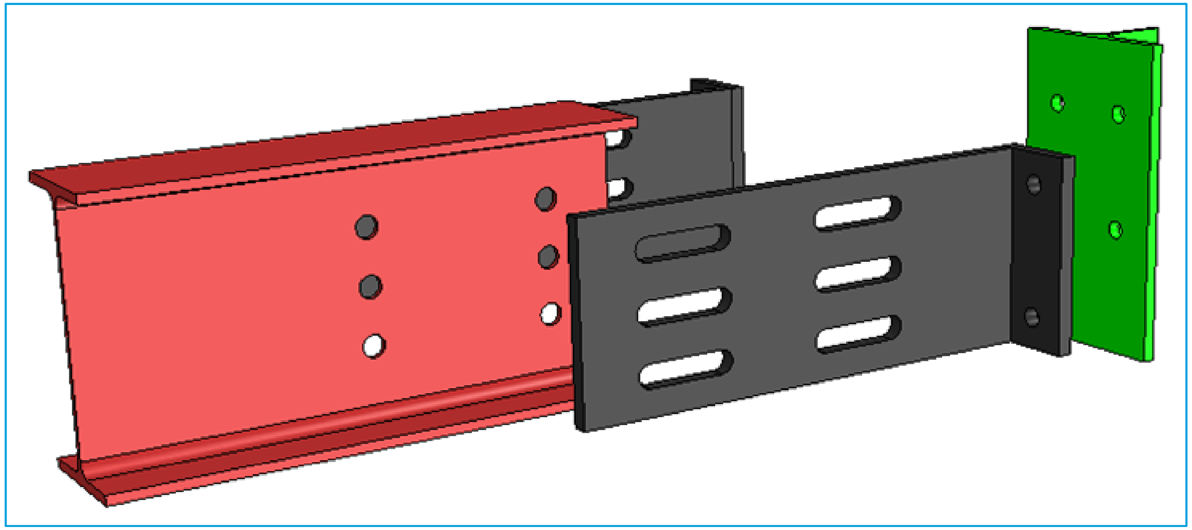
UNIVERSITY of BRADFORD

ArcelorMittal Chair of Steel Construction
Prof. Dr.-Ing. Christoph Odenbreit

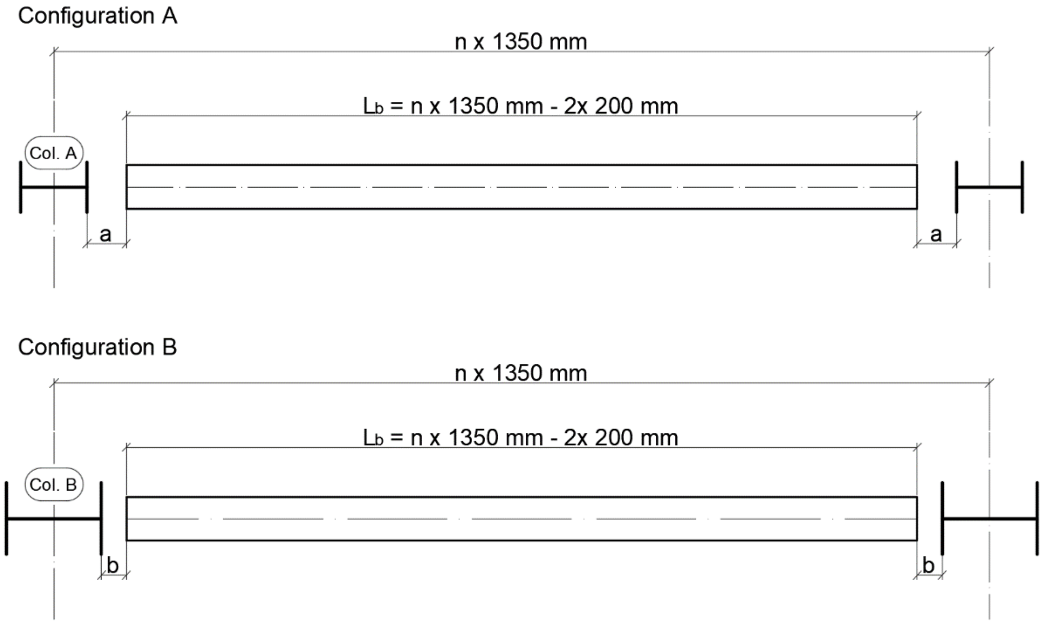
DEMOUNTABLE STEEL CONNECTIONS

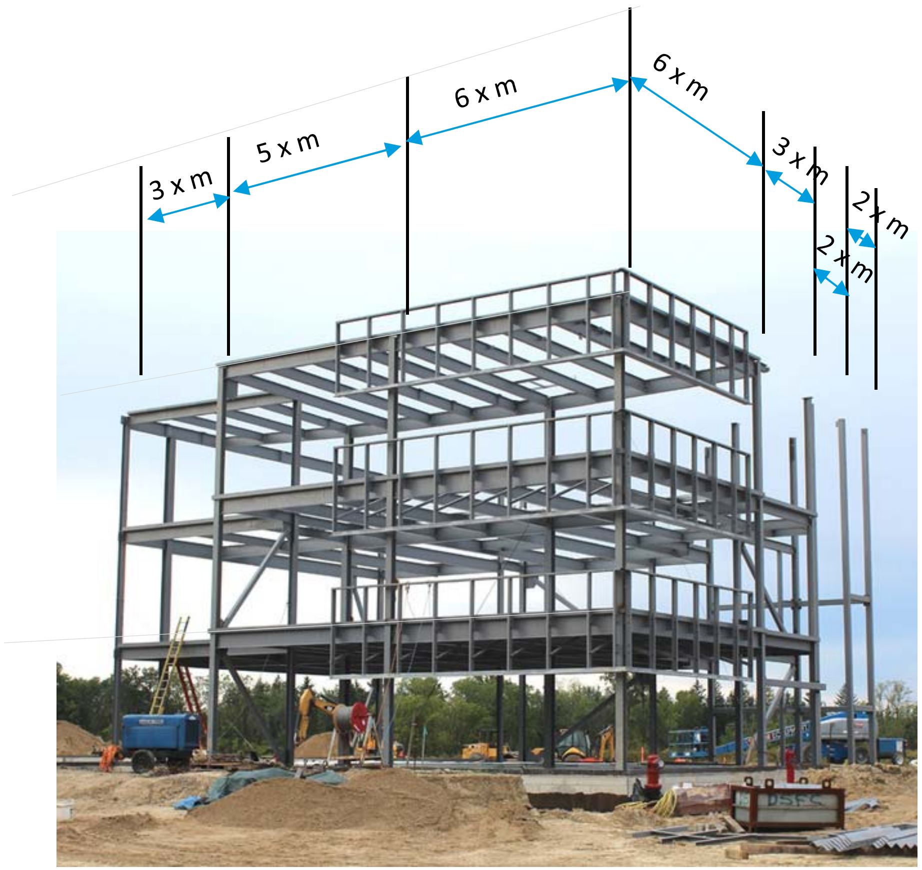
- PROF DENNIS LAM
- DR JIE YANG
- DR XIANGHE DAI
- DR THERESE SHEEHAN
- DR KAN ZHOU
- PROF CHRISTOPH ODENBREIT
- M.Sc ANDRAS KOZMA

1. Adjustable Slotted Hole Connection (ASHL)

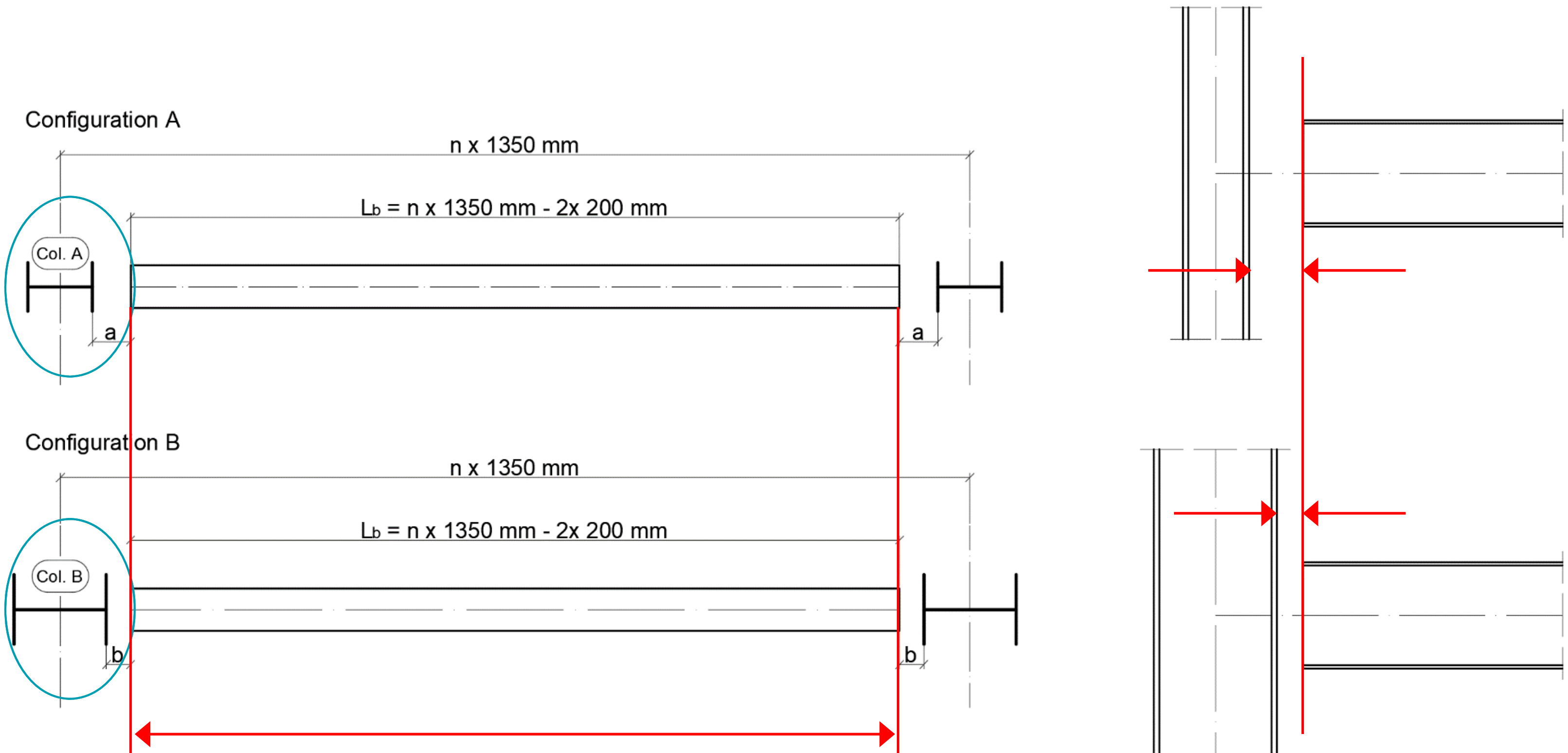


http://www.understandconstruction.com/steel-frame-structures.html

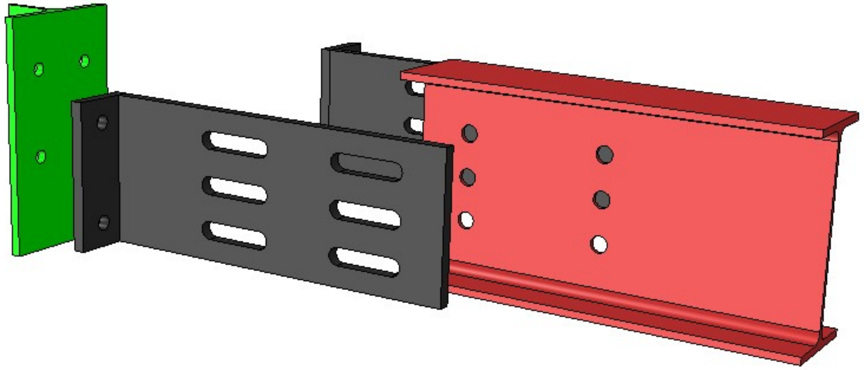


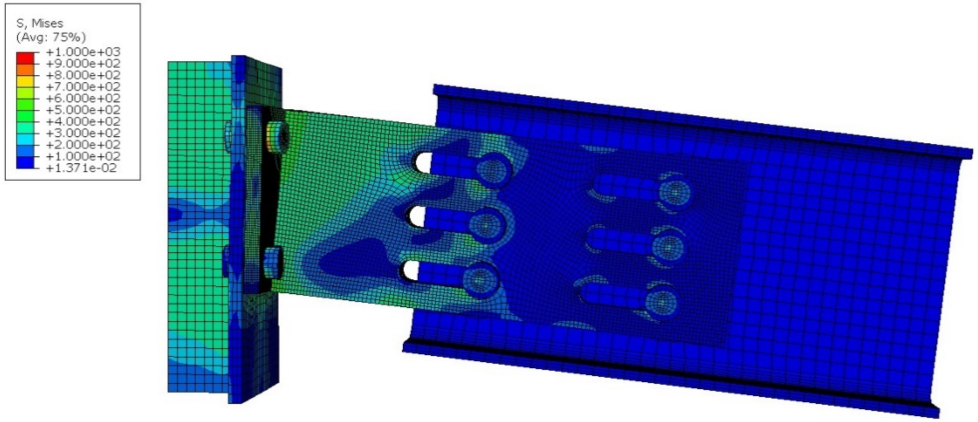


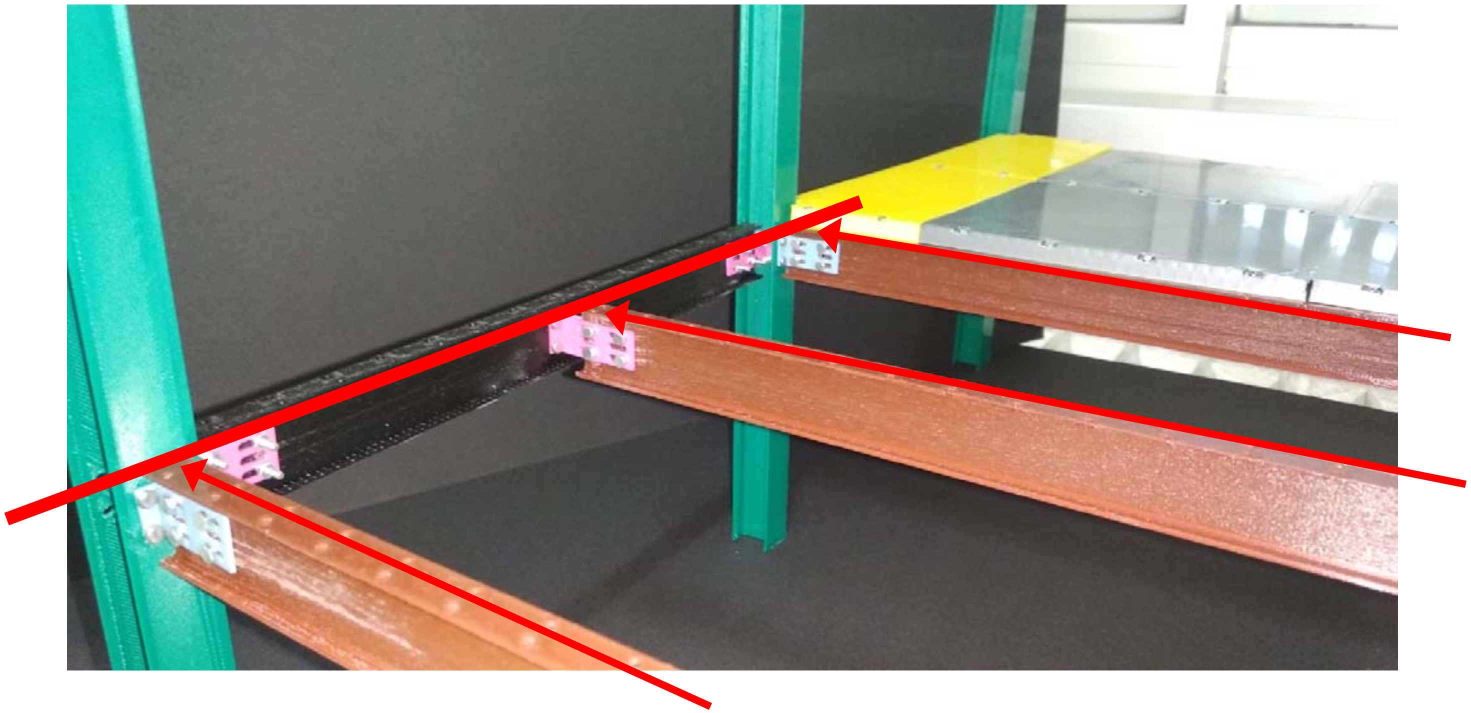
http://www.understandconstruction.com/steel-frame-structures.html



For all cases within the
grid number “n” = always
one standardized beam length

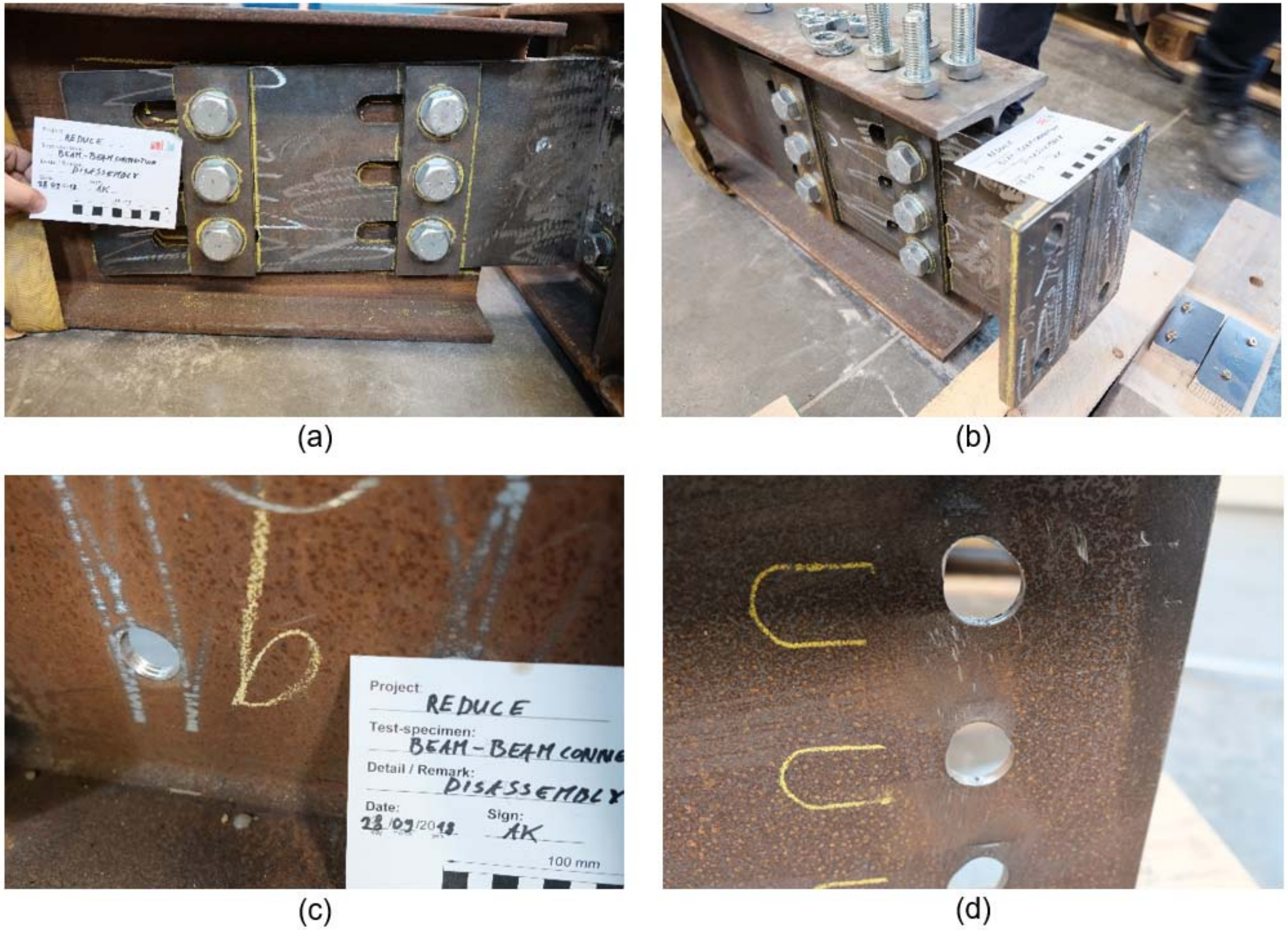



S, Mises
(Avg: 75%)
+1.000e+03
+9.000e+02
+8.000e+02
+7.000e+02
+6.000e+02
+5.000e+02
+4.000e+02
+3.000e+02
+2.000e+02
+1.000e+02
+1.371e-02




Project: REDUCE
Test-specimen: B-B 1
Detail / Remark:
Date: 17/07/2018
Sign: AK
100 mm

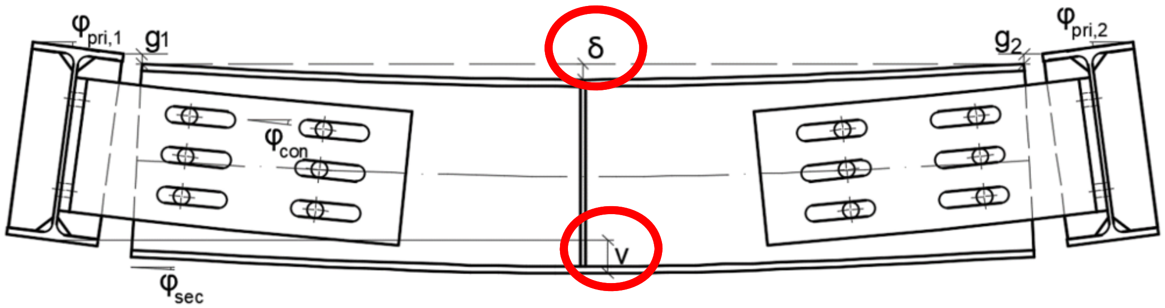

Project:
REDUCE
Test-specimen:
B-B1
Detail / Remark:
Unloaded from 940 kN
Date:
Sign:
AK
100 mm
uni.lu

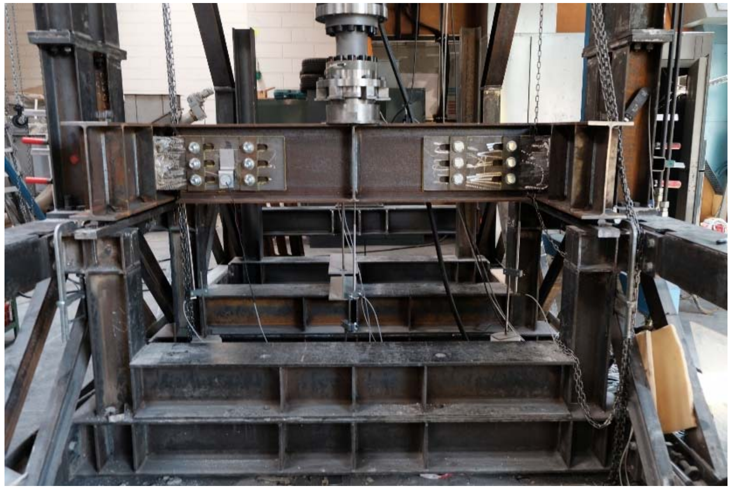

(a)
(b)
(c)
(d)
Project:
REDUCE
Test-specimen:
Detail / Remark:
DISASSEMBLY
Date:
Sign:
AK
100 mm

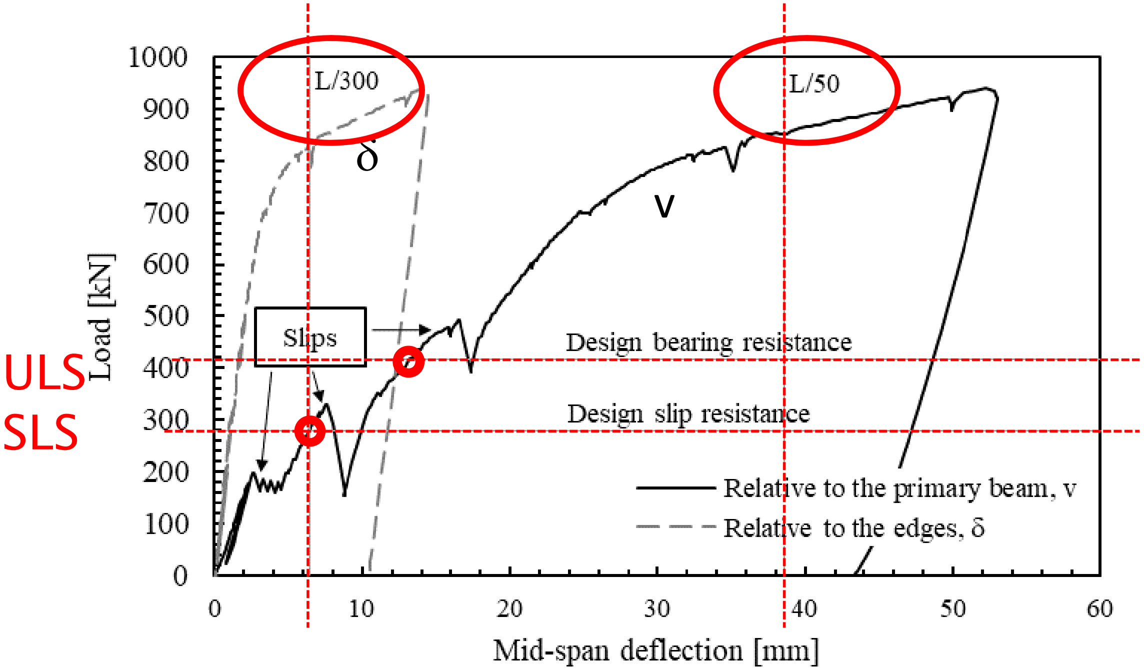
Test results

v mid-span deflection of the secondary beam relative to the primary beam

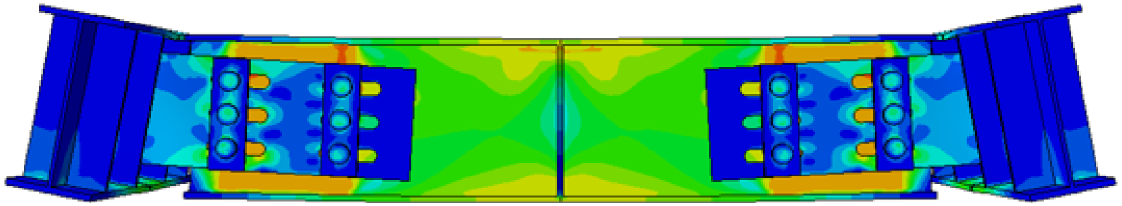
δ mid-span deflection of the secondary beam relative to its edges

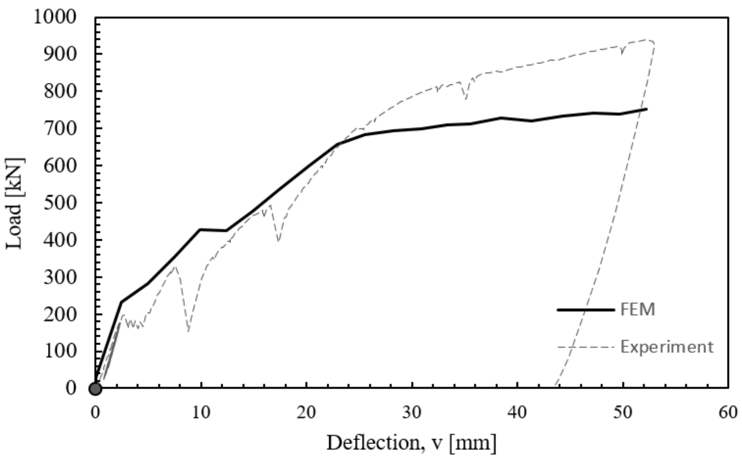


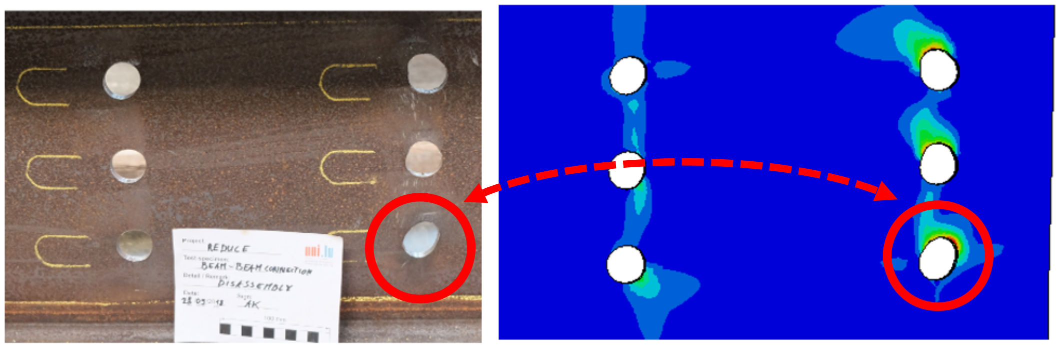




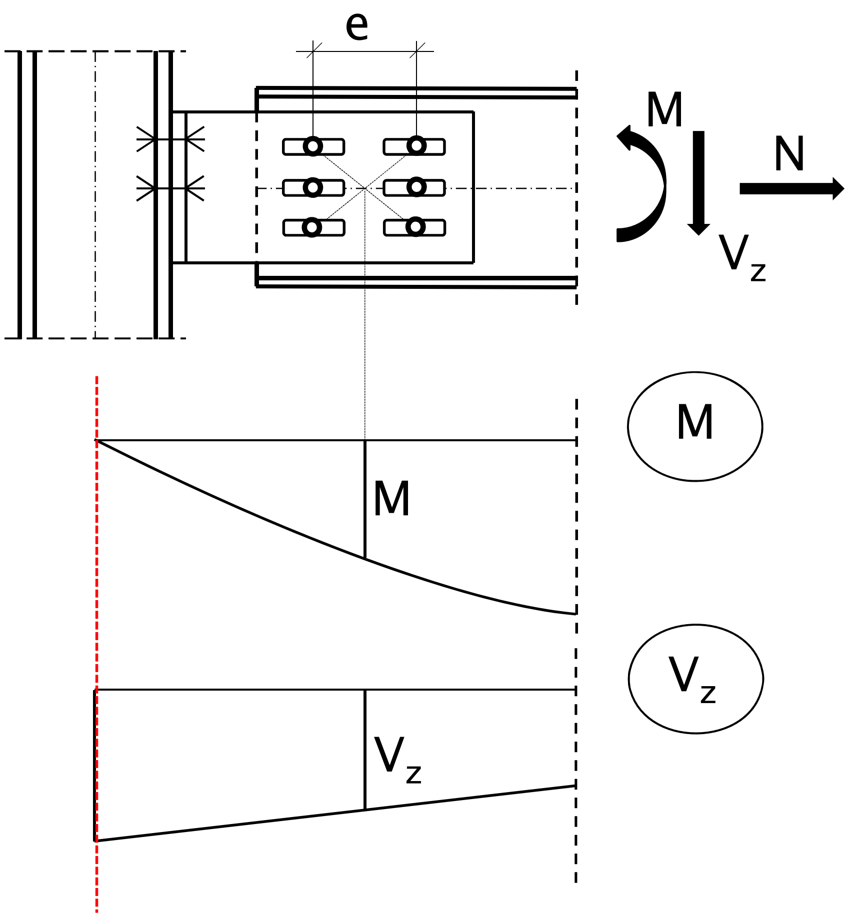
Test vs. Numerical model

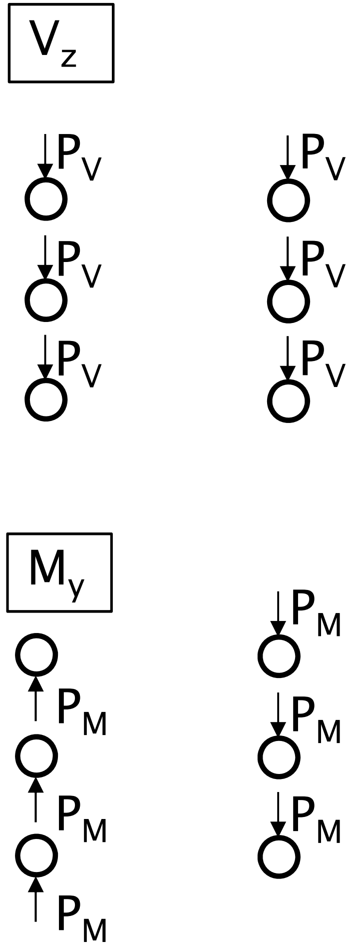






Hand-Calculation





$$P_V = V_z/6$$

$$P_M = \frac{M}{e}/3$$

$$P_R = P_V + P_M$$

Proof of the connection EN1993-1-8

1. Shear failure of the bolt.
2. Bearing failure of the beam web.
3. Bearing failure of the plate with slotted holes.

Table 3.4: Design resistance for individual fasteners subjected to shear and/or tension

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \frac{\alpha_v \, f_{ub} \, A}{\gamma_{M2}}$ - where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_s): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0{,}6$ - for classes 4.8, 5.8, 6.8 and 10.9: $\alpha_v = 0{,}5$ - where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt): $\alpha_v = 0{,}6$	$F_{v,Rd} = \frac{0{,}6 \, f_{ur} \, A_0}{\gamma_{M2}}$
Bearing resistance [1), 2), 3)]	AC2 $F_{b,Rd} = \frac{k_1 \, \alpha_b \, f_u \, d \, t}{\gamma_{M2}}$ AC2 where α_b is the smallest of α_d; $\frac{f_{ub}}{f_u}$ or 1,0; in the direction of load transfer: - for end bolts: $\alpha_d = \frac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$ perpendicular to the direction of load transfer: AC2 - for edge bolts: k_1 is the smallest of $2{,}8\frac{e_2}{d_0} - 1{,}7$, $1{,}4\frac{p_2}{d_0} - 1{,}7$ and 2,5 AC2 - for inner bolts: k_1 is the smallest of $1{,}4\frac{p_2}{d_0} - 1{,}7$ or 2,5	

1) The bearing resistance $F_{b,Rd}$ for bolts

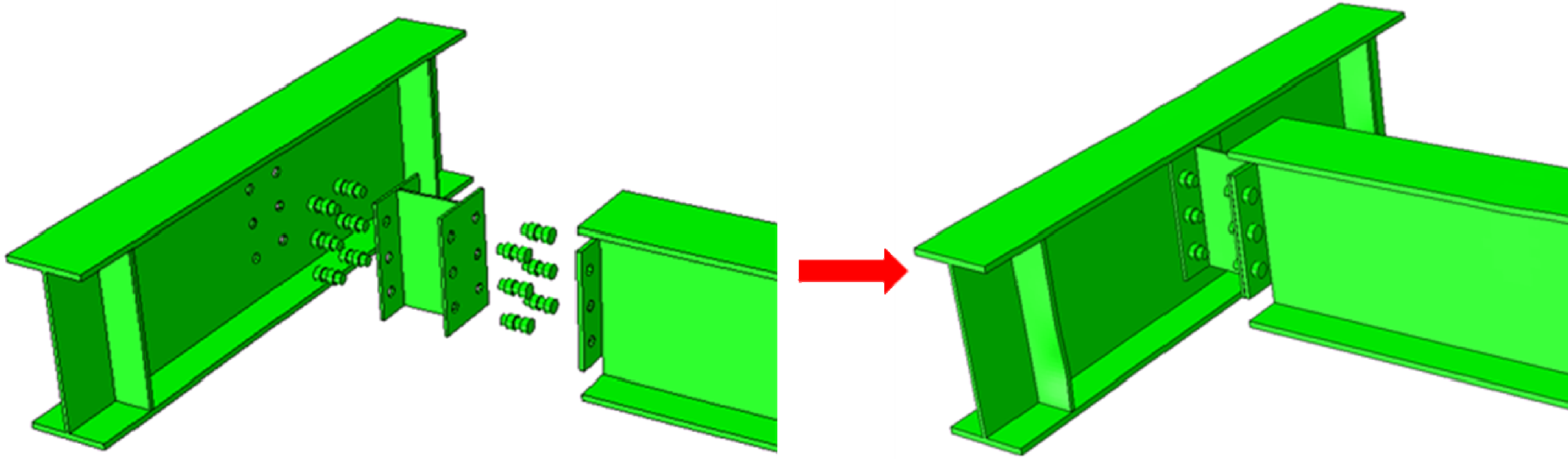
- in oversized holes is 0,8 times the bearing resistance for bolts in normal holes.
- in slotted holes, where the longitudinal axis of the slotted hole is perpendicular to the direction of the force transfer, is 0,6 times the bearing resistance for bolts in round, normal holes.

2. Aims and objectives

To develop a new connection system to facilitate reuse of steel components, explore a greater standardisation for framed structures:

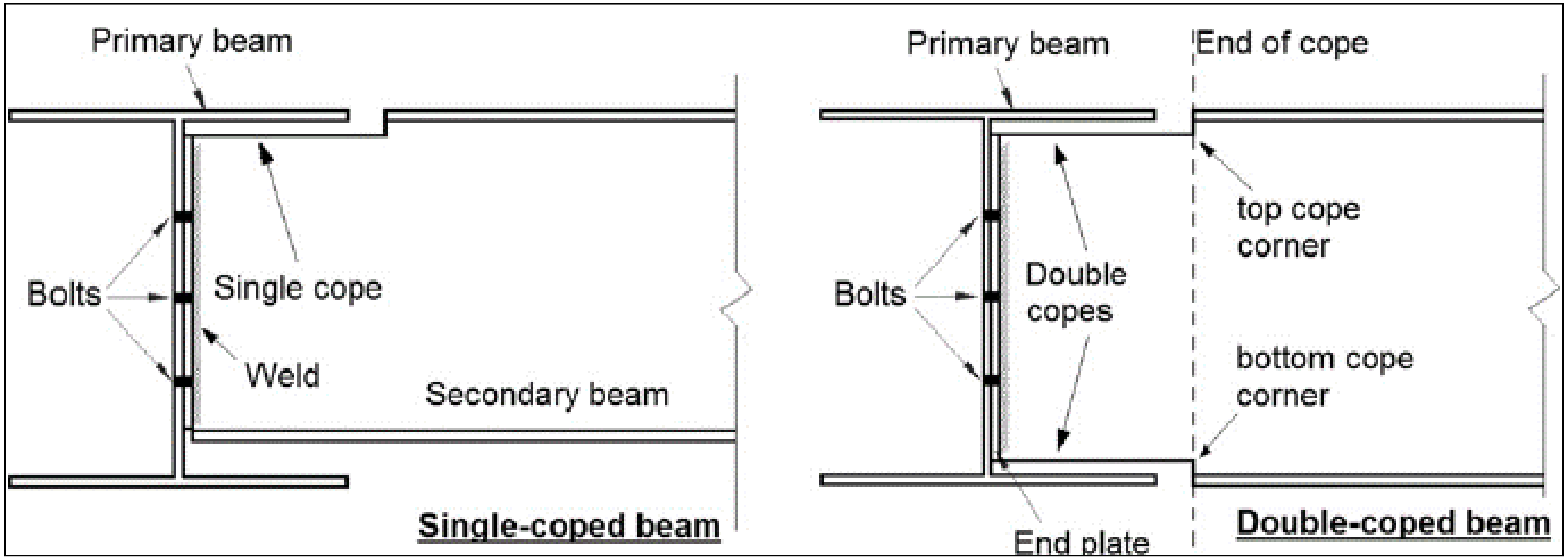
- Design an easy-fabricated, replaceable connection system to allow beam length to be standardized and suitable for a variety of supporting members within the same planning grid
- Ease of demountability and the reusability of the steel components
- Compare first use vs. reuse
- Parametric studies from finite element modelling on key influencing parameters

3. BSC connection system



Block shear connector

3. BSC connection system



Advantages of BSCs:

- Eliminate coping cost
- Easy and economic fabrication
- Replaceable (Reuse of beams)
- Standardization (Length of beams)

Use of BSCs:

- Beam-beam connections
- Minor-axis H/I columns

Block Shear Connector (BSC) Design

Design Assumptions for the Block Shear Connector (BSC):

The BSC is designed to use for 305UBs (S355), either in beam-column or beam-beam connections.

Assume span / depth ratio = 20, 305mm x 20 =6100mm, i.e. 6.1m

For 305x165x54UB (S355):

$M_{cx} = 846 \times 355 \times 10^{-3} = 300\text{kNm}$

$w = 300 \times 8 / 6.1^2 = 64.5\text{kN/m}$

Moment at the block connector = $\frac{wx}{2}(l - x) = \frac{64.5 \times 0.15}{2}(6.1 - 0.15) = 29\ \text{kNm}$

Maximum shear force = 64.5 x 6.1 / 2 = 197kN

For 356 x 171 x 57 UB (IPE360), S355

$Mcx = 1010 \times 355 \times 10^{-3} = 359\text{kNm}$

$w = 359 \times 8 / 7.2^2 = 55\ \text{kN/m}$

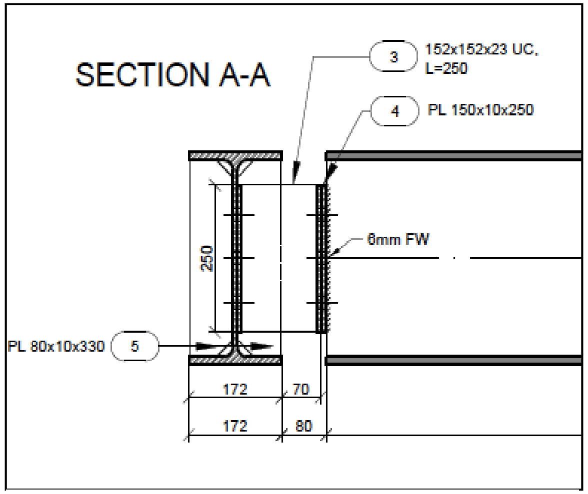
Moment at the block connector = $\frac{wx}{2}(l - x) = \frac{55 \times 0.15}{2}(7.2 - 0.15) = 29\ \text{kNm}$

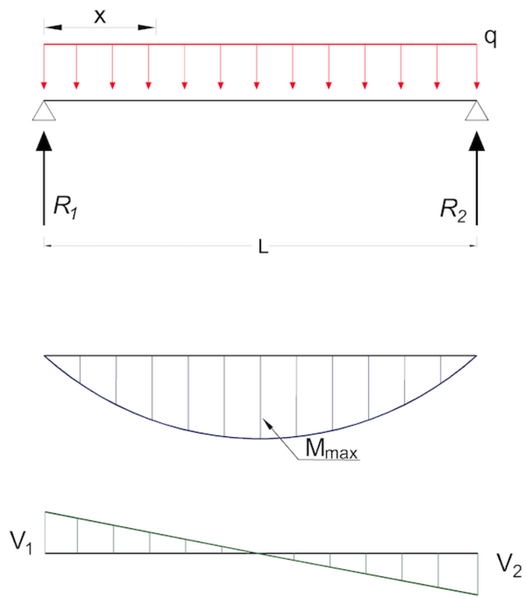
Maximum shear force = 55 x 7.2 /2 = 198kN

Therefore, under *ULS*, BSC is designed to sustain a max connection moment of 30kNm and a maximum shear force of 200kN.

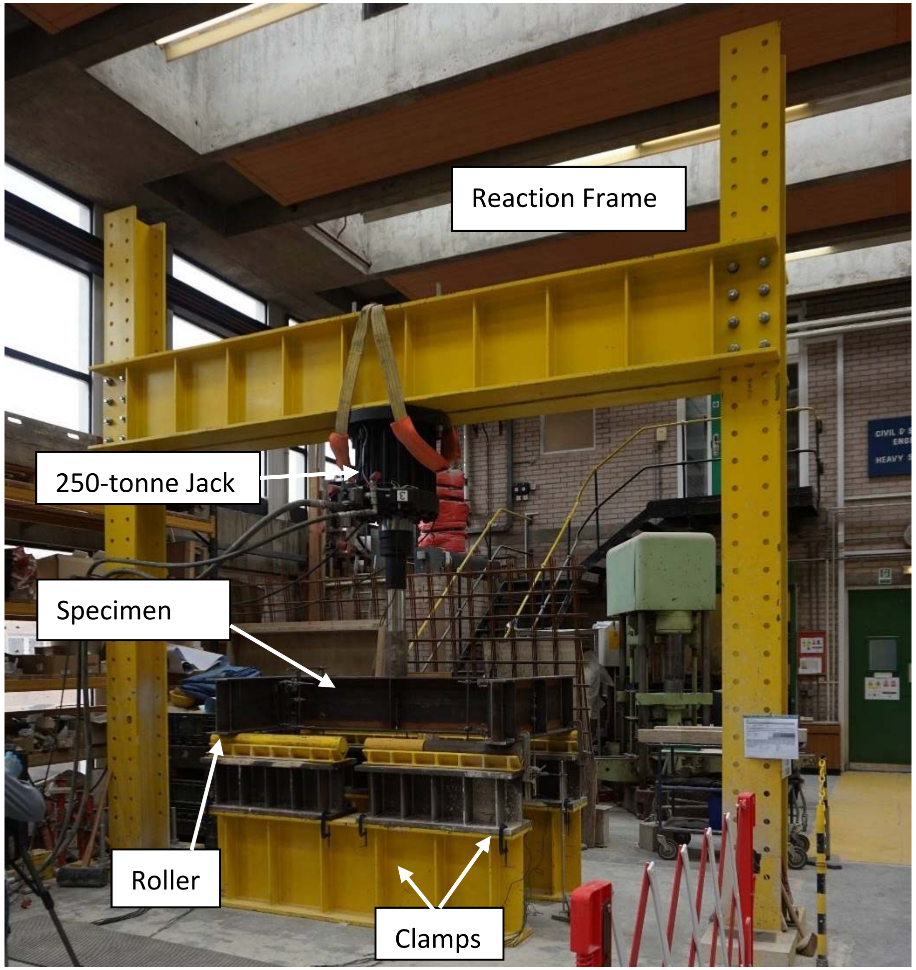
Block Shear Connector used:

152x152x23UC (S355), 250mm in length





4. Specimen and test setup



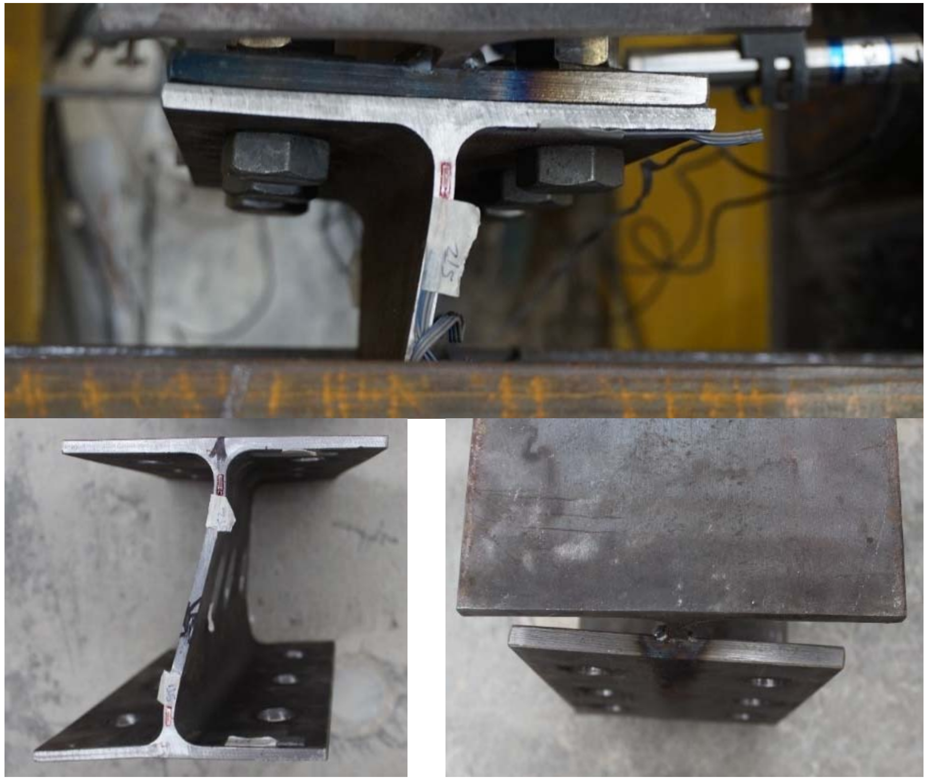
First test: propped construction

the specimen was assembled on the laboratory floor before it was lifted to the roller supports; loaded to failure

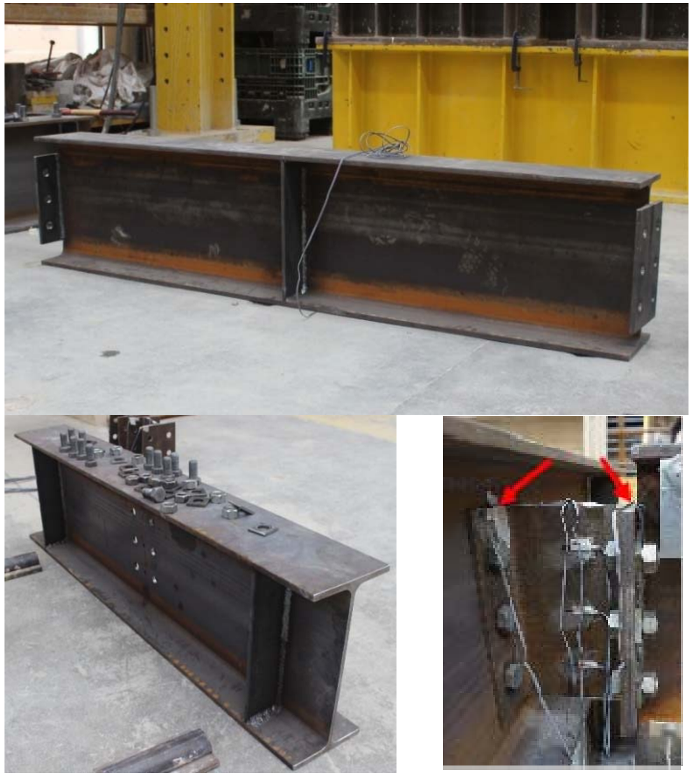
Second test: unpropped construction

the specimen was dismantled and re-assembled with new BSCs; the primary beams were resting on the roller supports while the secondary beam was lifted by using the crane, and the bolts were initially in contact with the bolt holes

5. BSC Test Results



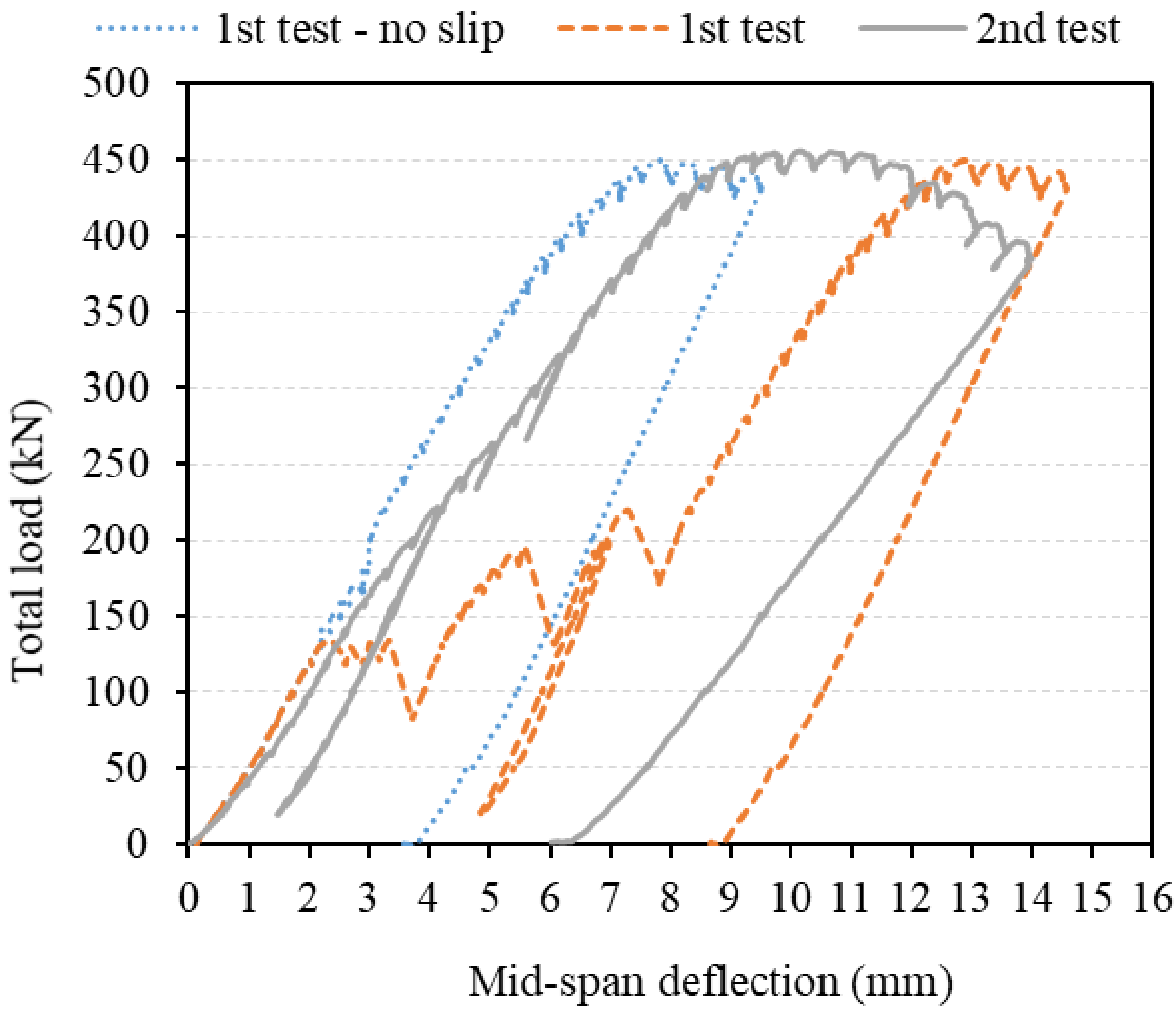
Web buckling of the BSC and web yielding of the secondary beam /rotation of the end plate (compression)



Dis-assembled steel components after tests and observed bolt slip during the first test

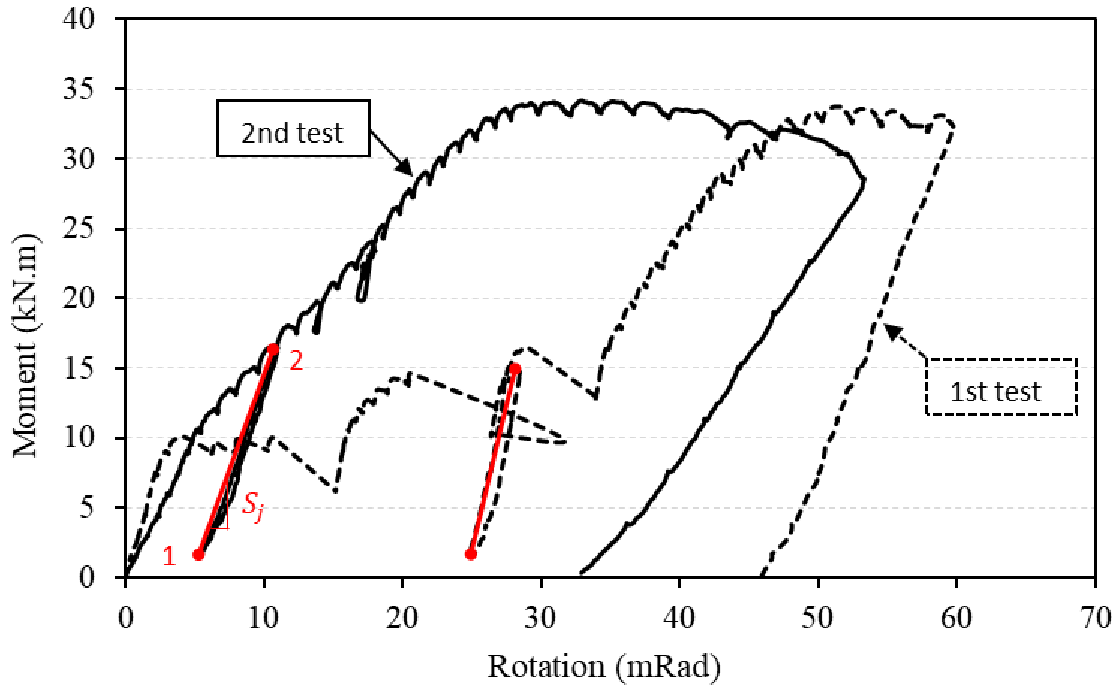
- no obvious deformation observed in the bolts, the beams and the end plates
- clearances were minimised and no obvious slippage and sudden load drop in the reuse test

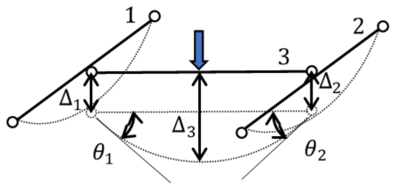
Total load vs. mid-span deflection (secondary beam)



- 1.2% resistance difference, suggesting that there was no resistance loss in the re-assemble specimen with reused steel beams
- Max. mid-span deflection was 7.8 mm (omitting bolt slip; L/250) and 10.2 mm (L/190)
- The un-propped construction technique used for the second test prevented large bolt slips and sudden load drop observed in the first test.

Moment vs. Rotation





Calculation data of the initial stiffness of the specimens

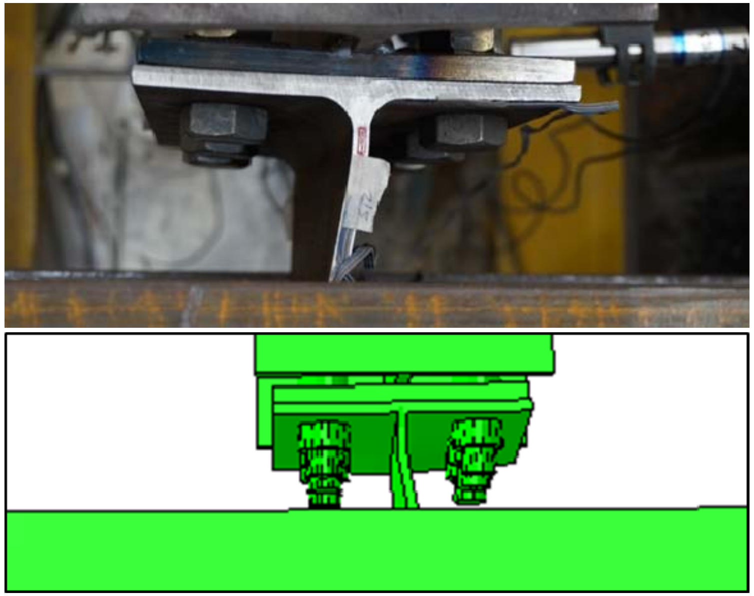
ID	Data point 1		Data point 2		Stiffness
	M (kN·m)	R (mRad)	M (kN·m)	R (mRad)	S_j (kN·m/mRad)
First test	1.63	5.28	16.36	10.65	2.74
Second test	1.67	24.91	14.96	28.09	4.18
				Average	3.46

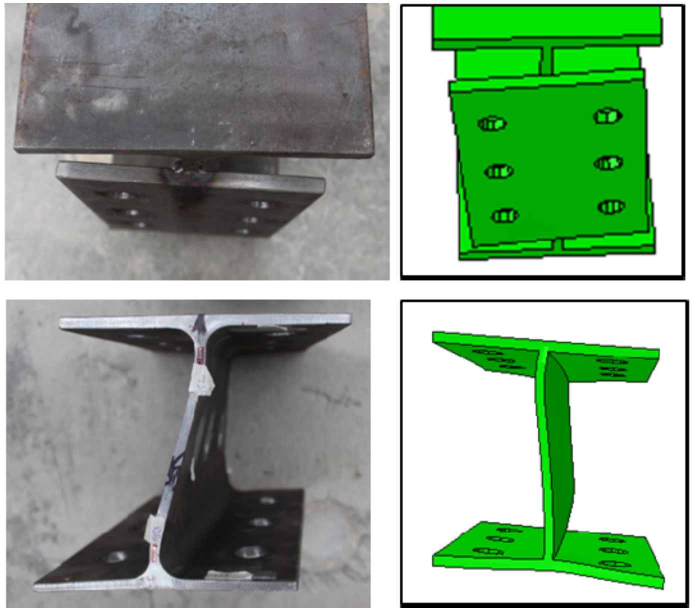
nominally pinned joint

Remarks on demountability and reusability

- Bolts were easily untightened by using hand-held normal spanner after tests;
- Beams and connectors were dismantled within a few minutes;
- Similar capacity for first use vs. reuse;
- The primary beams and bolts can be retrieved and re-used in their original forms.

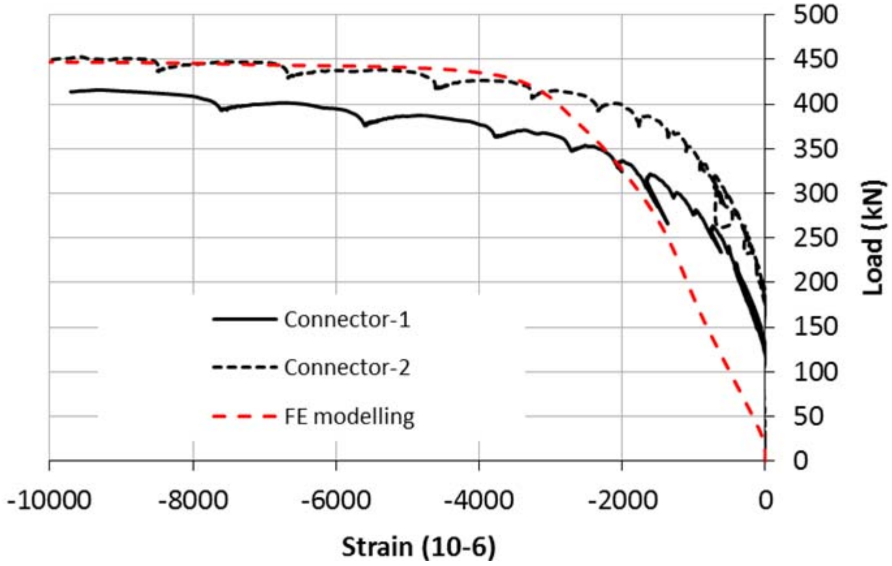
Test vs. FE mode of failure



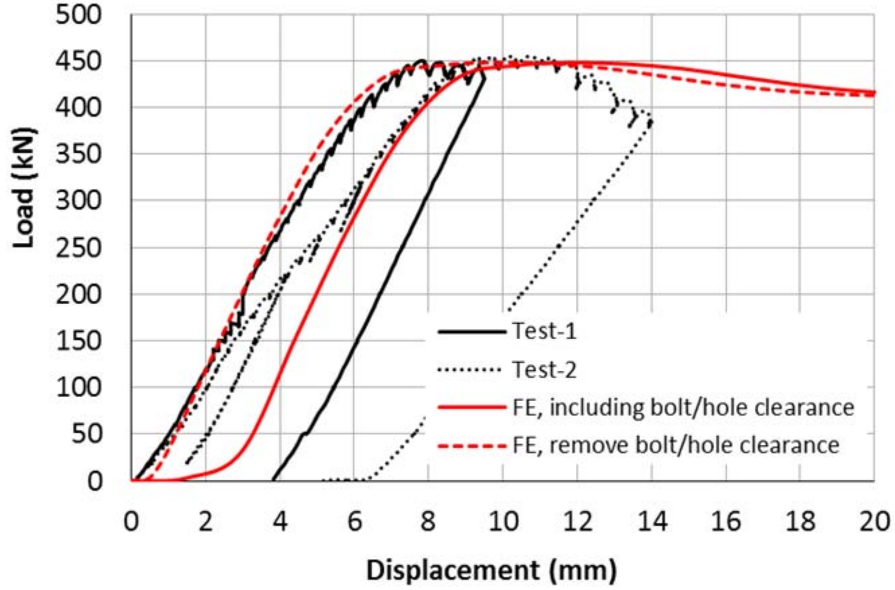


predicted failures and experimental observations, very good agreement achieved

Test vs. FE strain & load-deflection



compressive strain at the BSC web



Load vs. deflection

8. Summary for the BSC

- Mode of failure was web yielding followed by buckling of the BSC due to compression;
- Slippage can be minimised by adopting un-propped construction technique;
- Proposed connection system was easy to dismantle, the BSC was replaceable and the components can be reused in their original forms;
- All the structural components can be reused in another building by adjusting the BSCs selected;
- The finite element models developed can be used to predict and capture the main structural behaviour and failure modes of the block connection system.

ACKNOWLEDGEMENT

- This research is within the EU project (project number: 710040) entitled 'Reuse and Demountability using Steel Structures and the Circular Economy (REDUCE)'.
- The project is funded by European Community Research Fund for Coal and Steel (RFCS), and is jointly investigated by the Steel Construction Institute, Lindab S.A., University of Luxembourg, TAT Steel, Stichting Bouwen Met Staal, TU Delft, AEC3 Ltd and the University of Bradford.
- The financial support from the RFCS and technical support from th technicians (Stephen Robinson) at the University of Bradford and a the University of Luxembourg (Gilbert Klein, Marc Seil) are greatly appreciated.

UNIVERSITY of BRADFORD

Thank you

ArcelorMittal

uni.lu

ArcelorMittal Chair of Steel Construction

Prof. Dr.-Ing. Christoph Odenbreit