5, London

FIGURES CREDITS: Ruukki

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Building Information Modelling - BIM

- Lever of Information need (EN ISO 19650); material passport

Lever of information need:

Category	Description
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;

Permanent component tracking: bar codes, QR codes or RFID

Example of possible QR code for component tracking:

(Try me)

Type: Reclaimed
Origin: UK, Ascot
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

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: case study




100% circular design; design for deconstruction and reuse; all structural members were designed to be disassembled; cladding with screwing fixings; BIM and Material Passport to enhance future reuse.

FIGURES CREDITS: Fokker 7 Building ;Schiphol Airport

Final remarks – Reuse of existing steelwork

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;

PROGRESS 2017-2020 PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Final remarks – Reuse of existing steelwork

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.

PROGRESS 2017-2020
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Final remarks – Design for reuse

1. Small improvements to current practice for single storey buildings will have a large impact on the construction market;
2. Seek standardization as much as possible;
3. Facilitate access for all connections;
4. Design for deconstruction, not only construction;
5. Avoid permeant attachment between components;
6. Reduce number or layers, materials and components;
7. Design for relocation/adaptability, not for a single purpose and location;
8. Designers to specify allowable structural capacity to facilitate reuse;
9. Stress check, global elastic analysis and $\gamma_{M1,mod}$ = 1.15.

SCI Steel Knowledge

SCI is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. We work in partnership with clients, members and industry peers to help build businesses and provide competitive advantage through the commercial application of our knowledge. We are committed to offering and promoting sustainable and environmentally responsible solutions.

Thank you!

SCI Steel Knowledge