

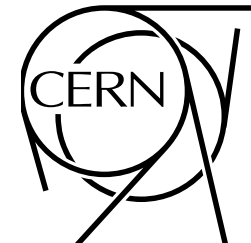
Structural assessment of the joints of the LBNF warm structure

Author(s): CERN EP-DT-EO

LBNF Cryostat, final design review

SURF, 21-22 August 2017

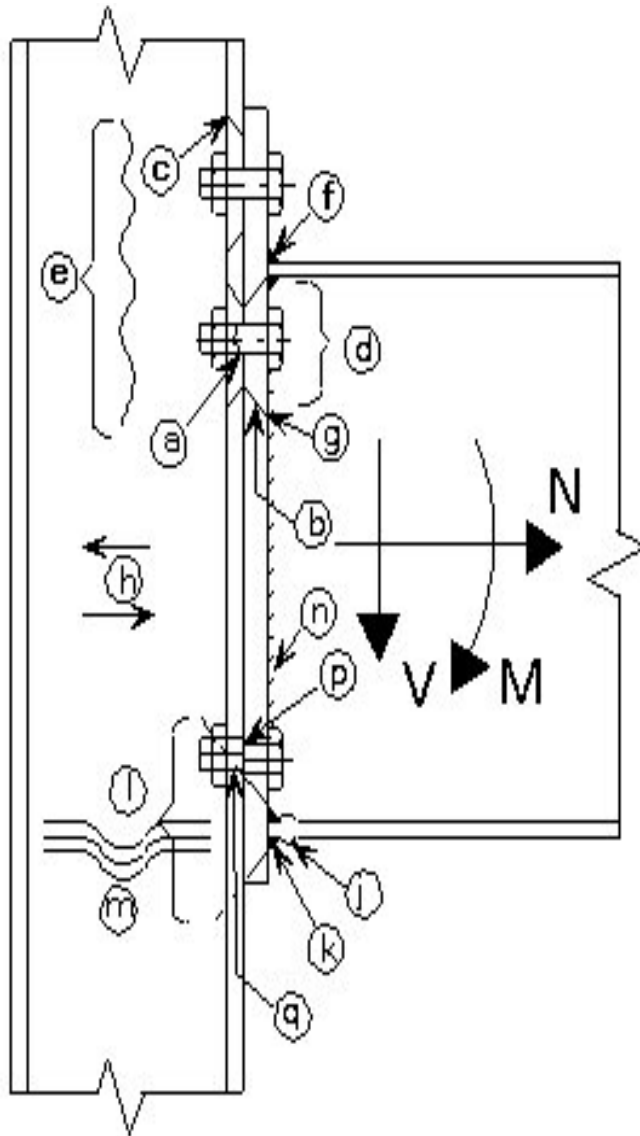
EDMS: 1832358



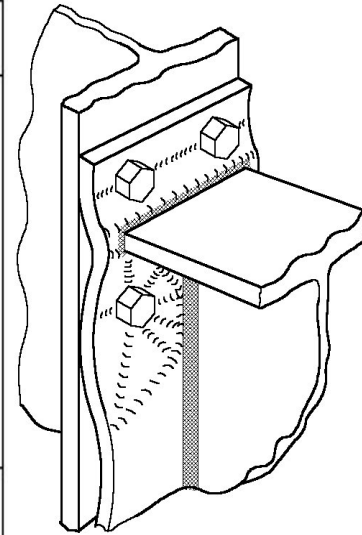
Purpose

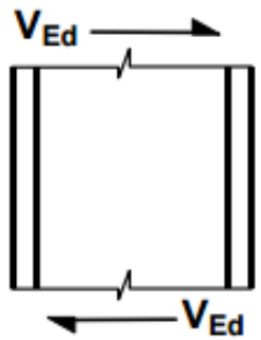
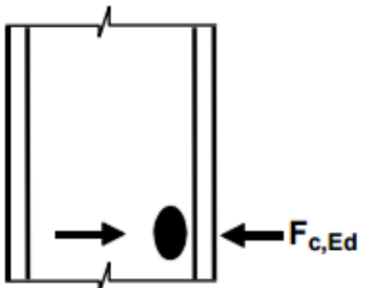
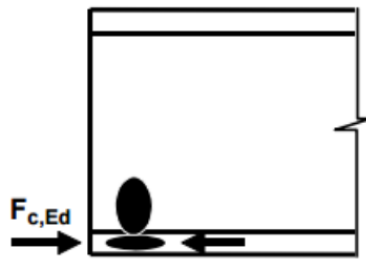
- To experimentally validate analytical and FEA calculations;
- To assess compliance of the connections;
- To validate the assembly and handling of the critical connections;
- **Ensure that connection are safe even beyond ULS**
 - Tests to be performed at 125% of the ULS

Background

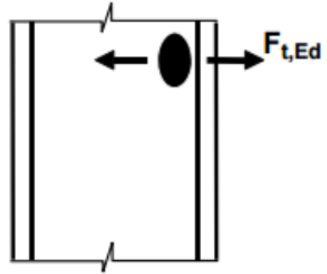


Zone	Ref	Checklist item
Tension	a	Bolt tension
	b	End plate bending
	c	Column flange bending
	d	Beam web tension
	e	Column web tension
	f	Flange to end plate weld
	g	Web to end plate weld
Horizontal shear	h	Column web shear
Compression	j	Beam flange compression
	k	Beam flange weld
	l	Column web bearing
	m	Column web buckling
Vertical shear	n	Web to end plate weld
	p	Bolt shear
	q	Bolt bearing



	Component	Design resistance	Stiffness coefficient (k_i) – Only components contributing to the stiffness coefficient
Shear	Column web in shear 	$V_{wp,Rd} = \frac{0,9 f_{y,wc} A_{vc}}{\sqrt{3} \gamma_{M0}}$	$k_1 = \frac{0,38 A_{vc}}{\beta z}$ Stiffened column web: $k_1 = \infty$
	Column web In transverse compression 	$F_{c,wc,Rd} = \frac{\omega k_{wc} b_{eff,c,wc} t_{wc} f_{y,wc}}{\gamma_{M0}}$	$k_2 = \frac{0,7 b_{eff,c,wc} t_{wc}}{d_c}$ Stiffened column web: $k_2 = \infty$
Compression	Beam or column flange and web in compression 	$F_{c,fb,Rd} = M_{c,Rd} / (h - t_{fb})$	

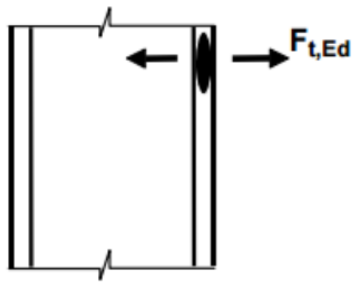
Column web in transverse tension



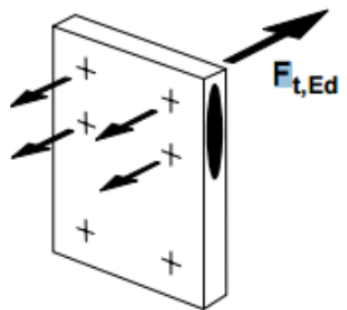
$$F_{t,wc,Rd} = \frac{\omega b_{eff,t,wc} t_{wc} f_{y,wc}}{\gamma_{M0}}$$

$$k_3 = \frac{0,7b_{eff,t,wc} t_{wc}}{d_c}$$

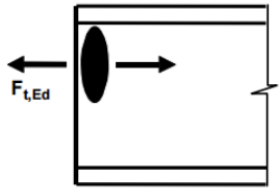
Column flange in bending



End-plate in bending



Beam web in tension



$$F_{t,wb,Rd} = b_{eff,t,wb} t_{wb} f_{y,wb} / \gamma_{M0}$$

Thin plate/
strong bolts

Mode 1: Complete flange yielding

$$F_t = \frac{4M_p \ell}{m}$$

Mode 2: Bolt failure with flange yielding

$$F_t = \frac{2M_p \ell + n \sum B_{t,Rd}}{m + n}$$

Mode 3: Bolt failure

$$F_t = \sum B_{t,Rd}$$

Thick plates/
weak bolts

Bolts M48

Yield strenght

$$f_{ybolt} := 900 \text{ MPa}$$

Ultimate tensile strenght

$$f_{ubolt} := 1000 \text{ MPa}$$

$$A_s := \frac{\pi}{4} \cdot (d_s - 0.938194 \cdot P)^2 = (1.473 \cdot 10^3) \text{ mm}^2$$

- bolt tensile strenght:

$$f_{ub} := 1000 \text{ MPa}$$

- Safety factor:

$$\gamma_{M2} := 1.25$$

- α_v is 0.6 for classes 4.6, 5.6, 8.8 other classes 0.5

$$\alpha_v := 0.5$$

- shear resistance:

$$F_{v.Rd} := \frac{\alpha_v \cdot f_{ub} \cdot A_s}{\gamma_{M2}} = 589.26 \text{ kN}$$

$$F_{t.Rd} := \frac{0.9 \cdot f_{ubolt} \cdot A_s}{\gamma_{M2}} = 1060.674 \text{ kN}$$

- Safety factor (2.2 EN1993-1-8)

$$\gamma_{M7} := 1.1$$

- Preloading force

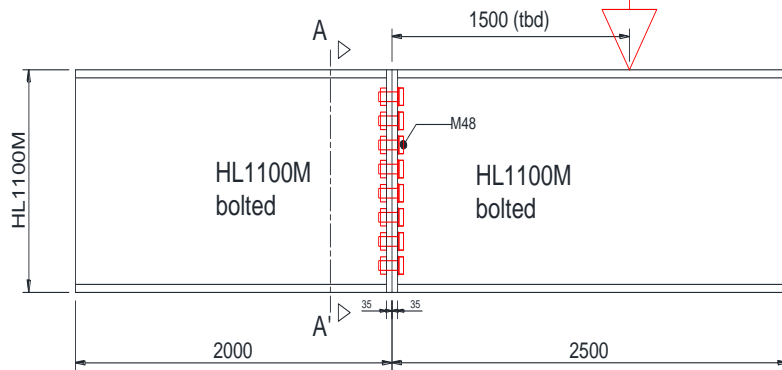
$$F_{p.C} := 0.7 \cdot f_{ub} \cdot A_s = (1.031 \cdot 10^3) \text{ kN}$$

- Preloading force

$$F_{p.Cd} := 0.7 \cdot f_{ub} \cdot \frac{A_s}{\gamma_{M7}} = 937.459 \text{ kN}$$

C3

Actuator

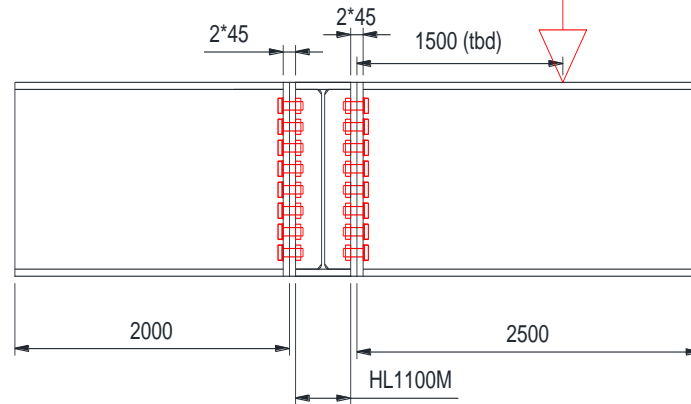


Envelope values:
 Msd=3.0MN
 Vsd=2.0MN

Welds:
 aw=15mm
 af=25mm

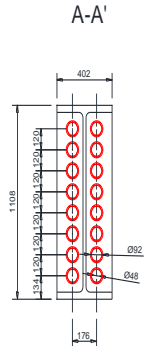
C4

Actuator



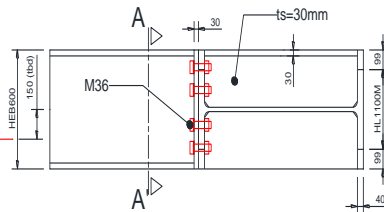
Envelope values:
 Msd=4.2MN
 Vsd=2.65MN

Welds:
 aw=15mm
 af=25mm



C5

Actuator

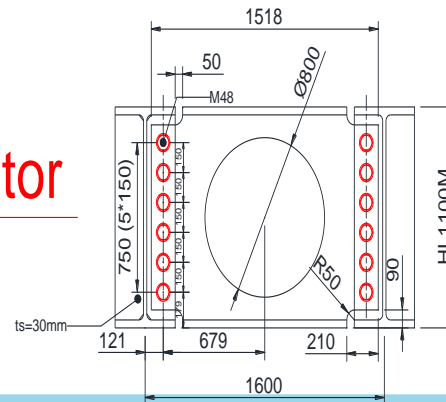


Envelope values:
 Msd=0.2MN
 Nsd=1.4MN

Welds:
 aw=10mm
 af=15mm

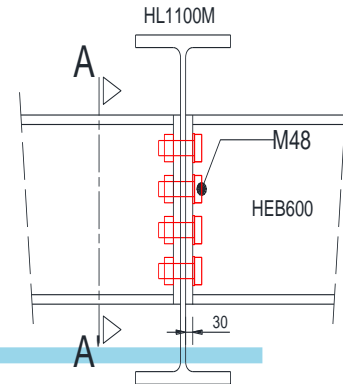
Actuator

C6



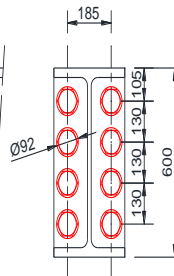
Envelope values:
 Nsd=2.7MN

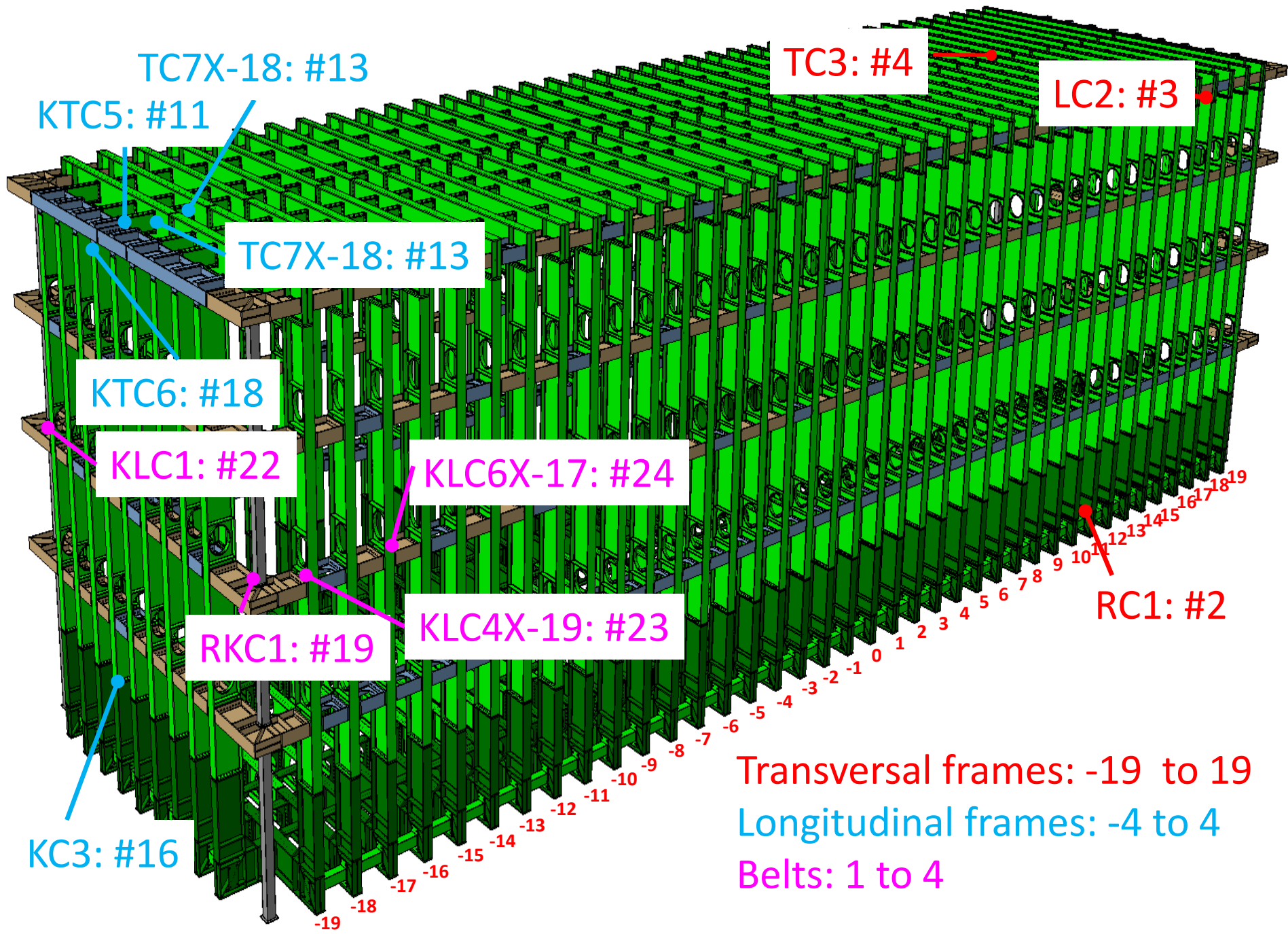
C7



CERN NP

A-A'





Worst case scenarios per connection

Drawing #	Frame	Joint ID	Joint type	Check #	check result	Load case	My [kNm]	N [kN]	Vz [kN]	Frame #	Location in frame
1	Transversal	LC1	C1	4	0.539339534	NC73	-6418.89	544.79	2563.18	16	2
2	Transversal	RC1	C1	1	0.443550638	NC73	6586.97	245.49	-2605.86	11	1
8	Longitudinal	KBC1	C1	4	0.728495929	NC39	-6096.26	2393.29	1988.49	1	4
14	Longitudinal	KC1	C1	4	0.480837333	NC39	6278.09	-128.01	-2432.29	-1	1
15	Longitudinal	KC1	C1	4	0.298629141	NC59	3555.06	-301.03	-1414.62	-4	1
19	Belt	RKC1	C1	4	0.912933328	NC73	-8483.59	2455.78	2832	2	1
22	Belt	KLC1	C1	4	0.95614156	NC39	-8478.68	2833.73	2455.61	2	3
3	Transversal	LC2	C2	4	0.986006341	NC73	-3829.03	727.08	-1442.81	16	2
4	Transversal	TC3	C3	4	0.409448574	NC37	1869.79	807.3	0	12	3
5	Transversal	LC3	C3	1	0.348029169	NC39	703.63	291.06	1813.58	-11	2
6	Transversal	LC3	C3	4	0.192624045	NC83	840.83	436.75	1217.45	16	2
7	Transversal	BC3_1	C3	4	0.357134864	NC73	339.97	2598.82	345.71	11	4
16	Longitudinal	KC3	C3	1	0.315012474	NC39	-471.01	-93.28	-1641.53	-1	1
17	Longitudinal	KC3	C3	4	0.210459432	NC87	-1166.68	-113.21	-216.33	-4	1
9	Longitudinal	KBC4X-19	C4	4	0.696770917	NC39	-2621.93	2393.29	1865.74	1	4
10	Longitudinal	KBC4X-19	C4	4	0.69931075	NC39	-2668.07	2351.08	1801.34	0	5
20	Belt	RKC4Y-3	C4	1	0.319197851	NC73	964.85	2449.26	1663.34	2	1
21	Belt	RKC4Y0	C4	4	0.936437341	NC73	4083.83	2436.76	39.1	2	1
23	Belt	KLC4X-19	C4	4	0.992530295	NC39	-4148.17	2833.73	2439.95	2	3
11	Longitudinal	KTC5	C5	4	0.60980831	NC73	138.22	1062.56	-138.59	-1	3
18	Longitudinal	KTC6	C6	1	0.29602852	NC73	0	113.19	830.36	-1	1
24	Belt	FLC6X-17	C6	3	0.761247892	NC39	0	2708.52	31.36	2	3
12	Longitudinal	TC7X-19	C7	1	0.056923378	NC39	-144.7	1050.59	-145.61	1	3
13	Longitudinal	TC7X-18	C7	4	0.414329574	NC73	-207.17	1049.85	41.94	-1	3



Institute for Sustainability and Innovation
in Structural Engineering



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UNIVERSIDADE DE COIMBRA



Universidade do Minho



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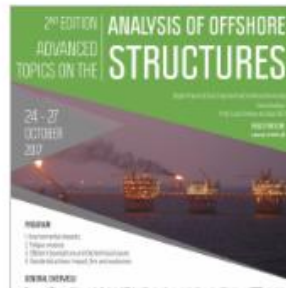
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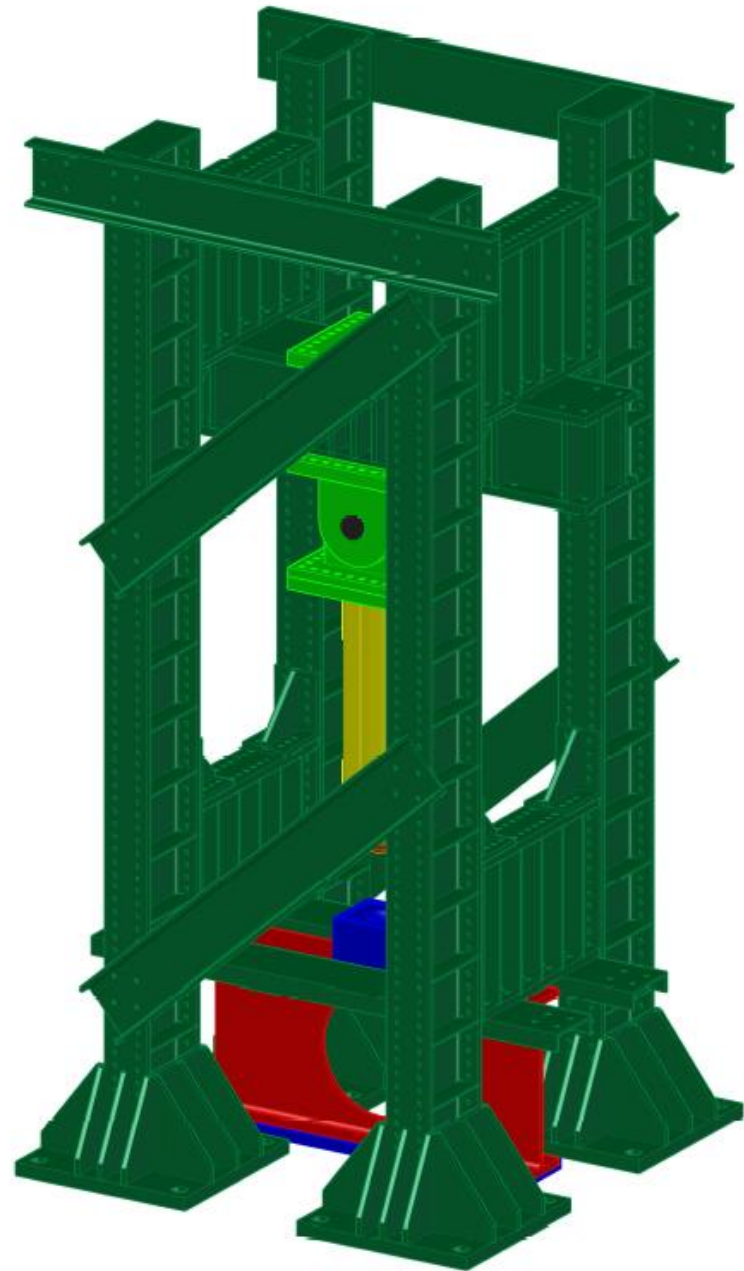
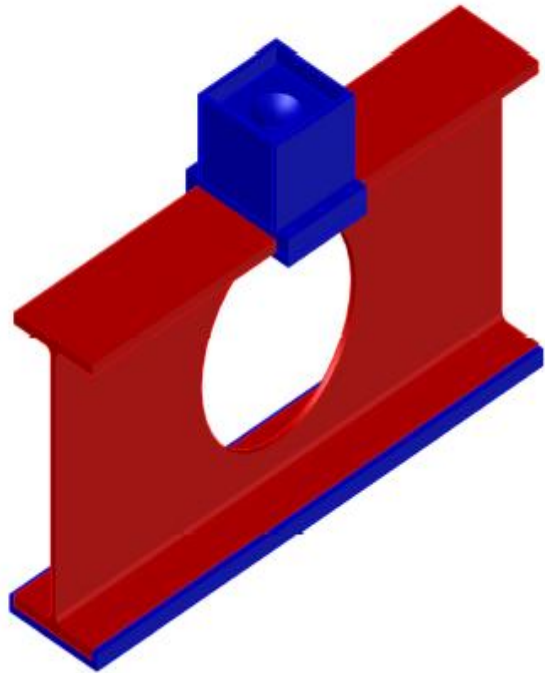


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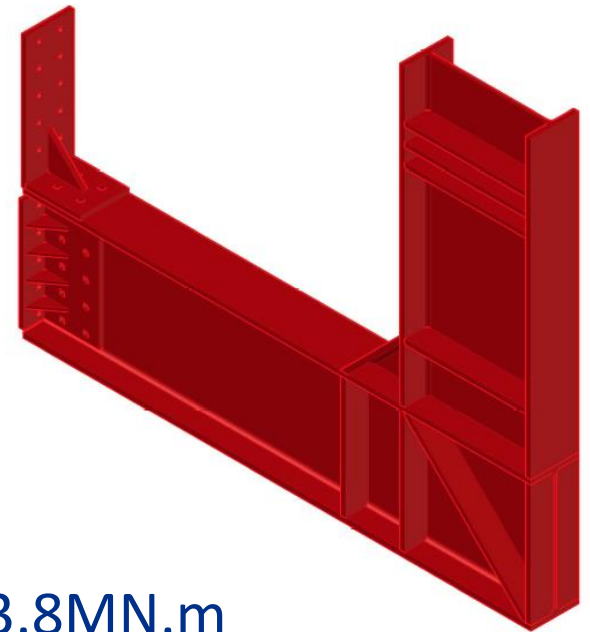
C0

- Compression test



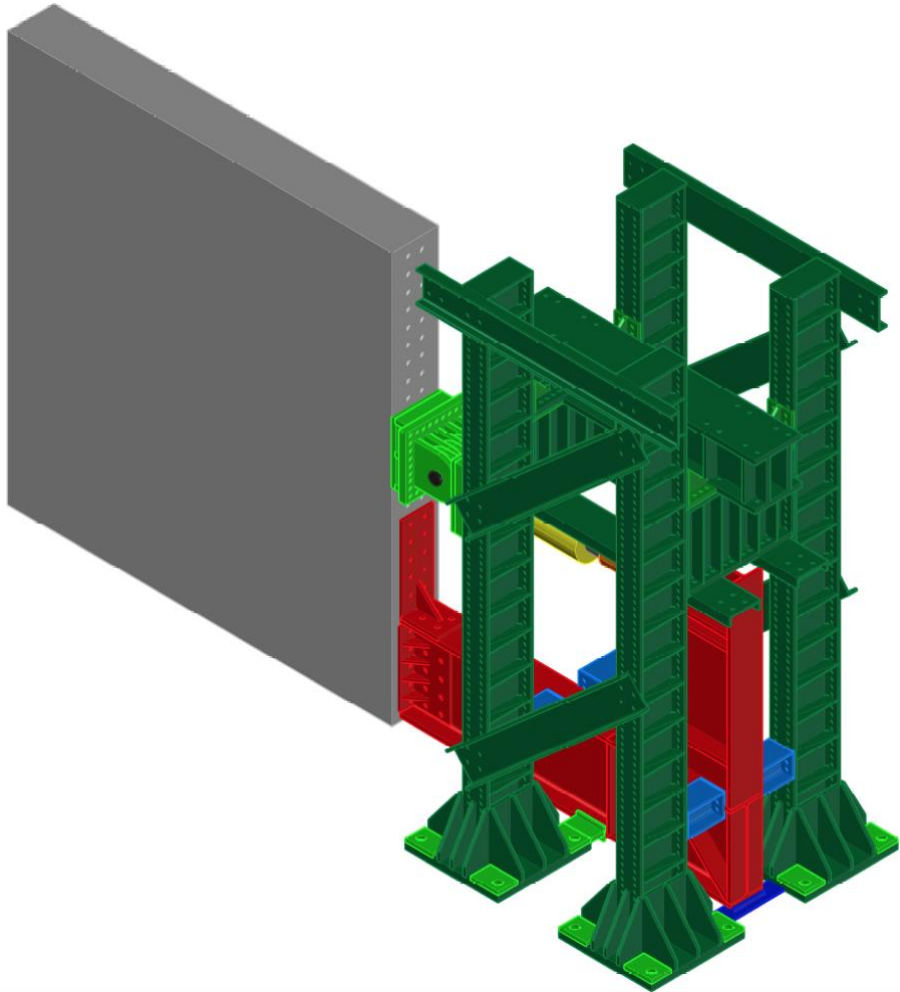
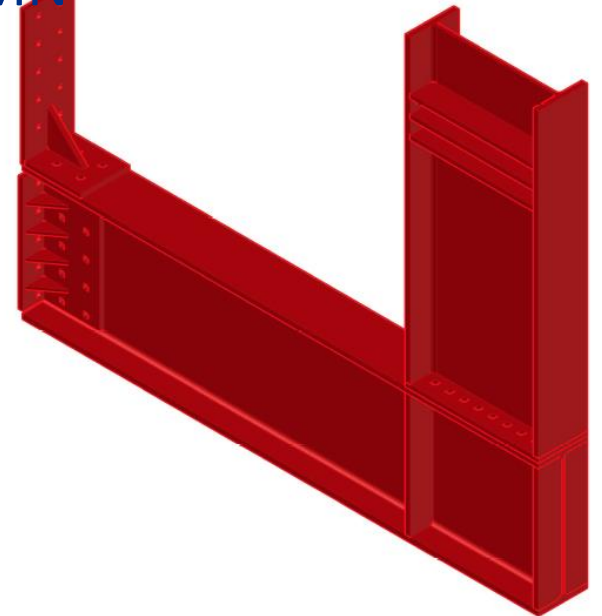
C1

- $M_{sd}=8.4\text{MN.m}$
- $V_{sd}=2.65\text{MN}$

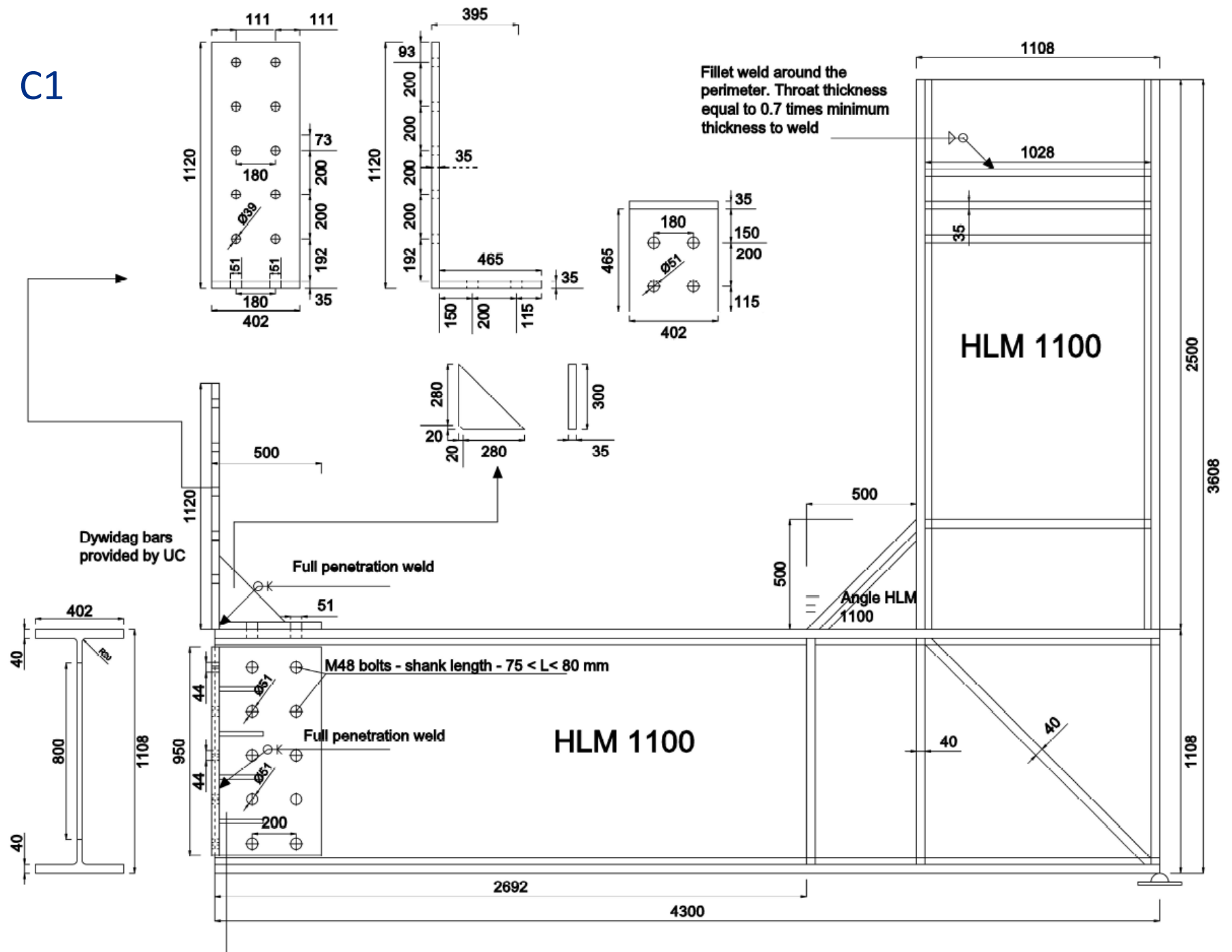


C2

- $M_{sd}=3.8\text{MN.m}$
- $V_{sd}=1.5\text{MN}$

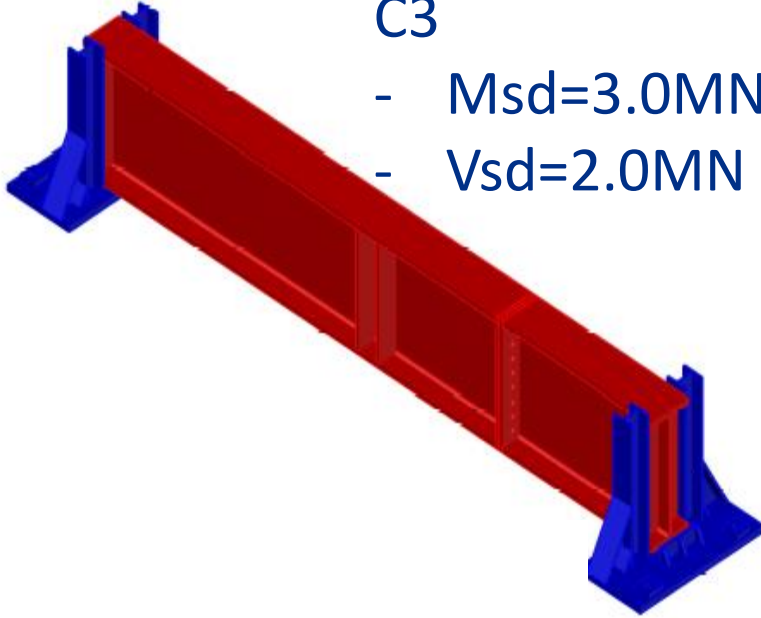


C1



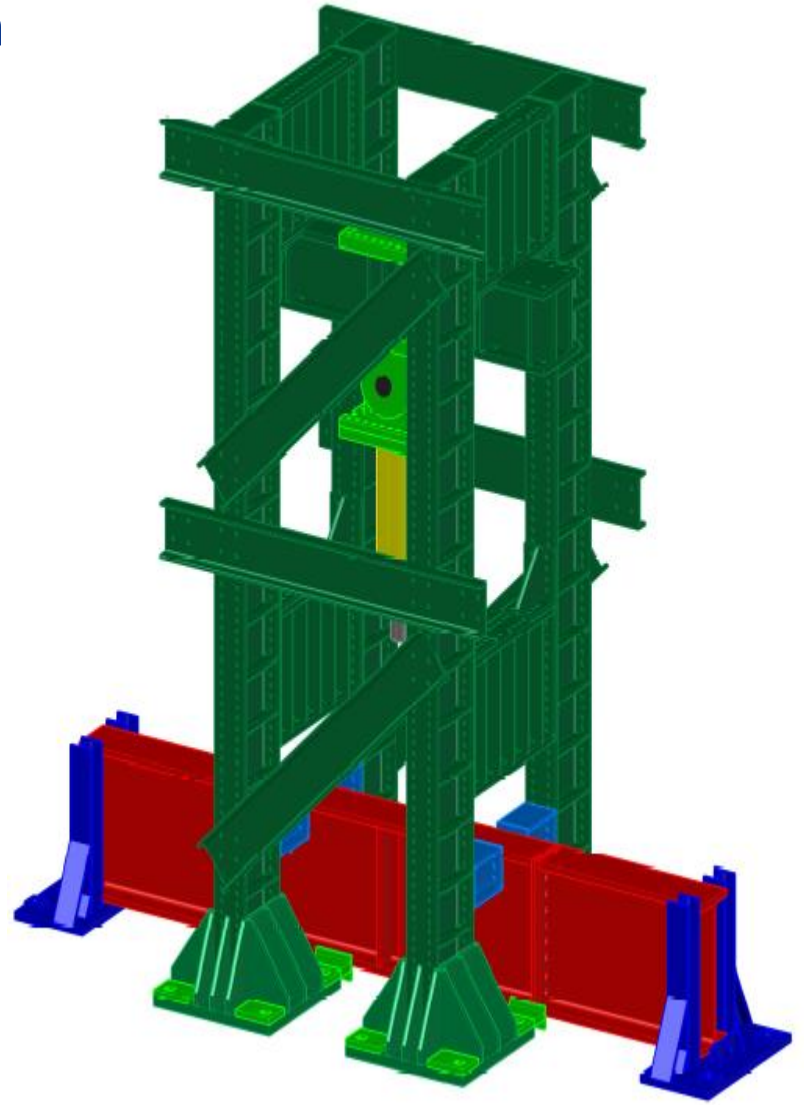
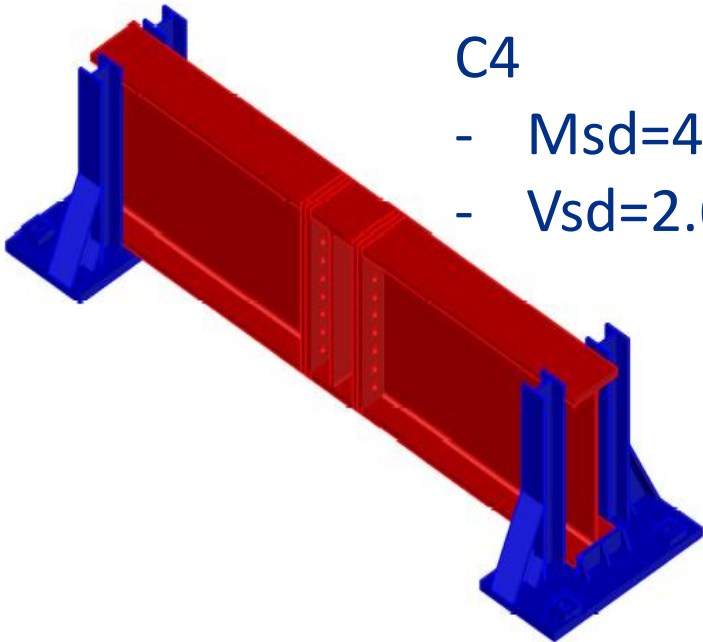
C3

- $M_{sd}=3.0\text{MN.m}$
- $V_{sd}=2.0\text{MN}$



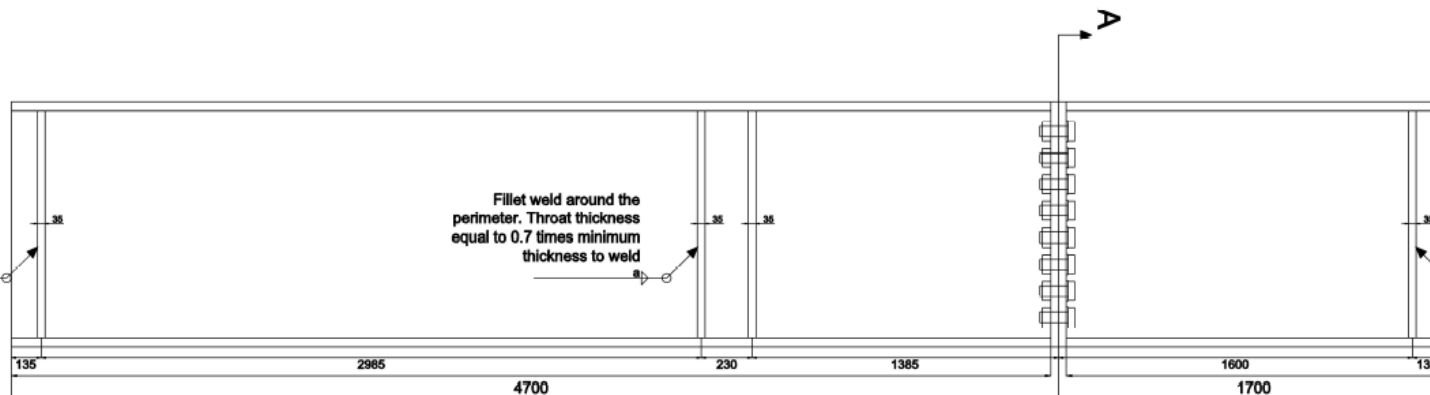
C4

- $M_{sd}=4.2\text{MN.m}$
- $V_{sd}=2.65\text{MN}$



C3

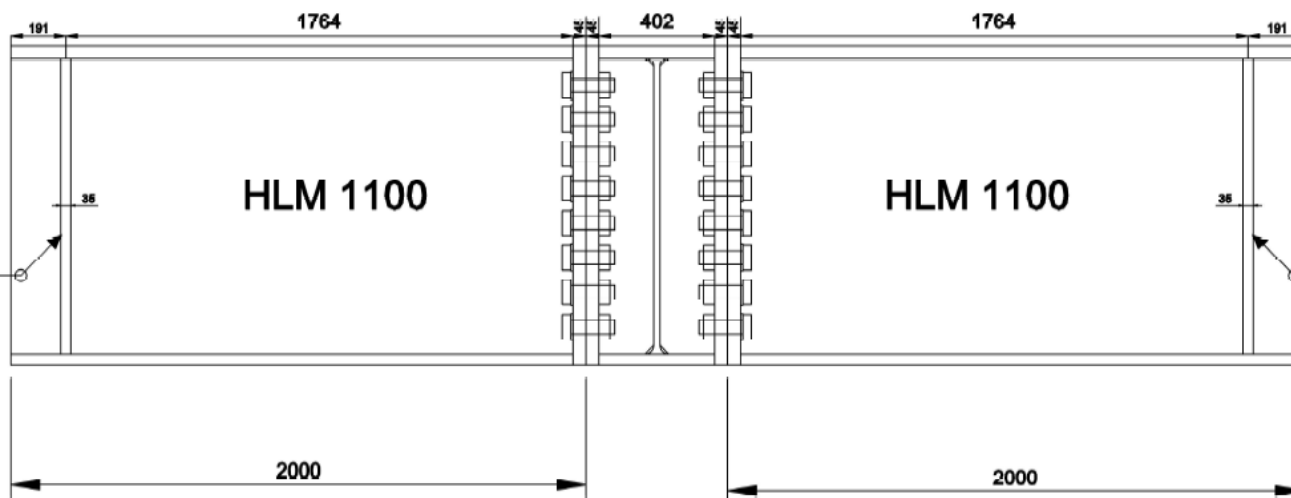
Fillet weld around the perimeter. Throat thickness equal to 0.7 times minimum thickness to weld



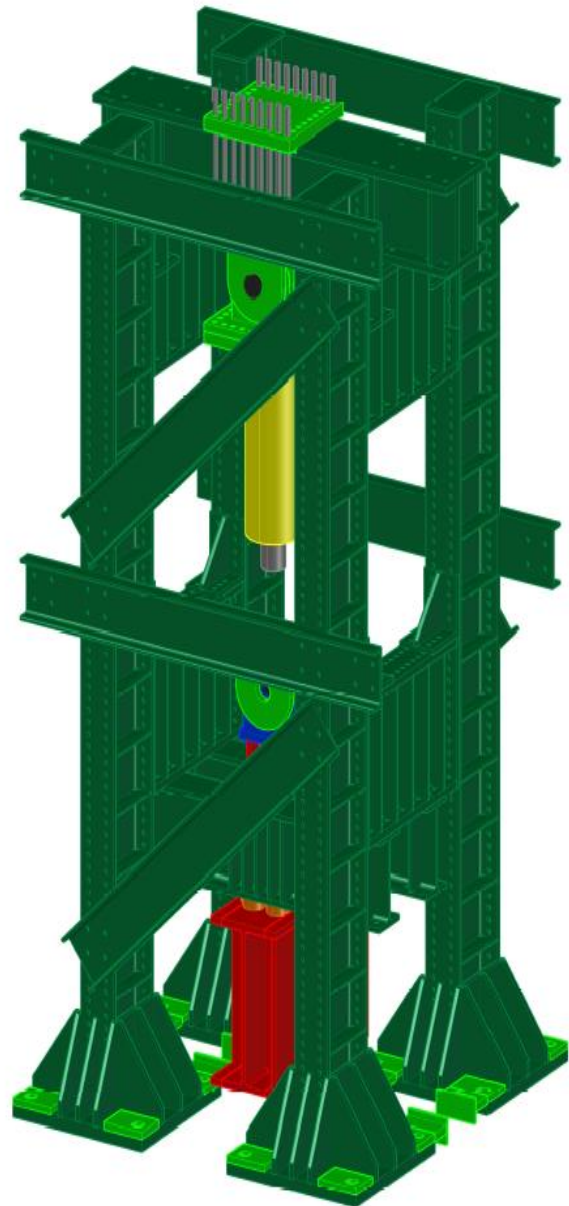
HLM 1100

C4

Fillet weld around the perimeter. Throat thickness equal to 0.7 times minimum thickness to weld

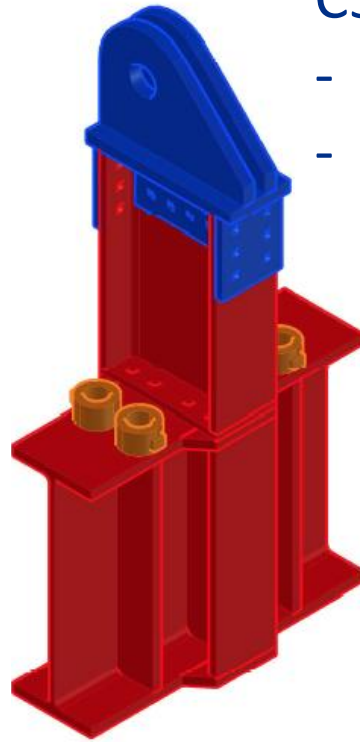


Fillet weld around the perimeter. Throat thickness equal to 0.7 times minimum thickness to weld



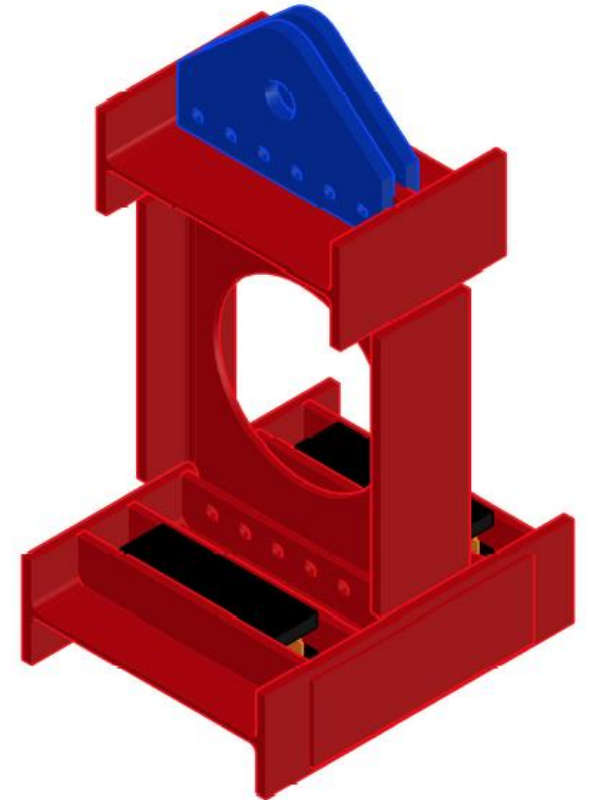
C5

- $M_{sd}=0.2\text{MN}\cdot\text{m}$
- $N_{sd}=1.4\text{MN}$

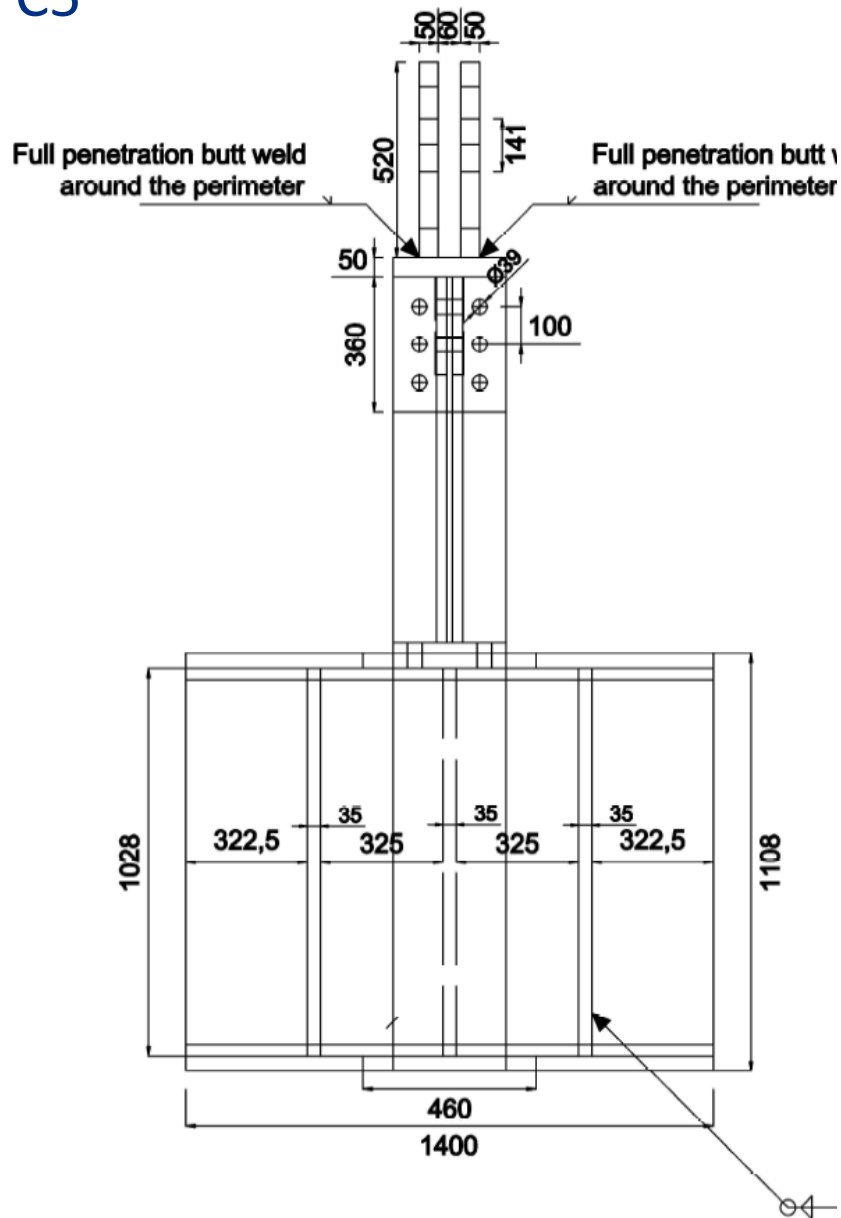


C6

- $N_{sd}=2.7\text{MN}$



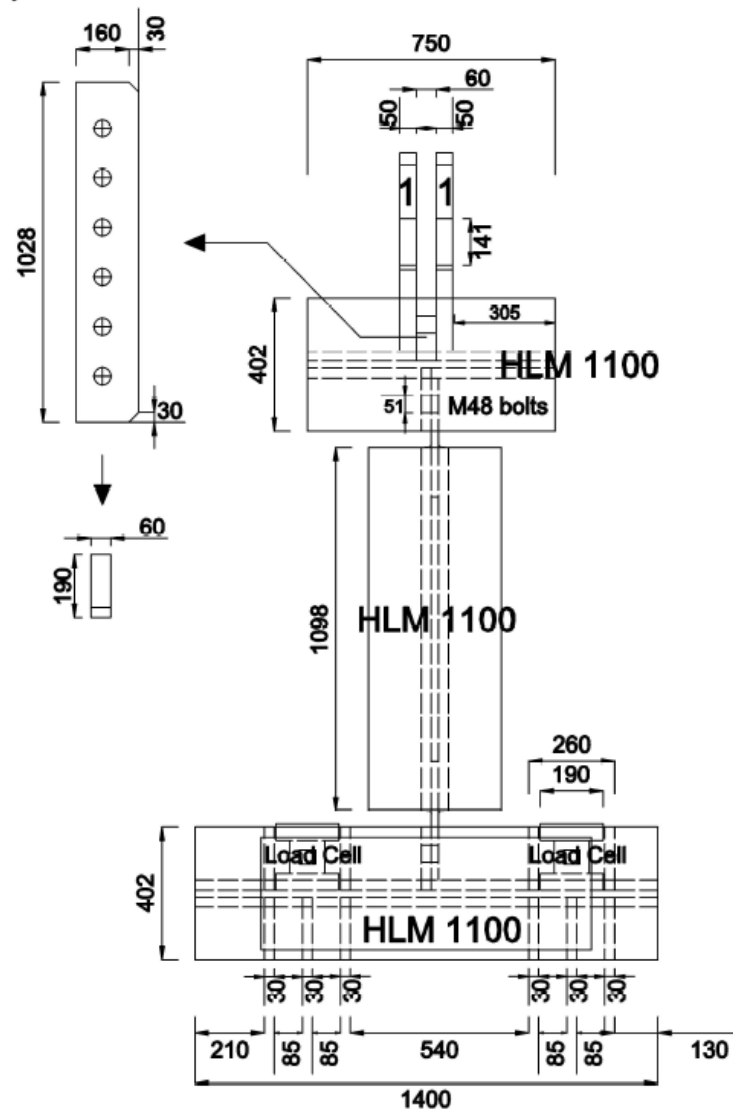
C5



C6

Front View

This steel plate is optional. Additional details to be provided by CERN.



Summary

- Capacity of the joints calculated by analytical methods (at CERN and checked by contracting company)
- Capacity of the joints verified with FEA at CERN
- Tests at University of Coimbra are planned to check capacity (125%)