DESIGN AND DEVELOPMENT OF HYDRAULIC-ELECTRO-MECHANICAL SYSTEM TO APPLY PRE-STRESSED CFRP LAMINATES ACCORDING TO THE NSM TECHNIQUE IN LABORATORY CONDITIONS

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The present report is part of the research Project PreLami - Performance of reinforced concrete structures strengthened in flexural with an innovative system using prestressed NSM CFRP laminates, supported by FCT and with the reference PTDC/ECM/114945/2009

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Keywords: prestress line unit; prestressed CFRP laminates; NSM

School of Engineering | Department of Civil Engineering | University of Minho | Fundação para a Ciência e Tecnologia

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SUMMARY

This document describes the design and implementation of a Hydraulic-Electro-Mechanical System to apply Pre-Stressed CFRP Laminates according to the NSM Technique in Laboratory conditions.

All the elements that constitute this system are described and its design is also presented. This document is also accompanied of Annexes, containing all the execution plans of this system.

1 INITIAL PRESTRESS SYSTEM

The initial setup designed consisted in a reinforced concrete tank able of providing the conditions to apply prestress to reinforced concrete elements either hardened or casted in place. The tank was idealized as consisting on modules 1.5 m long (Figure 1 and Table 1). Half of the tank module was modelled, ignoring the existence of any reinforcement since its existence had negligible effect, and simplified greatly the modelling process.

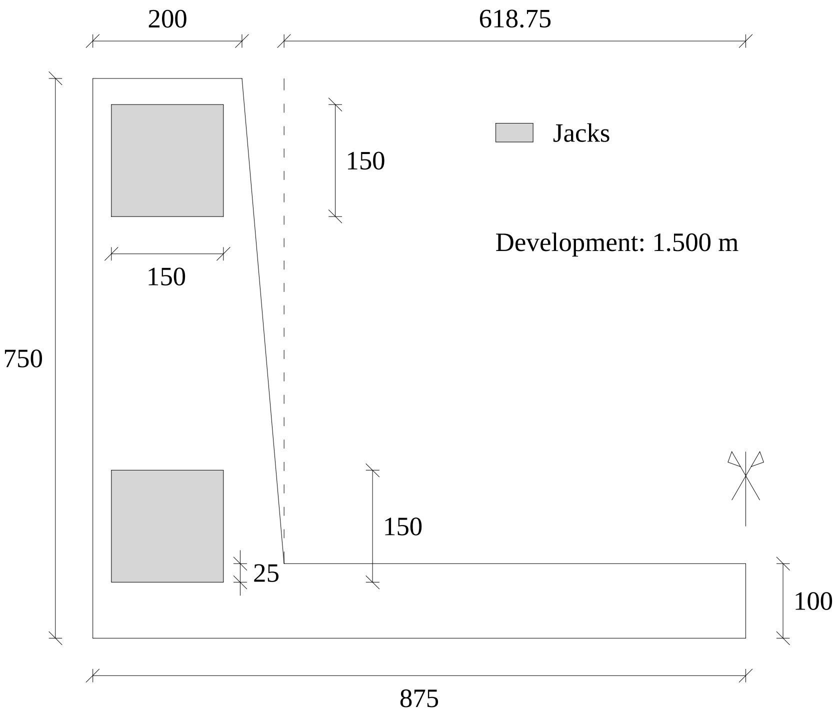


Figure 1 – Module dimensions.

Table 1 – Concrete and steel characteristics.

Property	Concrete (C30/37)	Steel (ϕ12 mm)
Weight (p)	2.5×10^{-5} N/mm^3	Negligible
Elastic Modulus (E)	33×10^3 MPa	200×10^3 MPa
Poison coefficient (ν)	0.20	0.30
Compressive strength	38 MPa	> 400 MPa
Tensile Strength	f_{ctm} = 2.9 MPa / $f_{ctk,0.05}$ = 2.0 MPa	> 400 MPa

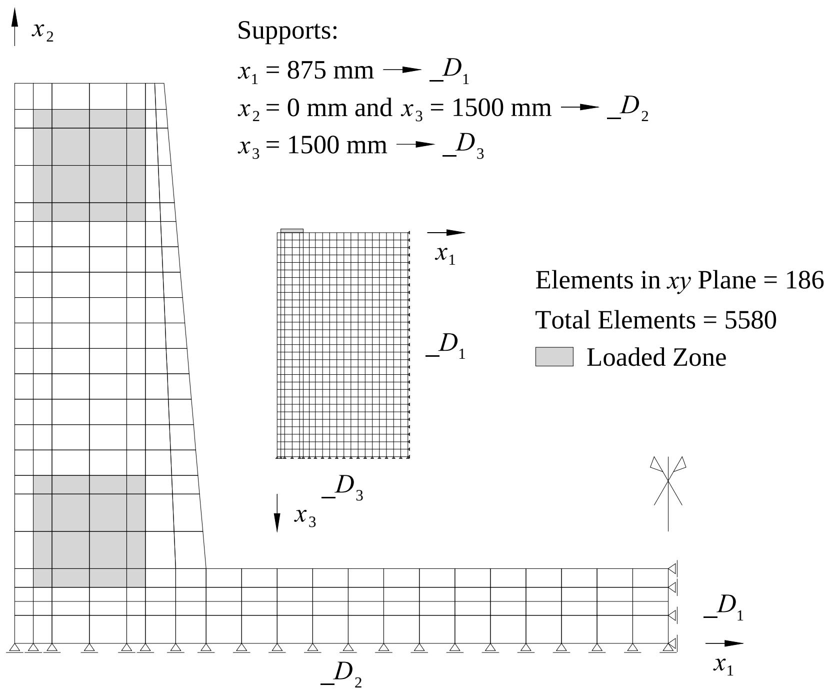
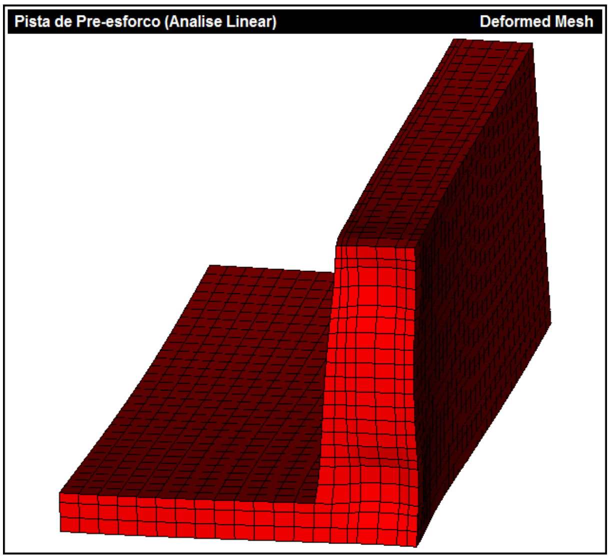
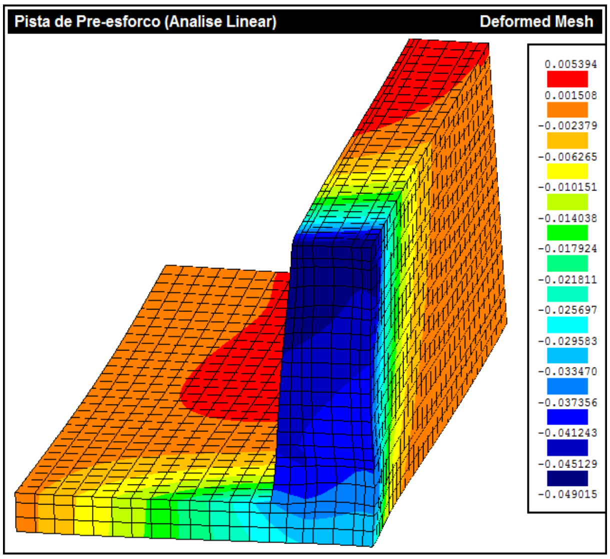


Figure 2 – Finite elements mesh.

The module was simulated considering an applied load of 400 kN, equivalent to a total load of 800 kN. This load was uniformly distributed in the nodes of the shaded elements depicted in Figure 2, considering the influence area of each node. The dead load of the modulus was considered in direction 2. The obtained deformed mesh is depicted in Figure 3 and the stresses produced in Figure 4.

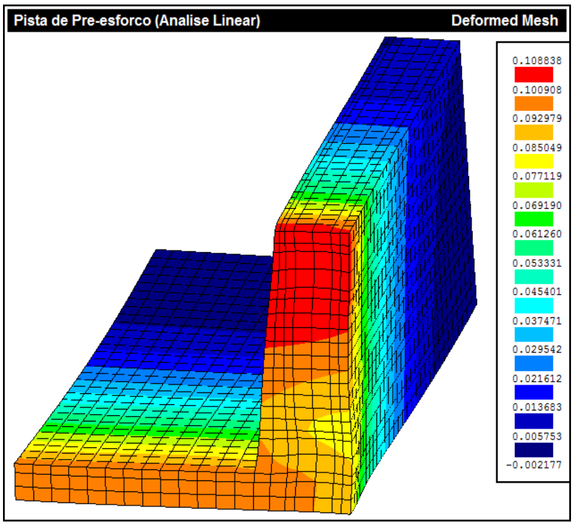


(a) – Deformed mesh.

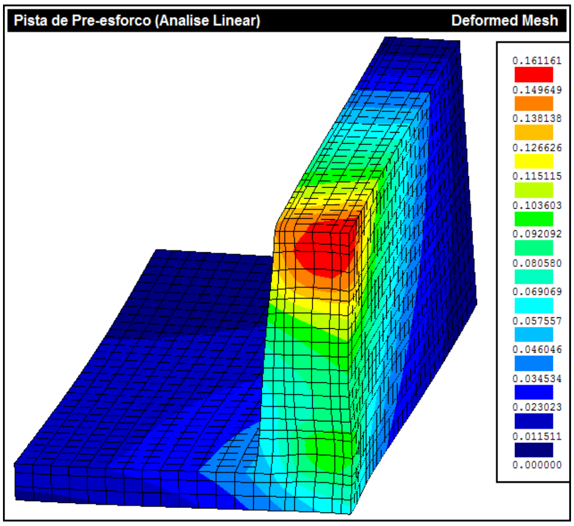


(b) – Displacements in x_1.

(cont.)

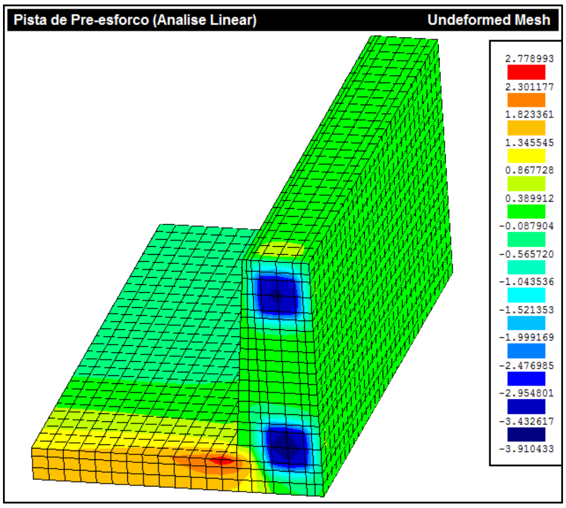


(c) – Displacements in x_2.

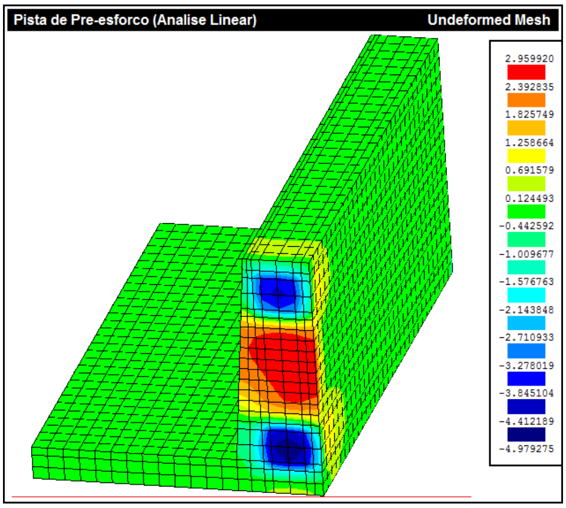


(d) – Displacements in x_3.

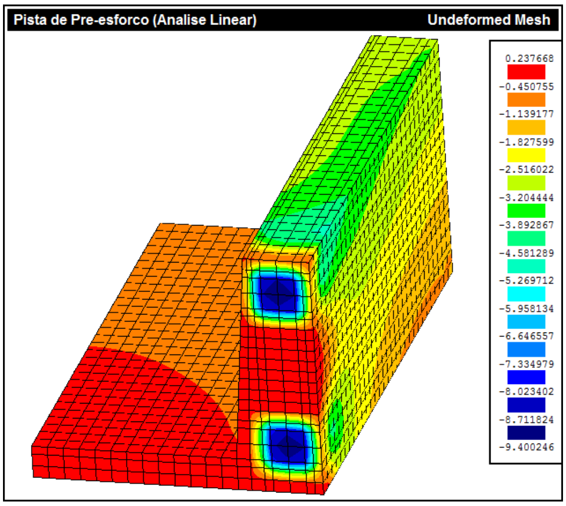
Figure 3 – Deformed mesh of the module.



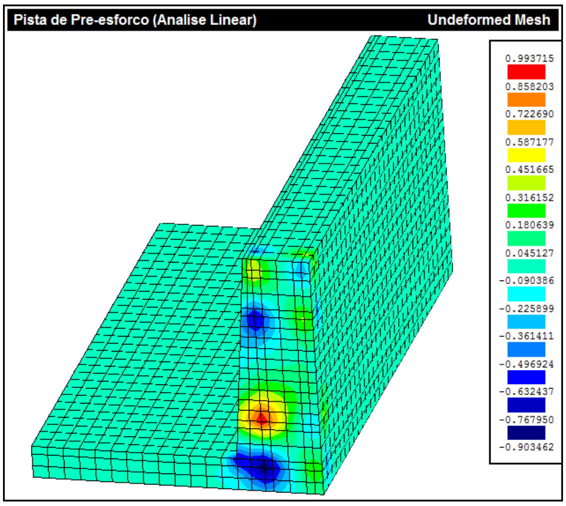
(a) – Stresses in x_1.



(b) – Stresses in x_2.

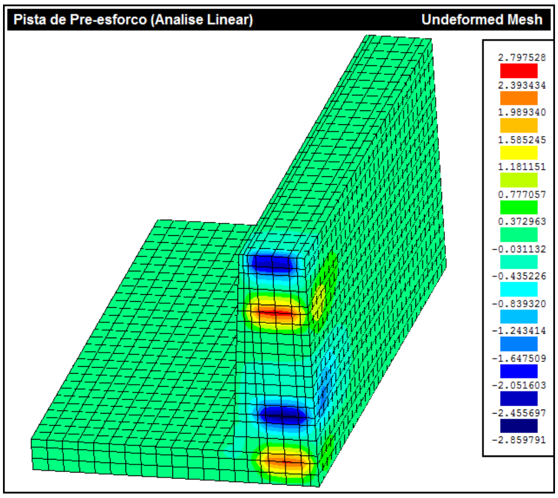


(c) – Stresses in x_3.

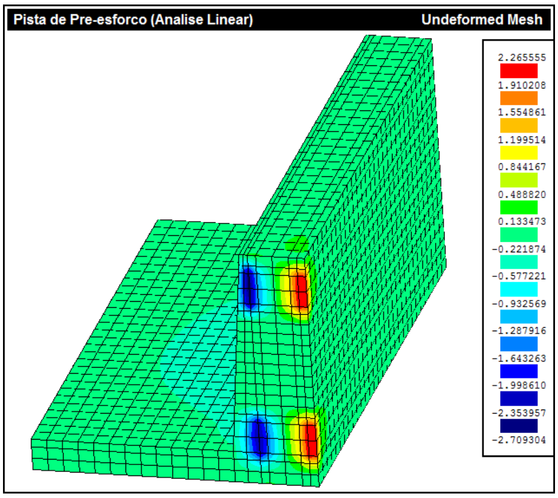


(d) – Stresses in the plane x_1x_2.

(cont.)



(e) – Stresses in the plane x_2x_3.



(f) – Stresses in the plane x_3x_1.

Figure 4 – Representation of the stress fields installed in the module.

Table 2 – Maximum and minimum displacements and stresses obtained in the simulation.

Value	Minimum	Maximum
Displacement in x_1	-0.049 mm	0.005 mm
Displacement in x_2	-0.002 mm	0.109 mm
Displacement in x_3	0.000 mm	0.161 mm
Stress σ_1 (axis x_1)	-3.910 MPa	2.779 MPa
Stress σ_2 (axis x_2)	-4.979 MPa	2.960 MPa
Stress σ_3 (axis x_3)	-9.400 MPa	0.238 MPa
Stress τ_{12} (plane x_1x_2)	-0.903 MPa	0.994 MPa
Stress τ_{23} (plane x_2x_3)	-2.860 MPa	2.798 MPa
Stress τ_{31} (plane x_3x_1)	-2.709 MPa	2.266 MPa
Principal compression stress	-8.975 MPa (-8.112 MPa)	-
Principal tensile stress	-	2.854 MPa (2.073 MPa)

(Average stress in the finite element)

Considering the Gauss points with principal tensile stress higher that $f_{ctk,0.05}$ (2.0 MPa in case of C30/37 plain concrete), the most stressed zones are presented in Figure 5.

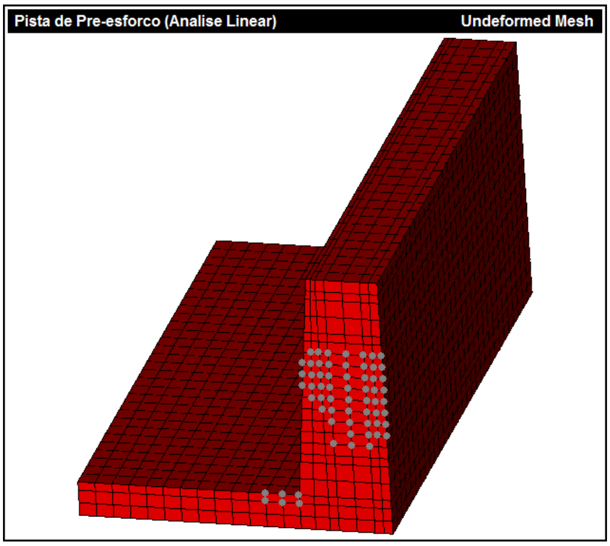


Figure 5 – Zones with principal tensile stress higher than $f_{ctk,0.05}$.

In all integration points, the principle compressive stress is lower than 30 MPa, and the maximum principle tensile stress lower than the average tensile strength, 2.9 MPa. According to these results, it is assumed that the adopted geometry and materials verify safety criteria.

1.1 Transport conditions

Given the fragility of the lower section of this U-shape, transport should be performed with special care. In this section, the safety verification of the transporting conditions is showed.

To simulate transport conditions the U-shape was assumed to be supported in centre of the top face, in two nodes, 700 mm apart (Figure 6). Besides the two nodal supports were placed in the top face, which prevent the displacement in directions 2 and 3, the symmetry supports were also considered.

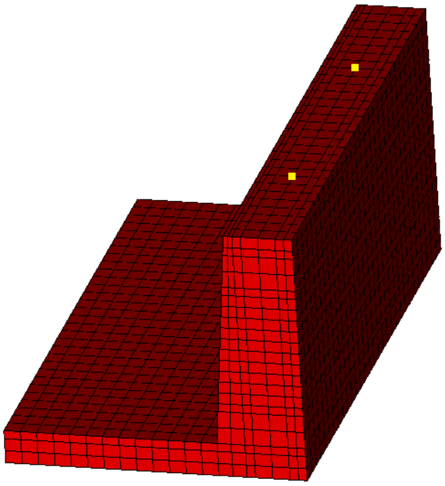
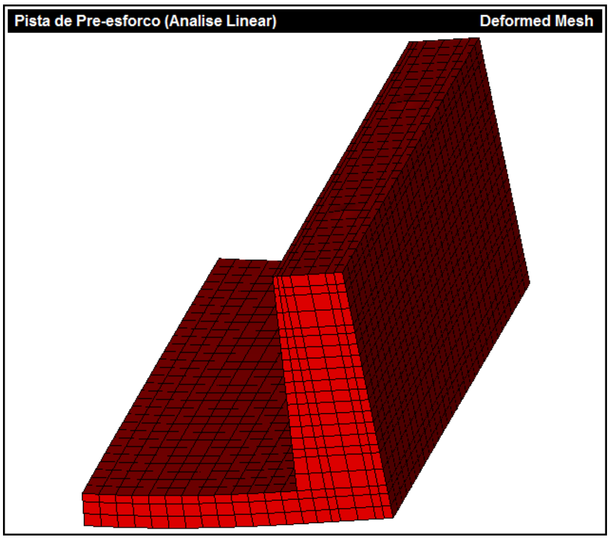
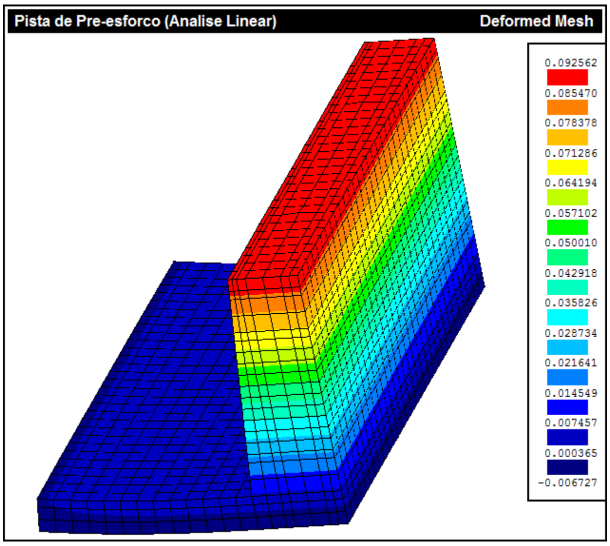


Figure 6 – Supports for transporting.

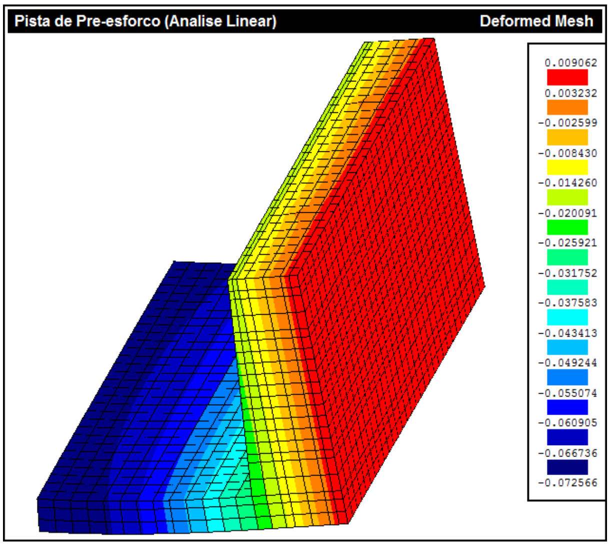
In this simulation, displacements and stresses were also observed and analysed (Figures 7 and 8).



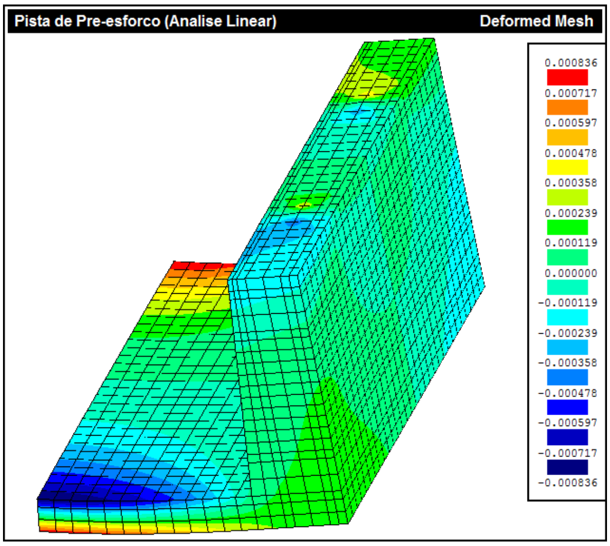
(a) – Deformed mesh.



(b) – Displacements in x_1.

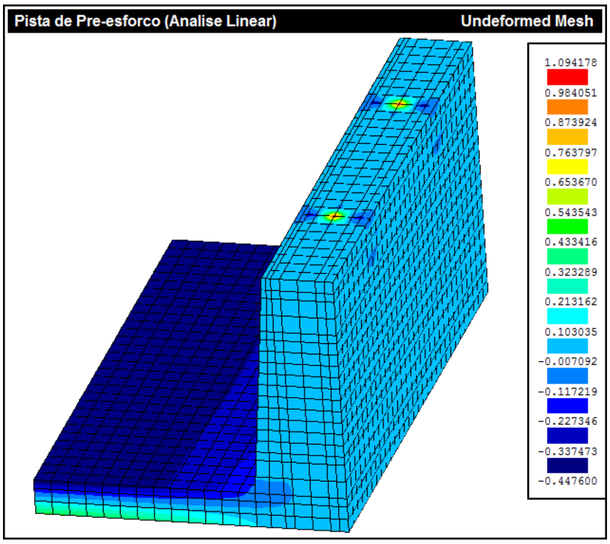


(c) – Displacements in x_2.

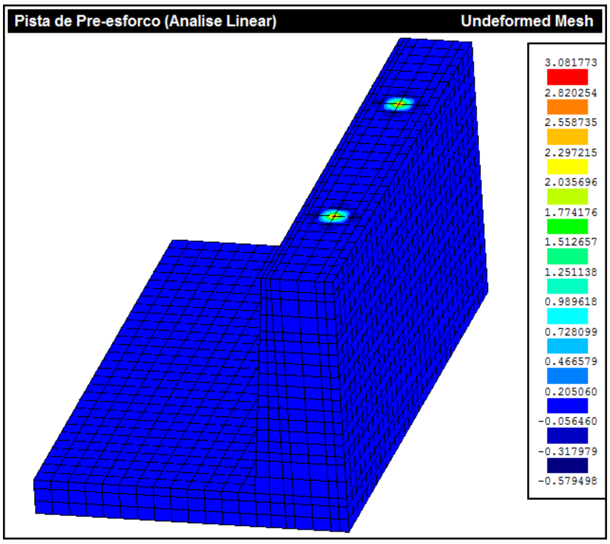


(d) – Displacements in x_3.

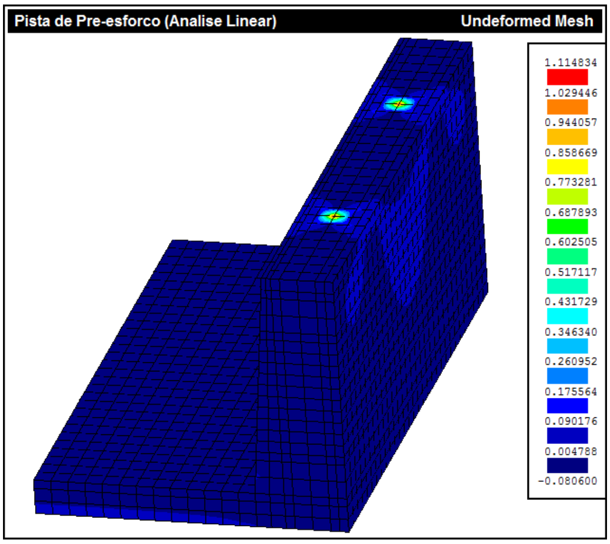
Figure 7 – Displacements under transporting conditions.



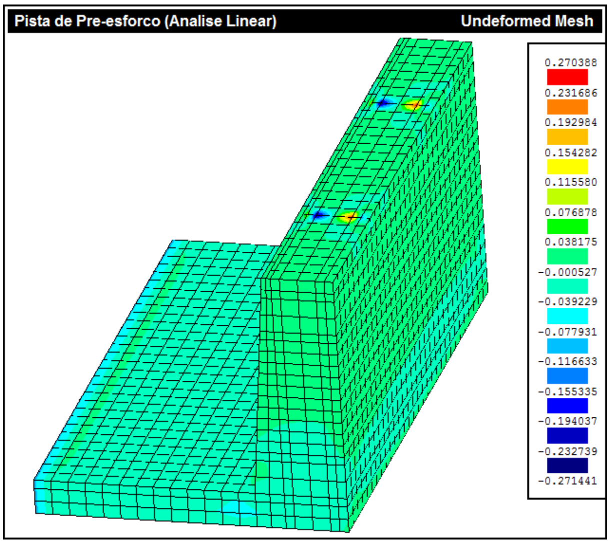
(a) – Stresses in x_1.



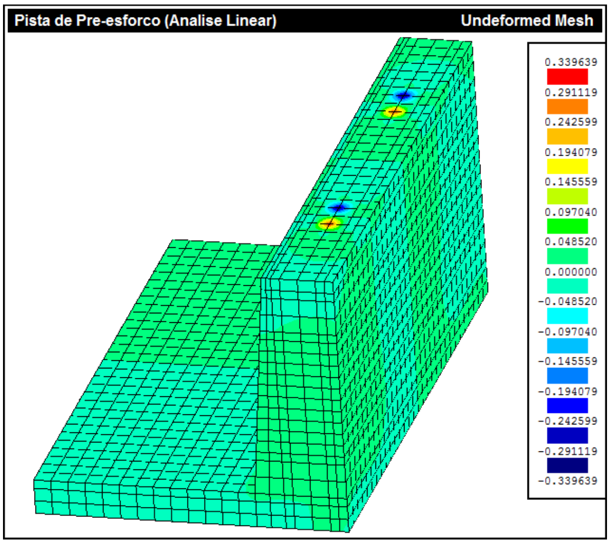
(b) – Stresses in x_2.



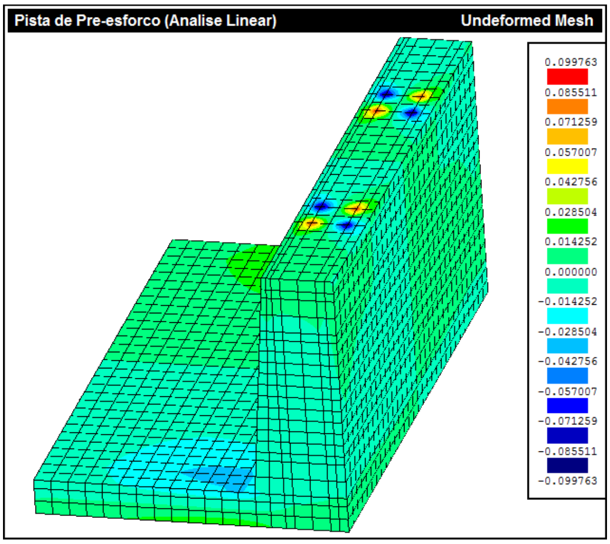
(c) – Stresses in x_3.



(d) – Stresses in the plane x_1x_2.



(e) – Stresses in the plane x_2x_3.



(f) – Stresses in the plane x_3x_1.

Figure 8 – Representation of the stress fields under transporting conditions.

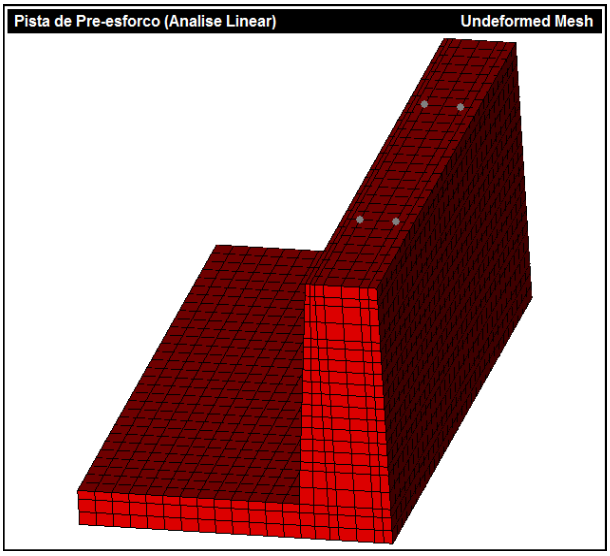


Figure 9 – Zones with principal tensile stress higher than $f_{ctk,0.05}$.

Table 3 – Maximum and minimum displacements and stresses under transporting conditions.

Value	Minimum	Maximum
Displacement in x_1	-0.007 mm	0.093 mm
Displacement in x_2	-0.073 mm	0.009 mm
Displacement in x_3	-0.001 mm	0.001 mm
Stress σ_1 (axis x_1)	-0.448 MPa	1.094 MPa
Stress σ_2 (axis x_2)	-0.579 MPa	3.082 MPa
Stress σ_3 (axis x_3)	-0.081 MPa	1.115 MPa
Stress τ_{12} (plane x_1x_2)	-0.271 MPa	0.270 MPa
Stress τ_{23} (plane x_2x_3)	-0.340 MPa	0.340 MPa
Stress τ_{31} (plane x_3x_1)	-0.100 MPa	0.100 MPa
Principal compression stress	-0.508 MPa (-0.336 MPa)	-
Principal tensile stress	-	2.356 MPa (0.851) MPa

Under transport conditions, safety is also verified, since the maximum principle stresses in the gauss points is also lower than the limit values.

1.2 TRANSPORTING SCHEME

Transport will be assured by S235 rectangular hollow sections with 80×40×5 (mm^3).

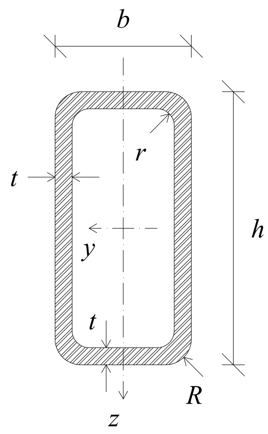


Figure 10 – Rectangular hollow section.

The geometric characteristics of the rectangular hollow section are given by the supplier:

Mass (p)	8.42 kg/m
Height (h)	80 mm
Width (b)	40 mm
Thickness (t)	5 mm
Internal radius (r)	5.0 mm
External radius (R)	7.5 mm
Cross section (A)	1070 mm^2
Second moment of area (I_y)	80.3×10^4 mm^4
Elastic section modulus ($W_{el,y}$)	20.1×10^3 mm^3
Radius of gyration (i_y)	2.74×10 mm
Second moment of area (I_z)	25.7×10^4 mm^4
Elastic section modulus ($W_{el,z}$)	$12.\ 9\times10^3$ mm^3
Radius of gyration (i_z)	1.55×10 mm

Table 4 – Maximum stresses and deflection of the hollow section.

Value	Device 1	Device 2
Applied load (P)	10000 N (1 ton)	20000 N (2 ton)
Span (L)	1470 mm	800 mm
Maximum applied moment ($M_{Ed} = PL/4$)	3.675×10^6 Nmm	4.000×10^6 Nmm
Resisting bending moment ($M_{el,y} = W_{el,y} \times f_y$)	4.724×10^6 Nmm	4.724×10^6 Nmm
Maximum deflection $L/200$	7.750 mm	3.500 mm
Installed deflection ($f_{max} = PL^3/48EI$)	4.121 mm	0.664 mm

f_y = 235 MPa

The constructive reinforcement consists in two steel rings, each with a diameter of 12 mm (or higher). These steel rings should be connected by means of stirrups also with 12 mm diameter. In each of these sets, two 12 mm handles provide the conditions to properly transport the concrete module. All details necessary to produce this modulus is detailed in Annex I.

1.3 PRESTRESS FRAME

The concrete structure previously shown is, in fact, the supporting frame of the structure to withstand the prestress operations. Additionally, a steel frame needs was designed to enable the anchorage of the prestress materials.

This steel frame is composed by 3 types of plates: type 1 (20 mm thick), type 2 (12 mm thick) and type 3 (8 mm thick). The disposition of these plates is depicted in Figures 11 to 13. Additionally, rectangular hollow sections that act as stiffeners are also modelled to reinforce the existent small windows.

Considering that prestress will be applied in different zones, depending on the prestress task defined, several load case combinations were defined to better understand the behaviour of this frame (Table 5).

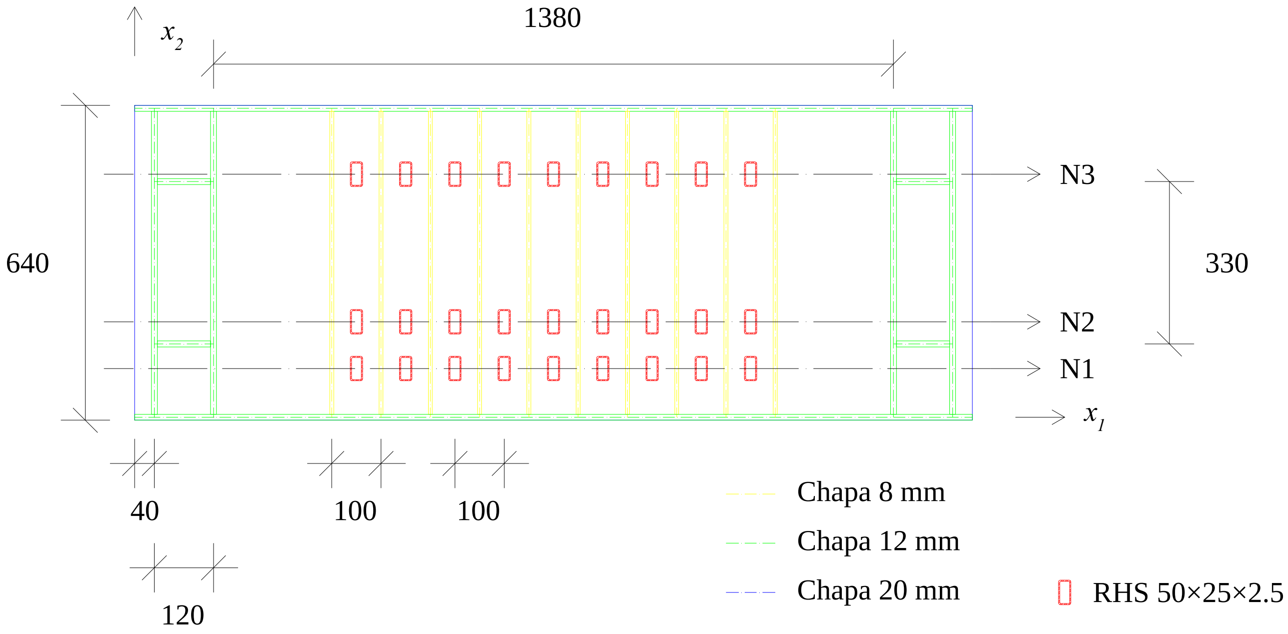


Figure 11 – Dimensions of the steel frame (in mm).

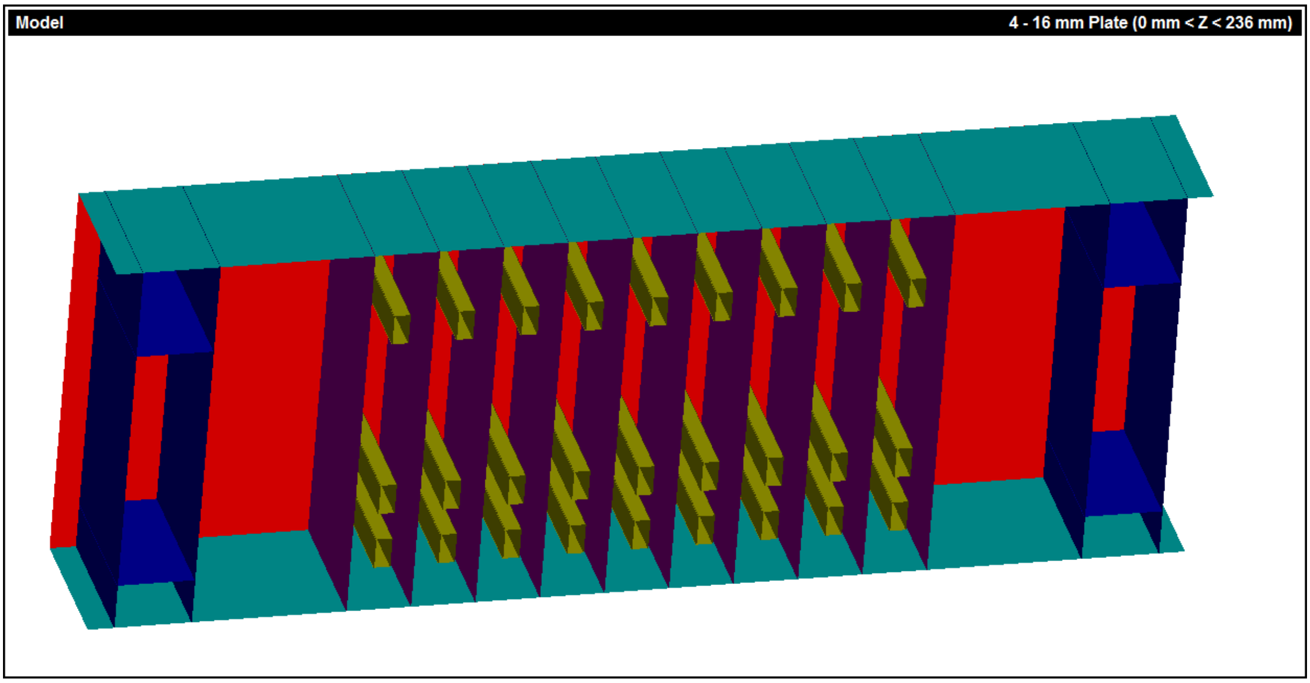


Figure 12 – Internal view.

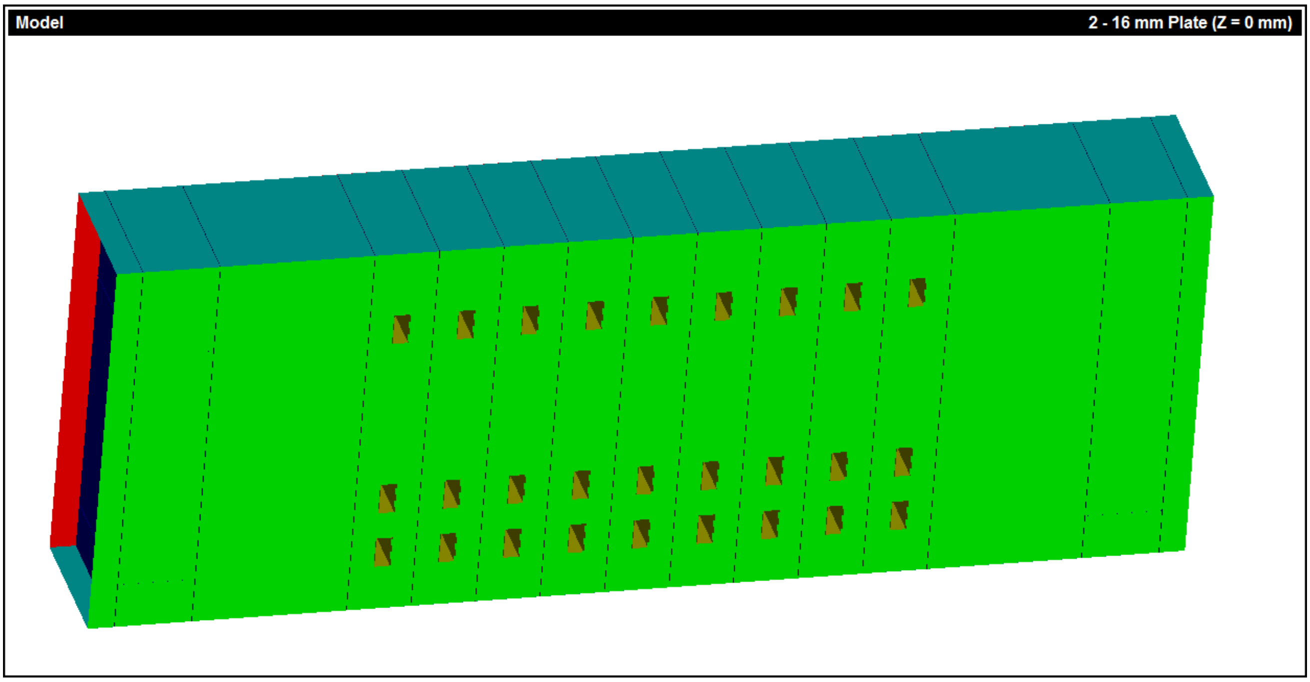


Figure 13 – External view.

Table 5 – Load case combinations.

Combination Number	Description
1	Control combination. Dead weight.
2	Dead weight + 80 ton prestress in N1.
3	Dead weight + 80 ton prestress in N2.
4	Dead weight + 80 ton prestress in N3.
5	Dead weight + 40 ton prestress in N1 + 40 ton prestress in N2.

The support conditions and the localization of the nodal loads applied are depicted in Figures 14 and 15. The elements were modelled as 8-nodes Mindlin shell elements. The integration scheme used 2 points of integrations for the flexural terms, as well as for the shear and membrane terms.

The results of the numerical model are also presented. In Figure 16 the deformed meshes are presented for the direction x_3. In Figure 17 the stress distribution is presented for the most unfavourable combination (Combination 3). No results are presented about combination 5 since, as the supports were modelled as springs, convergence was not attained. However, previous simulations have shown that the most unfavourable combination is, in fact, combination 2.

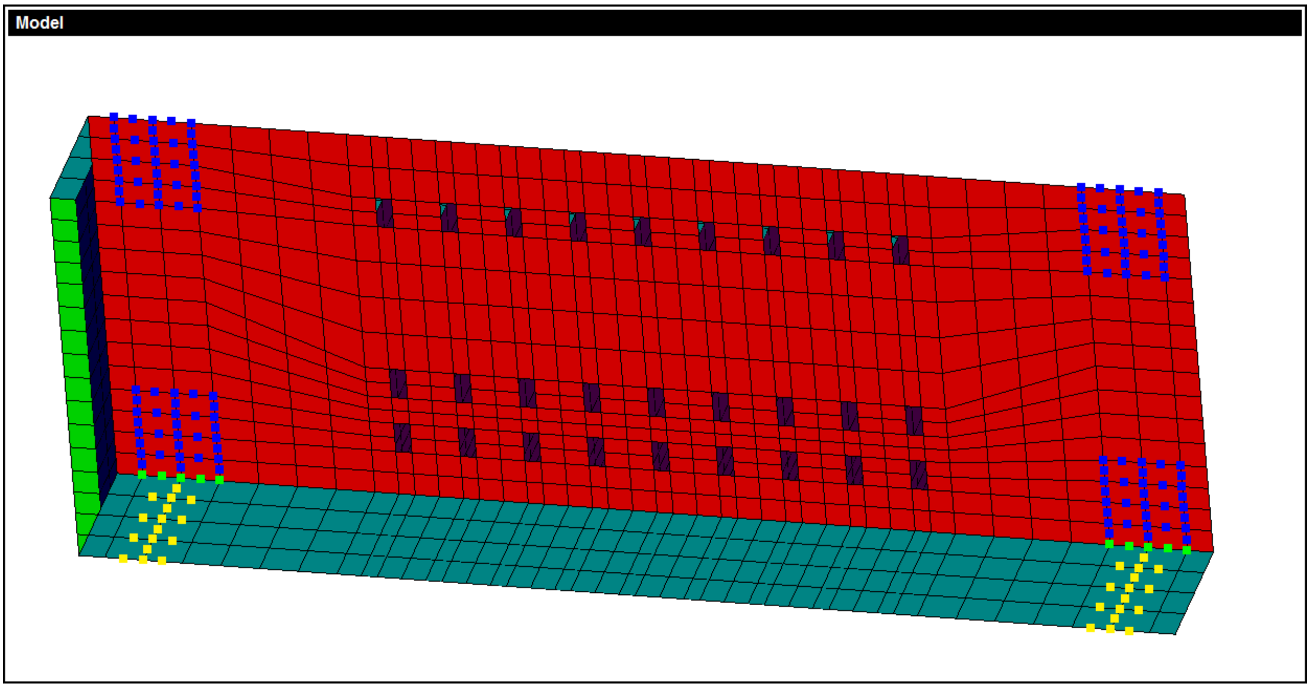


Figure 14 – Support conditions.

(Blue – Displacement blocked in x_3; Yellow – Displacement blocked in x_2; Green – Displacement blocked in x_2 and x_3)

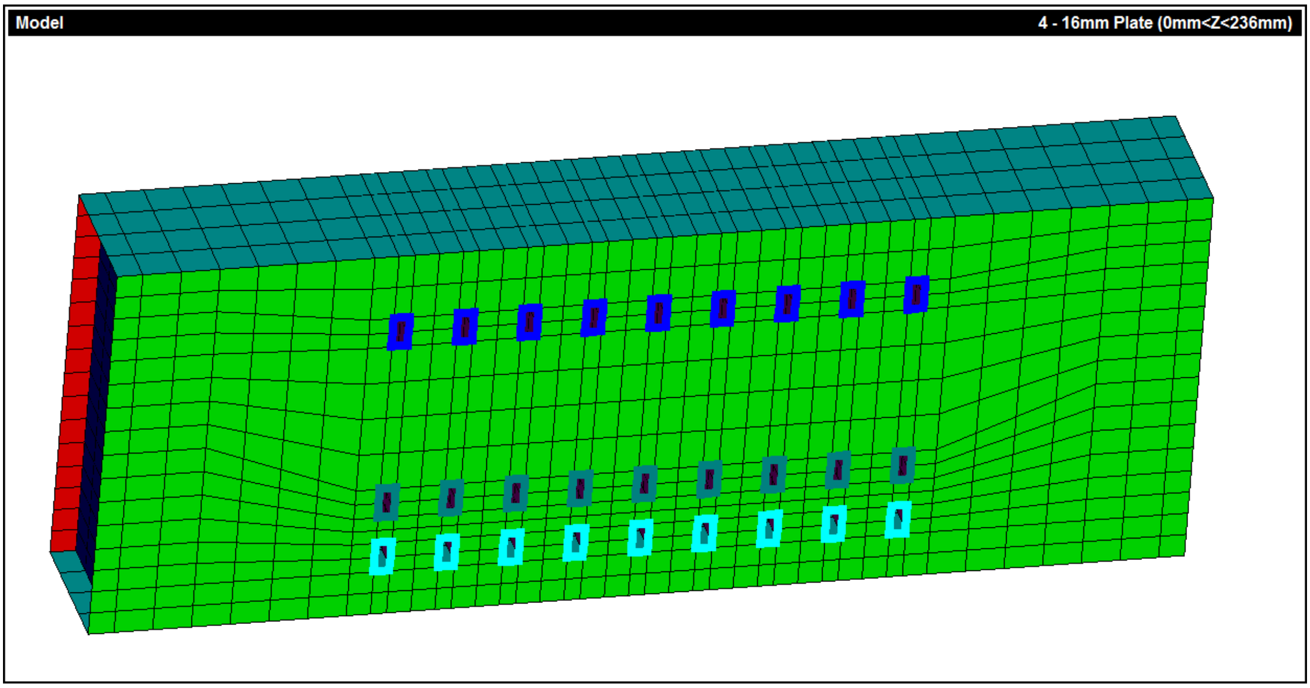


Figure 15 – Nodal points with applied loads.

(Cyan – N1; Sea green – N2; Blue – N3)

(a)

(b)

(c)

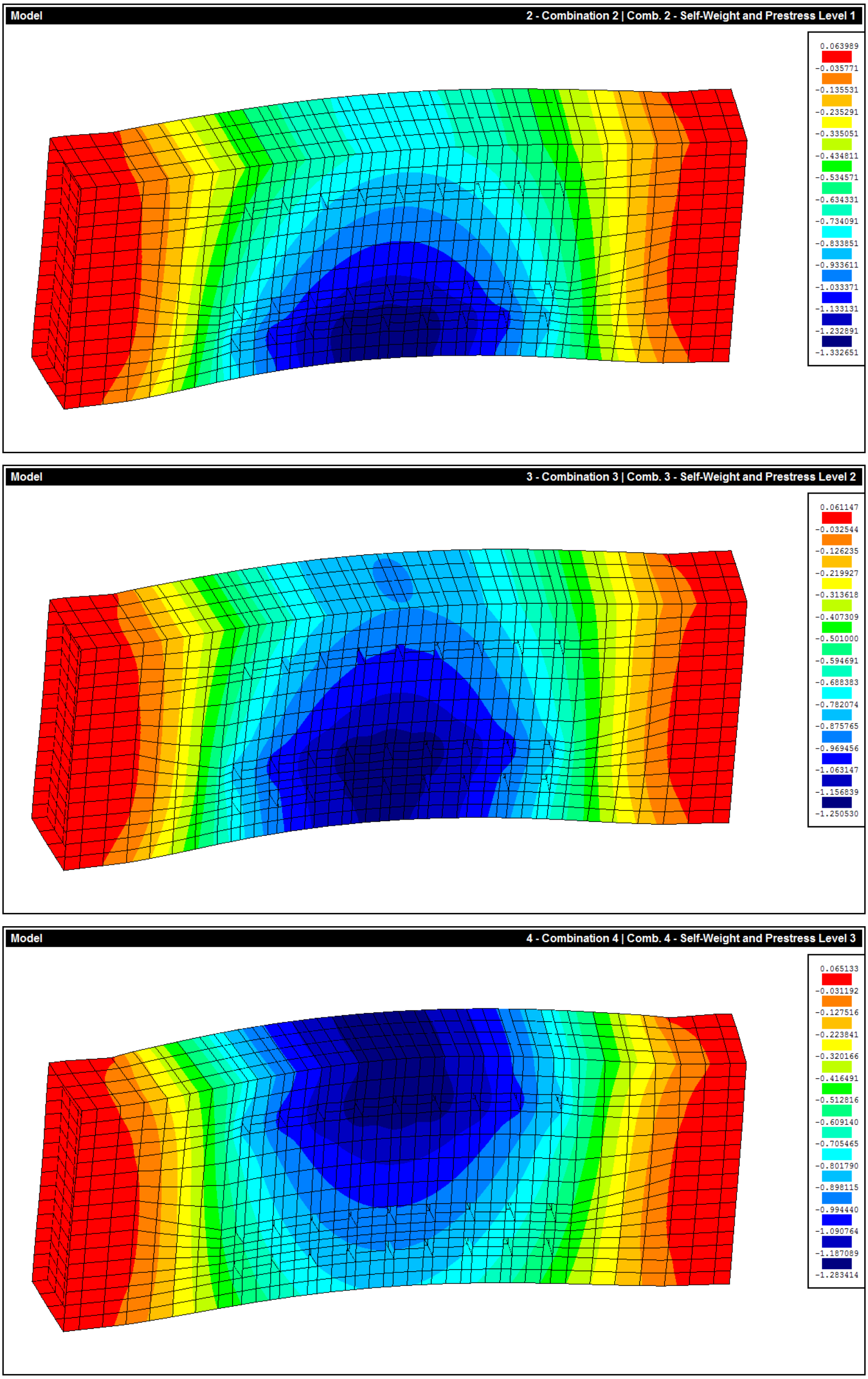


Figure 16 – Deformed meshes with deformation in x_3.

(a) – Combination 2, (b) – Combination 3, (c) – Combination 4.

(c)

(b)

(c)

(d)

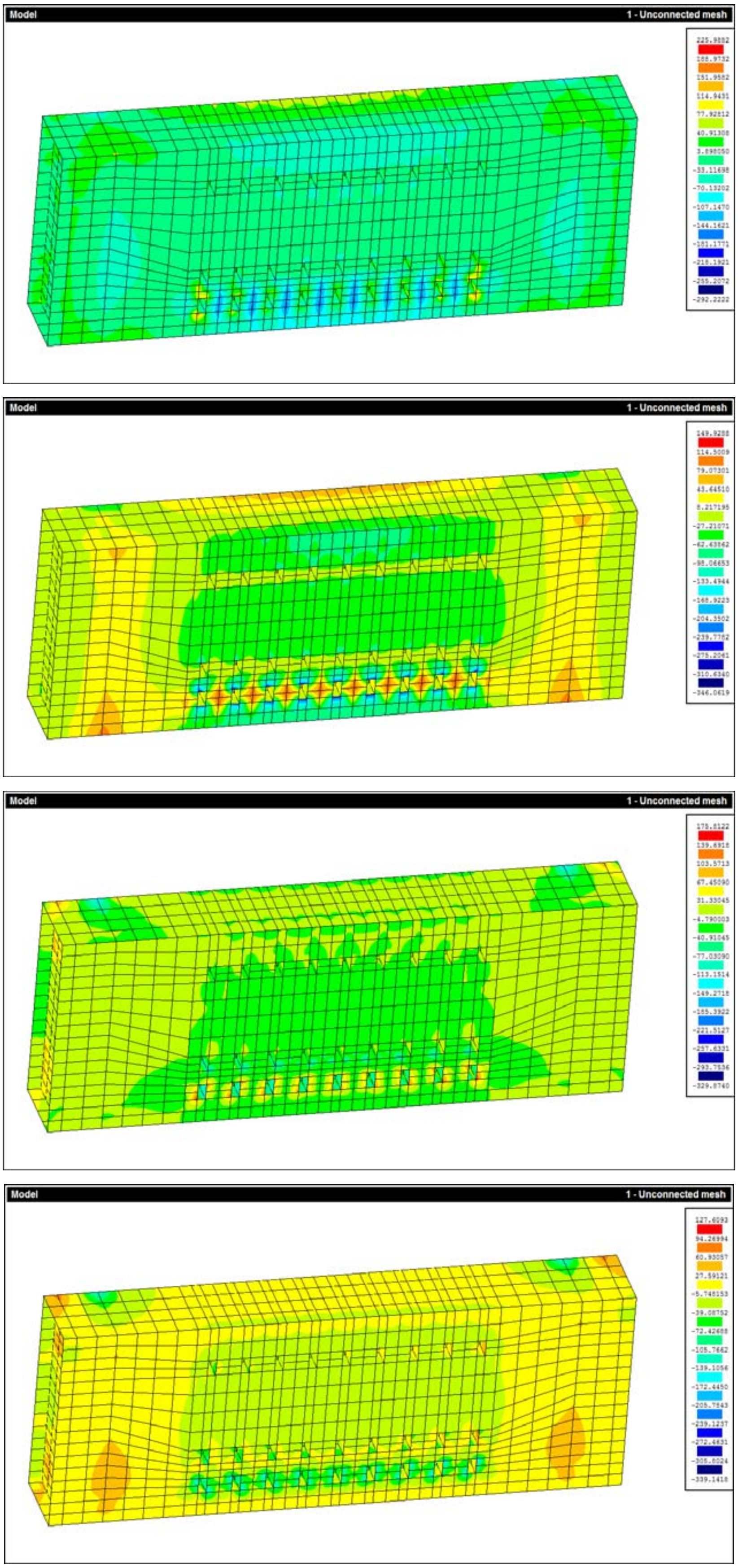


Figure 17 – Stress distribution in Combination 2.

(a) – $\sigma_{1,bot}$, (b) – $\sigma_{1,top}$, (c) – $\sigma_{2,bot}$, (d) – $\sigma_{2,top}$.

Table 6 – Maximum and minimum displacements in x_3 (values in mm).

Combination	Minimum displacement	Maximum displacement
Comb.2	-1.333	0.064
Comb. 3	-1.251	0.061
Comb. 4	-1.283	0.065

Table 7 – Maximum and minimum stresses (values in MPa).

Combination	$\sigma_{1,bot}$	$\sigma_{1,top}$	$\sigma_{2,bot}$	$\sigma_{2,top}$	$\tau_{12,bot}$	$\tau_{12,top}$	$\tau_{23,mid}$	$\tau_{31,mid}$
1	-0.6	-0.6	-0.9	-1.0	-0.5	-0.5	-0.1	-0.3
	0.6	0.5	0.3	0.3	0.5	0.5	0.1	0.3
2	-292.2	-346.1	-329.9	-339.1	-183.9	-222.5	-48.0	-147.8
	226.0	149.9	175.8	127.6	183.9	222.5	52.6	147.8
3	-265.8	-261.5	-286.5	-296.3	-161.3	-195.2	-55.7	-130.8
	224.5	134.2	129.6	114.5	161.3	195.2	39.9	130.8
4	-280.4	-251.1	-322.9	-315.9	-210.4	-173.2	-39.2	-140.5
	172.2	145.9	158.5	110.6	210.4	173.2	42.3	140.5

1.4 FINAL REMARKS

According to the obtained results, the prestress system design is able of withstanding the total prestress load, i.e., 800 kN. However, as no safety factors were introduced in this design, it is not recommended to exceed 90% of the ultimate resistance of this system.

2 PRESTRESS SYSTEM

Due to space limitations in the Civil Engineering Laboratory at University of Minho, the initial prestress system previously presented had to be totally remodelled. The new prestress system idealization started by selecting the hydraulic actuator to be used.

Assuming that a maximum load of 200 kN will be applied in each rod/laminate, it is necessary to first verify the existence of an equipment that enables this operation. A hollow plunger cylinder from Enerpac, RCH-206, was found to be the best solution. This 306 mm length and 98 mm wide hydraulic jack has a maximum capacity of 20 ton (or 215 kN), a maximum stroke of 155 mm.

Figure 18 – Enerpac Series actuator.

It is also necessary to define the lower bound of the actuator's stroke. The deformation of a linear elastic material can be obtained as follows:

$$\sigma = E\varepsilon \tag{1}$$

$$\varepsilon = \frac{\delta}{L} \tag{2}$$

$$\delta = \frac{\sigma L}{E} \tag{3}$$

where

- σ is the applied stress
- E is the material's Young modulus
- ε is the strain experienced by the material
- δ is the increment of length on the bar
- L is the initial length of the bar

Assuming a maximum prestress of 80%, a 6.0 m bar of the different materials will elongate as reported in Table 8. From Table 8, it is verified that the deformation is within the actuator's stroke.

Table 8 – Deformation levels in 6.0 m bars with an 80% prestress level.

Material	f_u [MPa]	E [GPa]	δ [mm]
Reinforcing Steel	400	200	9.6
Prestressing Steel	1600	195	39.4
Carbon Fibre Reinforced Polymer	2800	155	86.7
Glass Fibre Reinforced Polymer	1700	65	125.5

The solution proposed consists in embracing the two existent HEM profiles allowing the transmission of the prestress loading. Additionally, this system enables the prestress of cables up to 9.0 meters length, since the middle frame can be moved along the HEM profiles.

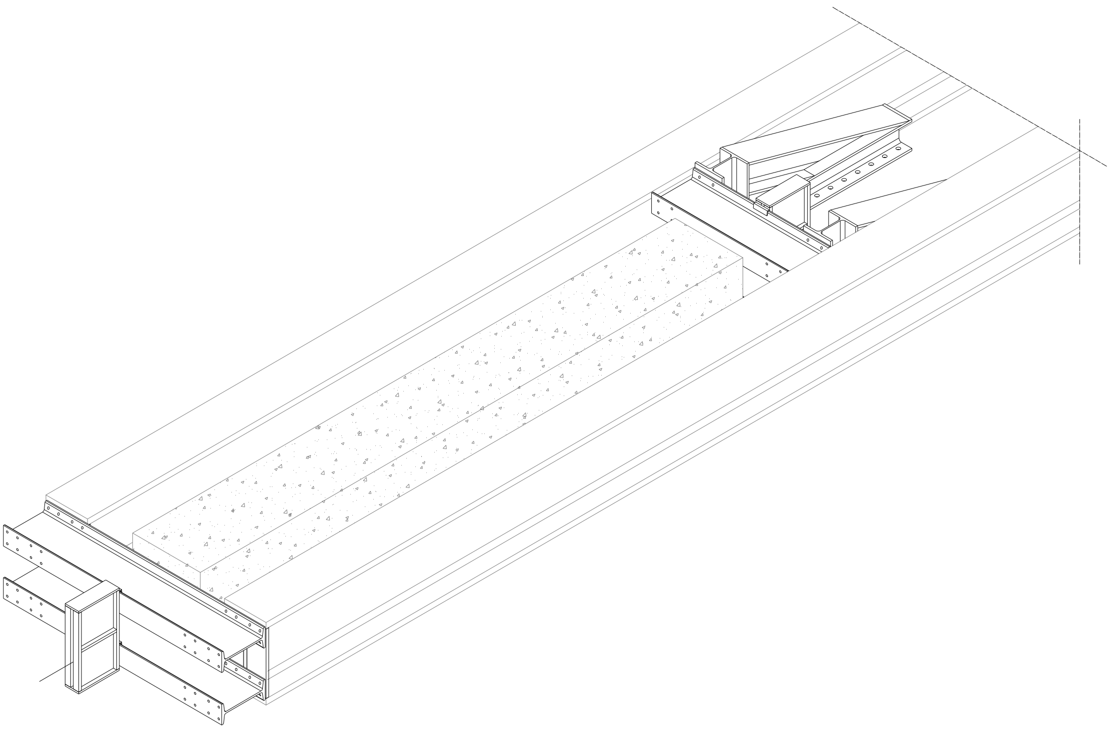


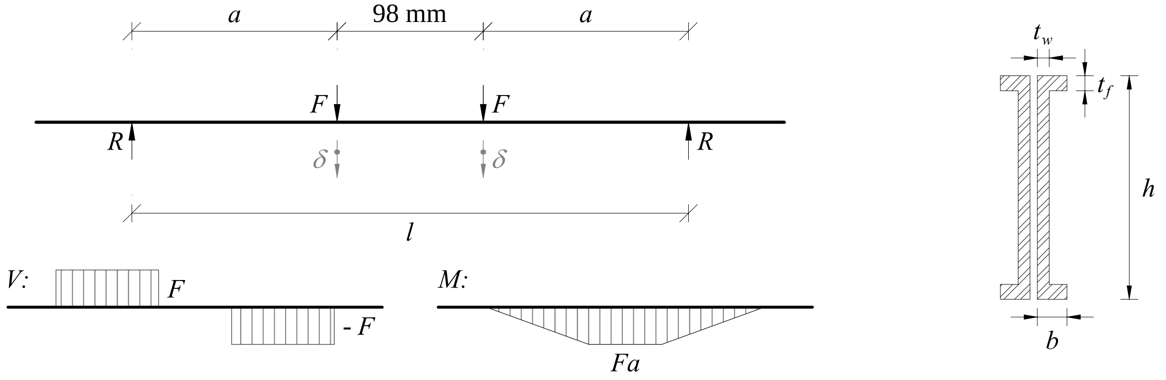
Figure 19 – Prestress System.

2.1 Design of the Profiles

All the necessary profiles to assemble this system were design as reported in this topic. The elements were considered to be made of S235, f_y, with an elastic modulus of 210 GPa, E. The actuators are known two have an external diameter of 98 mm.

2.1.1 Double-U profiles

The double-U profiles were considered to be centrally loaded with two actuators, each applying a load of 200 kN.



(a) - Diagrams (b) - Section

Figure 20 – Double-U profiles characteristics.

2.1.1.1 Geometric Properties

b = 40 mm

h = 300 mm

t_f = 20 mm

t_w = 16 mm

l = 381 mm

a = 140.5 mm

2.1.1.2 Relevant geometrical properties

$$I_y = \frac{t_w\left(h-2t_f\right)^3}{6} + \frac{b t_f^{\,3}}{3} + b t_f\left(h-t_f\right)^2$$

I = 5484.8 cm^4

$$W_{el} = \frac{2I_y}{h}$$

W_{el} = 365.7 cm^3

$$A_{vz} = t_w\left(h-2t_f\right)$$

A_{vz} = 41.6 cm^2

2.1.1.3 Actions

$M_{Ed} = Fa$ | M_{Ed} = 28.1 kNm

$V_{Ed} = F$ | V_{Ed} = 200 kN

2.1.1.4 Relevant results

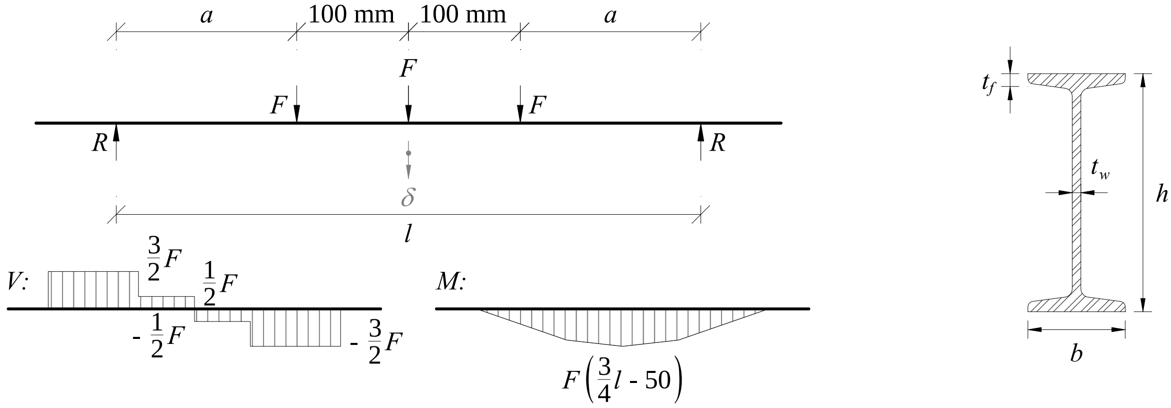
$\delta = \dfrac{Fa^2(3l-4a)}{6EI}$ | δ = 0.033 mm

$M_{Rd} = W_{el} f_y$ | M_{Rd} = 85.9 kNm > M_{Ed}

$V_{Rd} = \dfrac{A_{vz} f_y}{\sqrt{3}}$ | V_{Rd} = 564.4 kN > 2 V_{Ed}

2.1.2 Design of the Double-U support

It is forecasted that a maximum of 3 double-U profiles will be used. Considering the dimensions and loading given in the previous item, an IPN320 was designed.



(a) - Diagrams (b) - Section

Figure 21 – Double-U support.

2.1.2.1 Geometric Properties

b = 131 mm	t_f = 17.3 mm	l = 785 mm
h = 320 mm	t_w = 11.5 mm	a = 292.5 mm

2.1.2.2 Relevant geometrical properties

I = 12510 cm^4

From the supplier's tables

W_{el} = 782 cm^3

A_{vz} = 39.26 cm^2

2.1.2.3 Actions

$$M_{Ed} = F\left(\frac{3}{4}l - 50\right)$$

M_{Ed} = 107.8 kNm

$$V_{Ed} = \frac{3}{2}F$$

V_{Ed} = 300 kN

2.1.2.4 Relevant results

$$\delta = \frac{F}{48EI}\left(l^3 + 6al^2 - 8a^3\right)$$

δ = 0.216 mm

$$M_{Rd} = W_{el} f_y$$

M_{Rd} = 183.7 kNm > M_{Ed}

$$V_{Rd} = \frac{A_{vz} f_y}{\sqrt{3}}$$

V_{Rd} = 532.7 kN < $2V_{Ed}$ [1]

$$\rho = \left(\frac{2V_{Ed}}{V_{Rd}} - 1\right)^2$$

ρ = 0.016

$$V_{Rd,corr} = \frac{A_{vz}(1-\rho) f_y}{\sqrt{3}}$$

$V_{Rd,corr}$ = 524.2 kN

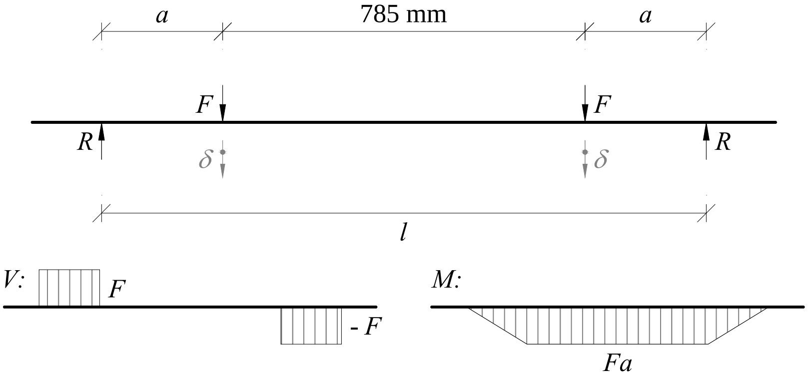
$$M_{Rd,corr} = \left(W_{el} - \frac{\rho A_{vz}}{4t_w}\right) f_y$$

M_{Rd} = 183.7 kNm > M_{Ed}

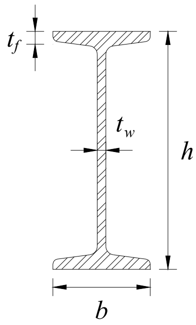
2.1.3 Support at the top of the HEM profiles

These profiles double-U supports should be also connected to the HEM profiles, the same IPN320 profile was used to safely guarantee this transfer.

[1] Requires a reduction of the resistant stress.



(a) - Diagrams



(b) - Section

Figure 22 – Support at the top of the HEM profiles.

2.1.3.1 Geometric Properties

b = 131 mm	t_f = 17.3 mm	l = 785 mm
h = 320 mm	t_w = 11.5 mm	a = 292.5 mm

2.1.3.2 Relevant geometrical properties

From the supplier's tables	I = 12510 cm^4 W_{el} = 782 cm^3 A_{vz} = 39.26 cm^2

2.1.3.3 Actions

$M_{Ed} = Fa$	M_{Ed} = 78.9 kNm
$V_{Ed} = F$	V_{Ed} = 300 kN

2.1.3.4 Relevant results

$\delta = \dfrac{Fa^2(3l-4a)}{6EI}$	δ = 0.378 mm
$M_{Rd} = W_{el} f_y$	M_{Rd} = 183.7 kNm > M_{Ed}
$V_{Rd} = \dfrac{A_{vz} f_y}{\sqrt{3}}$	V_{Rd} = 532.7 kN < $2V_{Ed}$ [2]

[2] Requires a reduction of the resistant stress

$\rho = \left(\frac{2V_{Ed}}{V_{Rd}} - 1 \right)^2$	ρ = 0.016
$V_{Rd,corr} = \frac{A_{vz}(1-\rho) f_y}{\sqrt{3}}$	$V_{Rd,corr}$ = 524.2 kN
$M_{Rd,corr} = \left(W_{el} - \frac{\rho A_{vz}}{4t_w} \right) f_y$	M_{Rd} = 183.7 kNm > M_{Ed}

2.1.4 OTHER DEFORMATIONS – HEM PROFILES

The deformation of other components, *i.e.*, of this system also needs to be assessed.

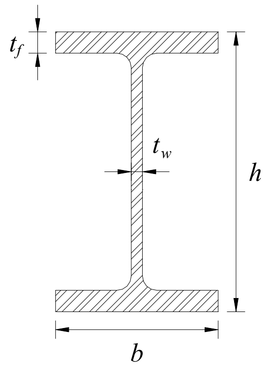


Figure 23 – HEM profile.

2.1.4.1 GEOMETRIC PROPERTIES

b = 306 mm	t_f = 40 mm	L = 6500 mm
h = 524 mm	t_w = 21 mm	

2.1.4.2 RELEVANT GEOMETRICAL PROPERTIES

From the supplier's tables	A = 344.3 cm^2 I_z = 19150 cm^4

2.1.4.3 ACTIONS

Half of the total prestress load	N_{Ed} = 600 kN

2.1.4.4 RELEVANT RESULTS:

$\sigma_{Ed} = \frac{F}{A}$	σ_{Ed} = 17.4 MPa

$$\delta = \frac{FL}{EA}$$

δ = 0.539 mm

$$P_E = \frac{\pi^2}{L^2} EI$$

P_E = 9394 kN < N_{Ed}

2.1.5 TOTAL DEFORMATION

The total deformation of the system will be given by the sum of the following portions:

δ_{total} = 2×(U profiles) + (support IPN) + (movable IPNs) + (HEM500)

δ_{total} = 2×0.033 + 0.378 + 0.216 + 0.539 (mm)

δ_{total} = 1.199 mm

Adding this deformation to the maximum deformation of a prestressed material (GFRP, 125.5 mm), the required stroke will be 126.7 mm, below the limit of the actuators selected.

2.2 ANCHORING SYSTEM

Initially, it was expected to anchor the profiles to the ground. However, in situ conditions revealed to be insufficient to guarantee safety, and therefore, another solution had to be found. It was decided to again, take advantage of the HEM profiles by designing a passive support that could be bolted to the profiles and withstand the prestress load.

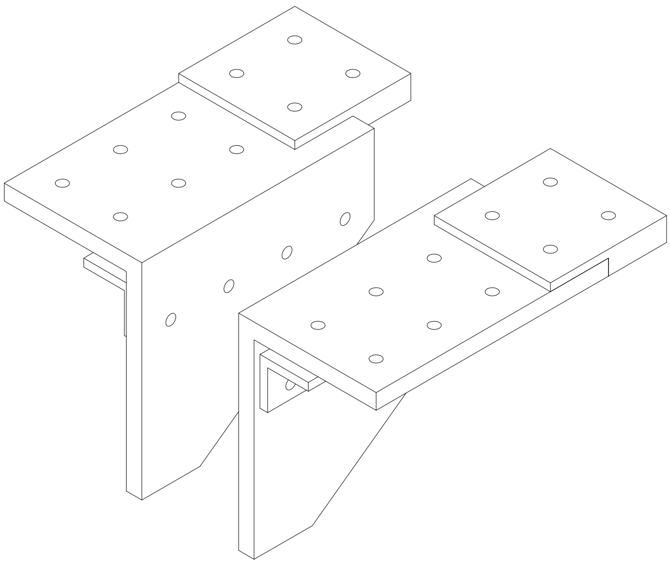


Figure 24 – Prestress Support.

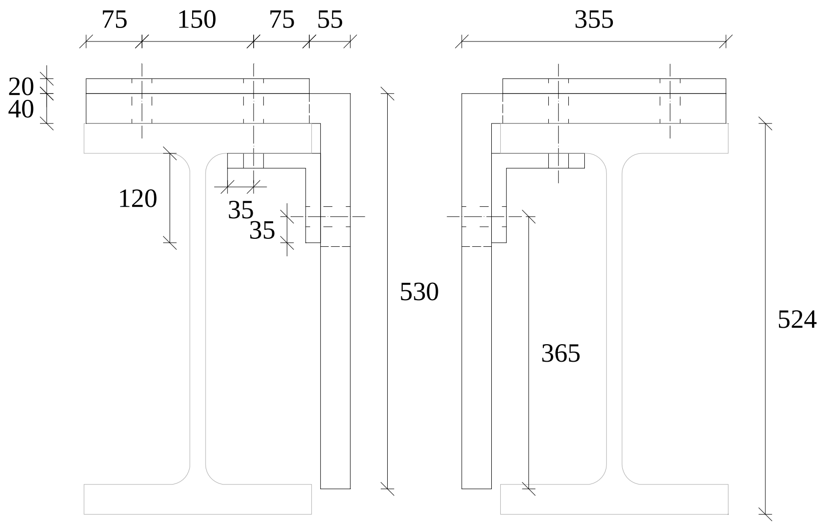


Figure 25 – Prestress support dimensions (in mm) – frontal view.

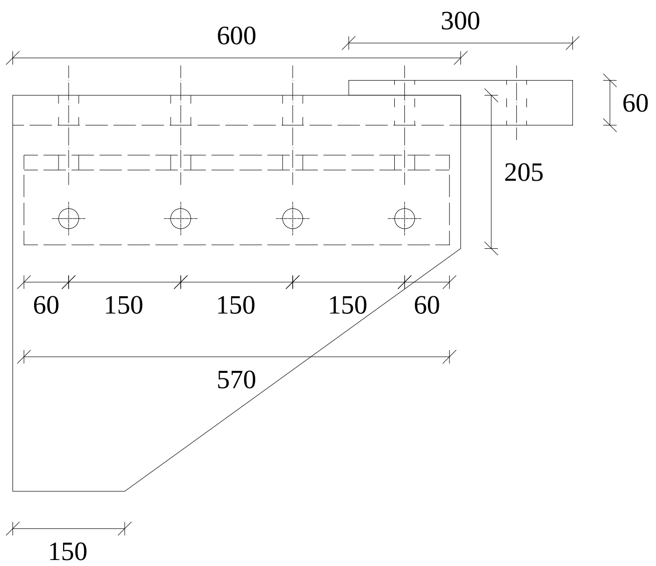
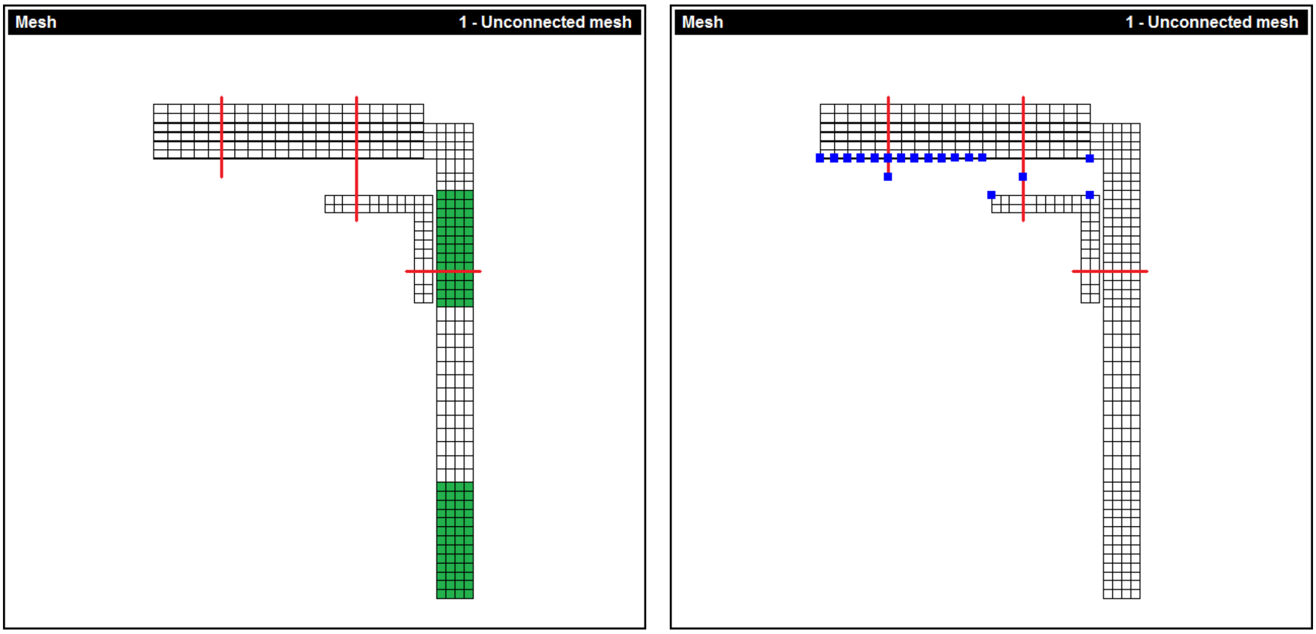


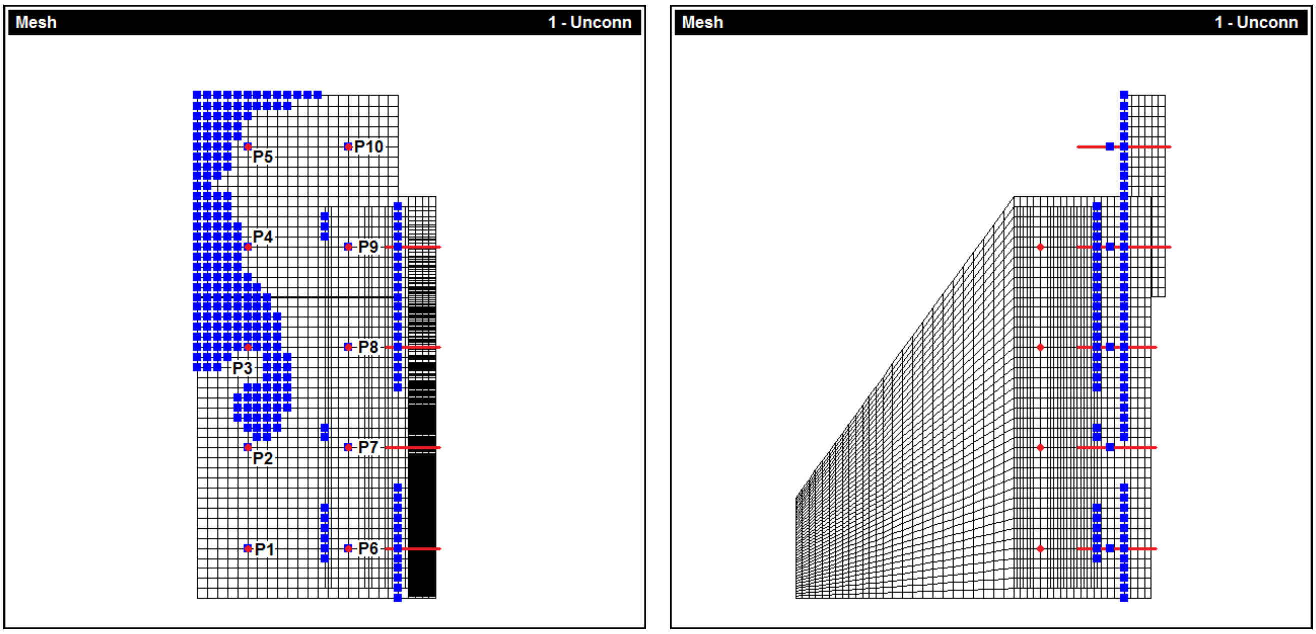
Figure 26 – Prestress support dimensions (in mm) – lateral view.

This system was introduced in the finite elements analysis software according to Figure 27. A total load of 400 kN was applied, considering the most unfavourable load configuration.

The stresses produced were later analyzed and are presented in Figure 28, as well as the corresponding displacements (Figure 29).

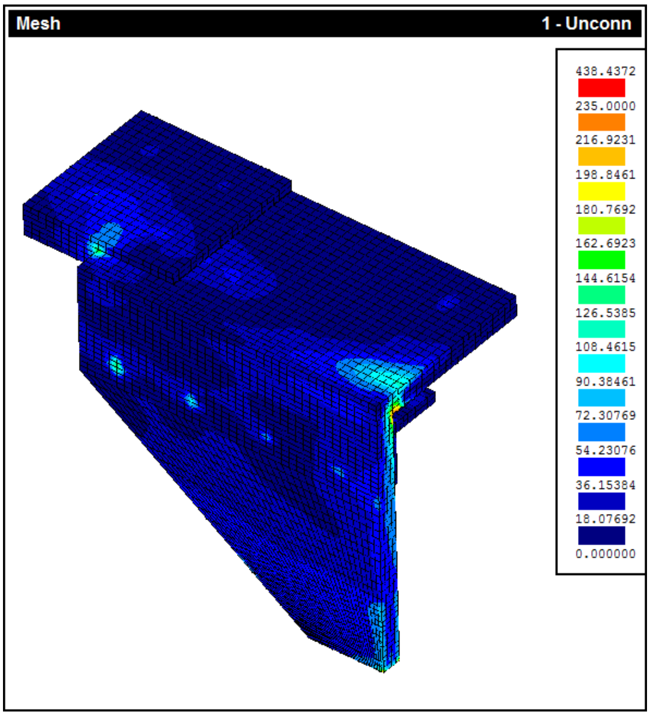


(a) – Loaded Zone (b) – Front view of the supports (xy)

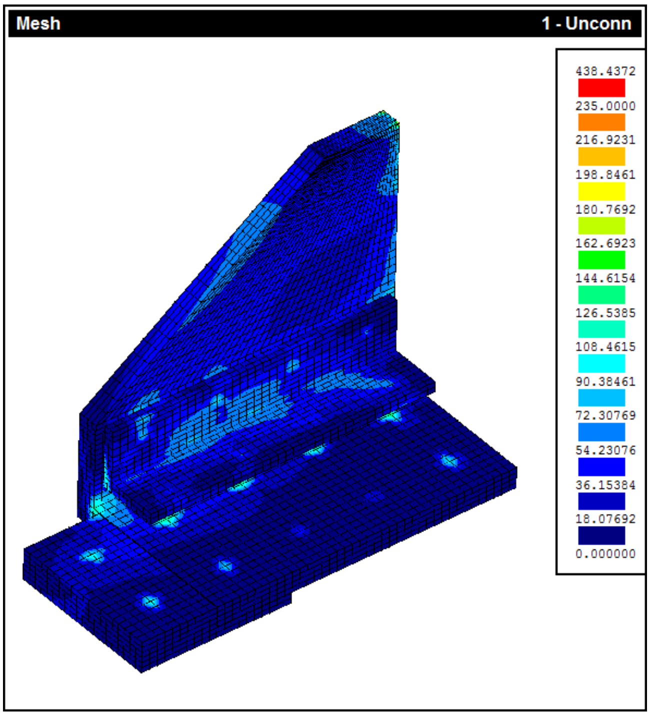


(c) – Top view of the supports (xz) (d) – Lateral view of the supports (yz)

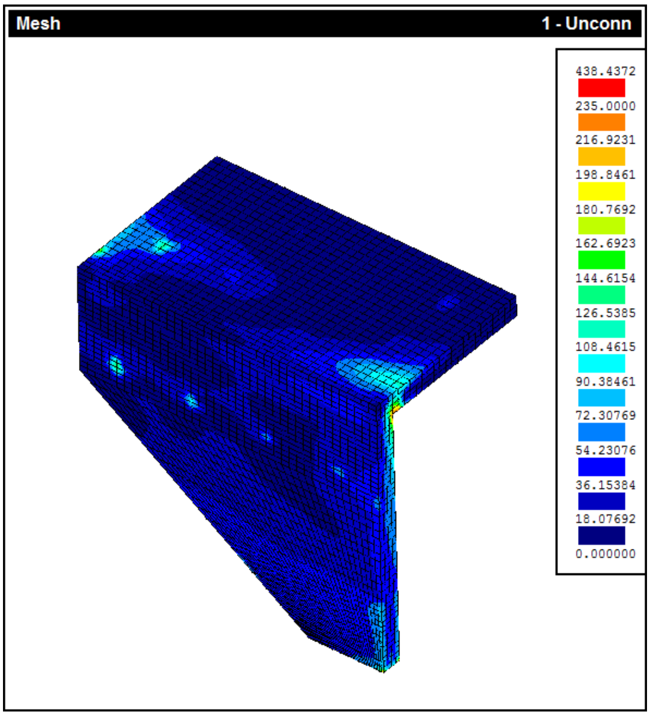
Figure 27 – Load and supports of the prestress support.



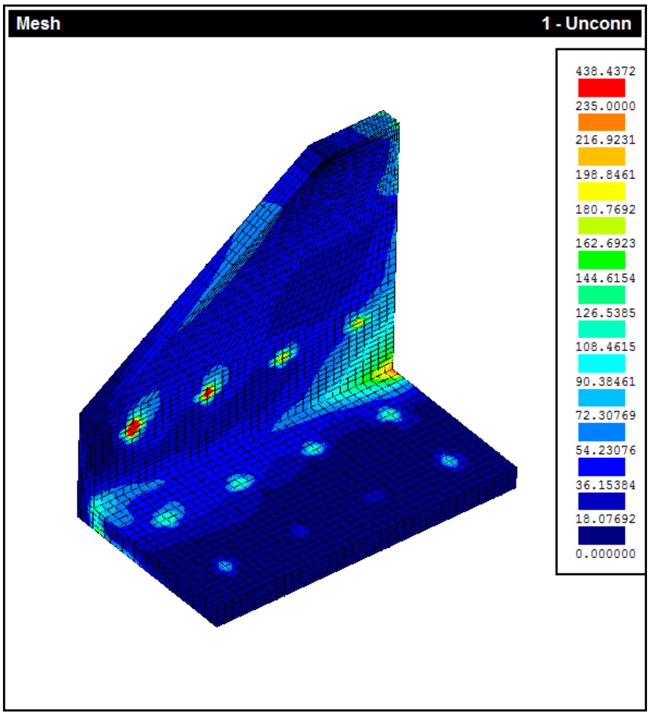
(a) – All elements – External view



(b) – All elements – Internal view

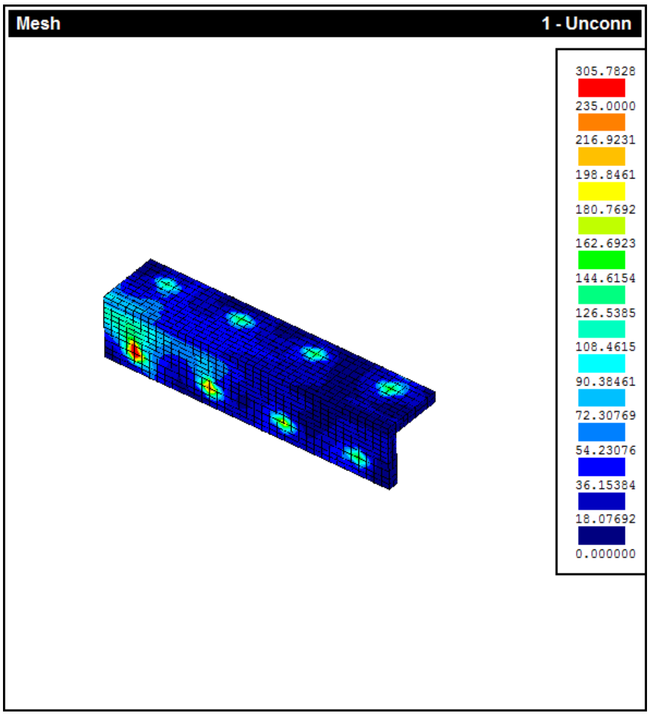


(c) – External profile – External view

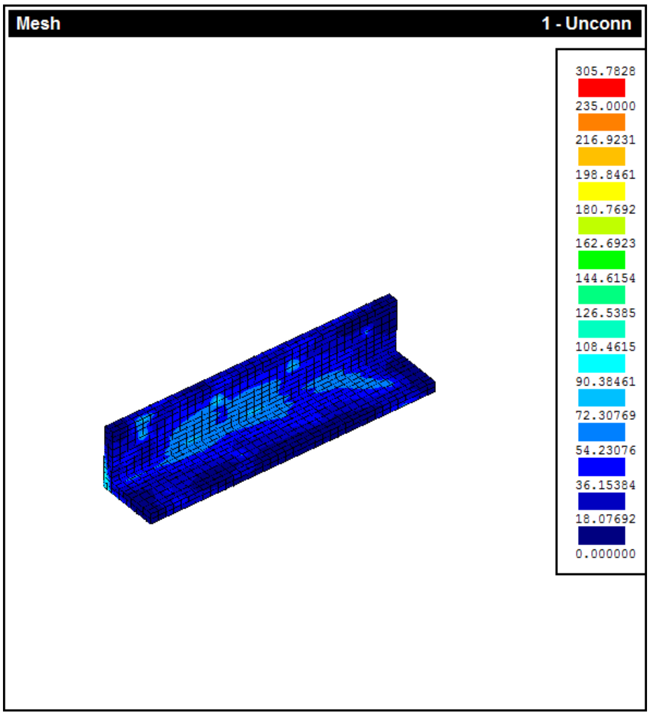


(d) – External profile – Internal view

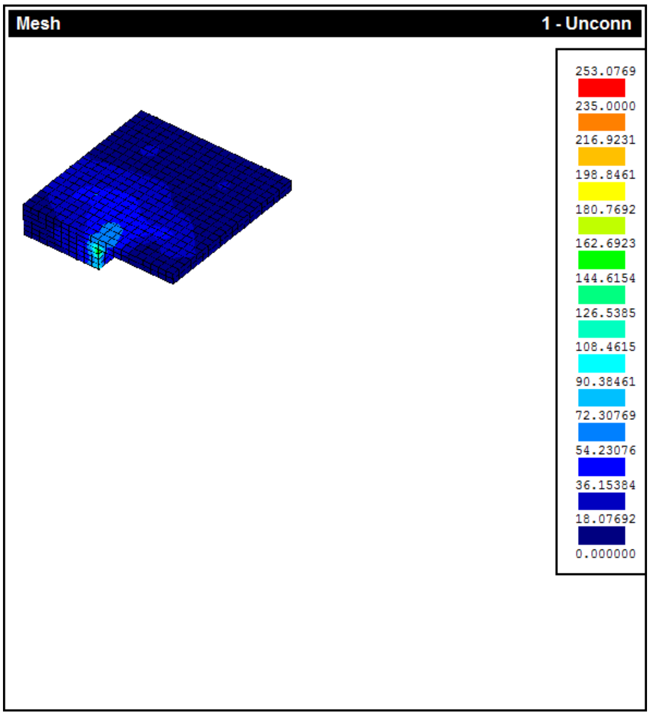
(cont.)



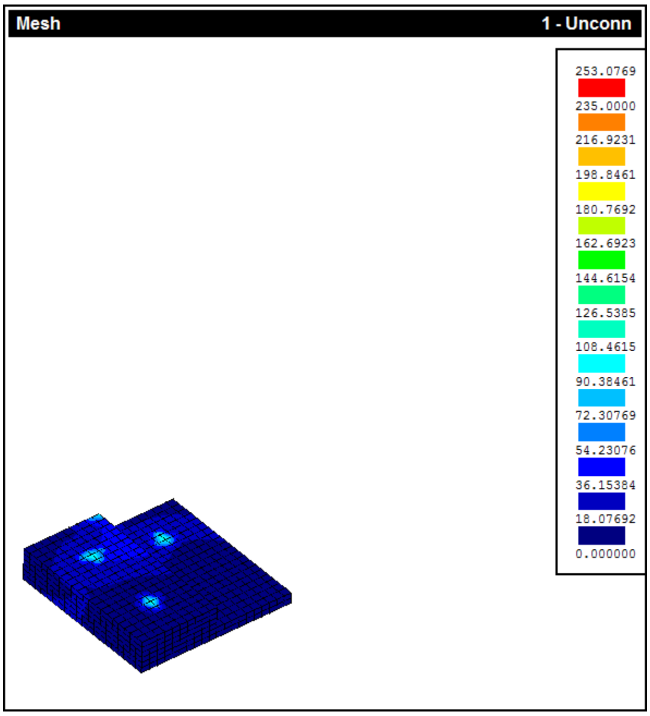
(e) – Internal profile – External view



(f) – Internal profile – Internal view

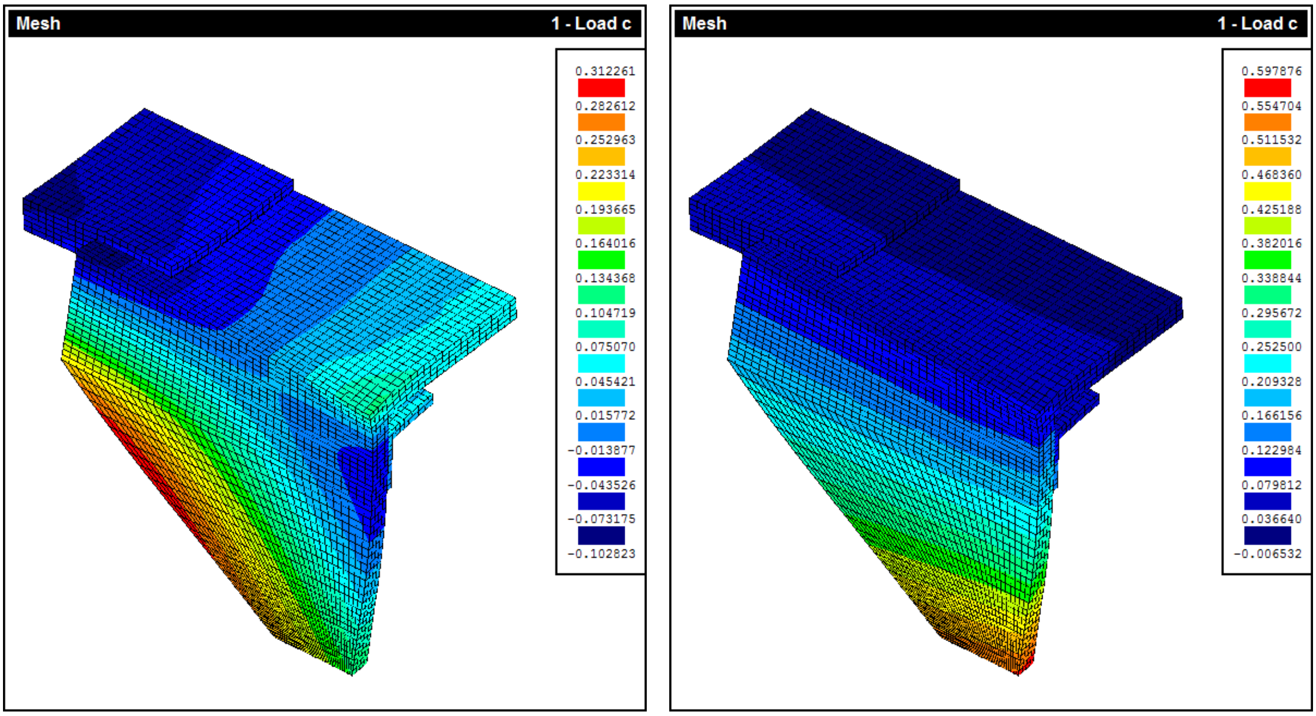


(g) – Extra plate – External view



(h) – Extra plate – Internal view

Figure 28 – Representation of the Von Mises stress fields in the support elements.



(a) – Displacements in y (b) – Displacements in z

Figure 29 – Prestress support deflections.

2.3 REACTIONS – DESIGN OF THE BOLTS

The reactions obtained in the simulation were used to determine the stress level on the bolts. The safety verifications of these elements were performed using the following expression (EC3-1-8:2004)

$$SF = \frac{F_{v,Ed}}{\beta_{Lf} F_{v,Rd}} + \frac{F_{t,Ed}}{1.4 F_{t,Rd}} \leq 1.0 \quad (4)$$

where β_{Lf} is a shear reduction factor, relevant in the case of long joints.

In the cases were the joint length, L_j, in the transfer direction, is higher than 15 times the diameter of the bolt, d, this factor is given by

$$\beta_{Lf} = 1 - \frac{L_j - 15d}{200d} \qquad 0.75 \leq \beta_{Lf} \leq 1.00 \quad (5)$$

In this case, the connection was considered a M24 bolt connection with 5 bolts, 150 mm between them, and therefore β_{Lf} is estimated to be 0.95.

M24 bolts have a cross section, A, of 353 mm^2 and the nominal resistance of these type of elements is given in Table 9. The bearing resistance of the plate was also calculated, but given its high thickness and the existence of multiple shear planes, it was always verified that this value was higher than shear strength of the bolts.

Table 9 – Concrete and steel characteristics.

Property	Class 8.8	Class 10.9
$F_{v,Rd}$ [kN]	135.552	141.200
$F_{t,Rd}$ [kN]	203.328	254.160

The shear and tensile components applied in the bolts were combined to verify safety, and the result of these calculations in reported in Table 10. According to these results, safety is guaranteed.

Table 10 – Concrete and steel characteristics (Values in kN).

Bolt	No. of shear planes	Shear (x)	Tension (y)	Shear (z)	Shear	Tension	SF (8.8)	SF (10.9)
P1	1	-18.65	-14.45	-3.09	18.90	14.45	0.20	0.18
P2	1	-5.00	-0.59	-5.48	7.42	0.59	0.06	0.06
P3	1	6.03	0.00	-6.28	8.71	0.00	0.07	0.06
P4	1	18.84	-0.32	-7.72	20.36	0.32	0.16	0.15
P5	2	23.80	-1.06	-7.31	24.90	1.06	0.10	0.10
P6	2	-59.21	-8.97	-83.61	102.45	8.97	0.43	0.41
P7	2	-23.59	-3.17	-92.32	95.28	3.17	0.38	0.36
P8	2	-1.02	-24.74	-93.83	93.84	24.74	0.45	0.42
P9	3	45.14	-57.84	-86.05	97.17	57.84	0.45	0.40
P10	2	13.67	-54.82	-14.30	19.78	54.82	0.27	0.23

2.4 Final remarks

This system was designed and modelled and revealed to be capable of withstanding the prestress loads initially imposed, with sufficient safety.

3 CONCLUSIONS

In this report, the different steps towards the implementation of a Hydraulic-Electro-Mechanical System to apply Pre-Stressed CFRP Laminates according to the NSM Technique in Laboratory conditions were described and detailed.

This system was executed and it is available in the Laboratory of Civil Engineering at University of Minho. At this time, all the steel pieces are available to be assembled and two hollow hydraulic actuators of 200 kN are available to apply prestress to CFRP elements.

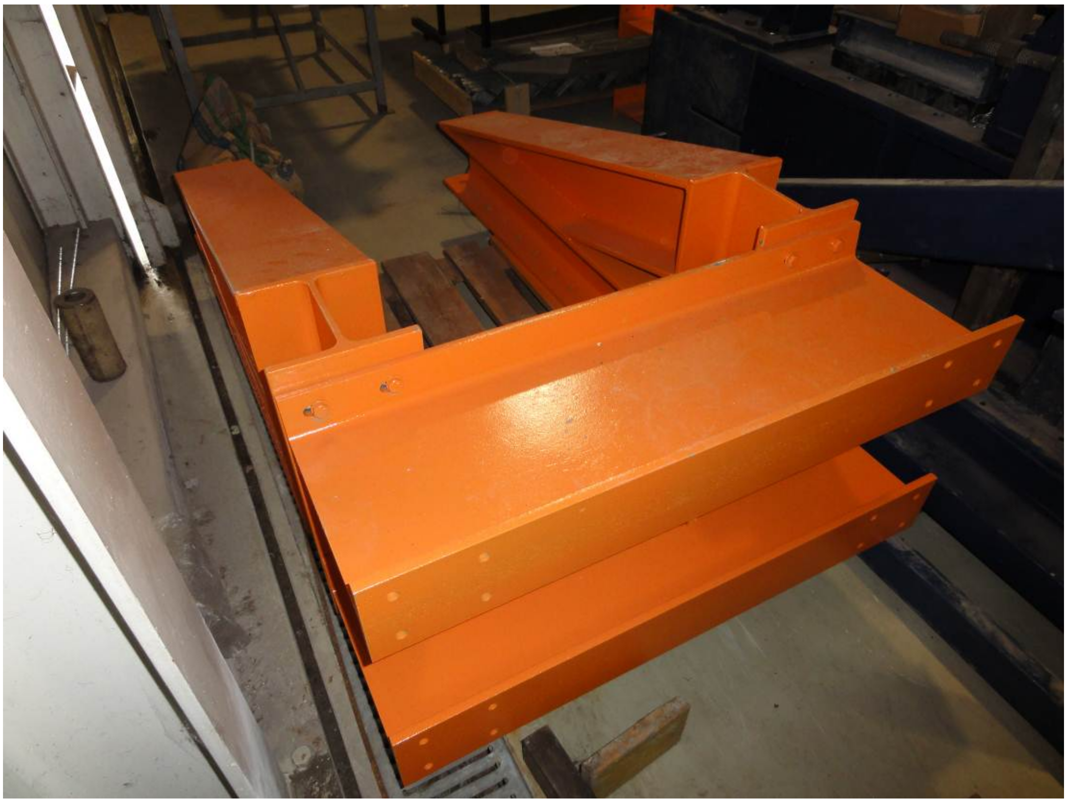


Figure 30 – Prestress system movable end.

Figure 31 – Prestress system fixed end.

Figure 32 – Prestress system steel components.

Figure 33 – Prestress system hydraulic system and hollow actuators.

Figure 34 – Prestress system hollow load cells.

ANNEX I – INITIAL PRESTRESS SYSTEM EXECUTION DRAWINGS

Este documento é composto pelas seguintes partes:

- Desenho 1.1
    Módulo de Betão: Corte A-A'
- Desenho 1.2
    Módulo de Betão: Corte B-B'
- Desenho 2.1
    Cabeça de Pré-esforço: Corte A-A'
- Desenho 2.2
    Cabeça de Pré-esforço: Corte B-B'
- Desenho 2.3
    Cabeça de Pré-esforço: Corte B-B'

Os materais a utilizar na execução são:
- Betão: tipo C30/37 ou superior
- Armaduras ordinárias: A400NR
- Aço em perfis e chapas: 355MPa

Os olhais de elevação/suspensão serão compostos por pares de capacidade igual a 0.5ton.

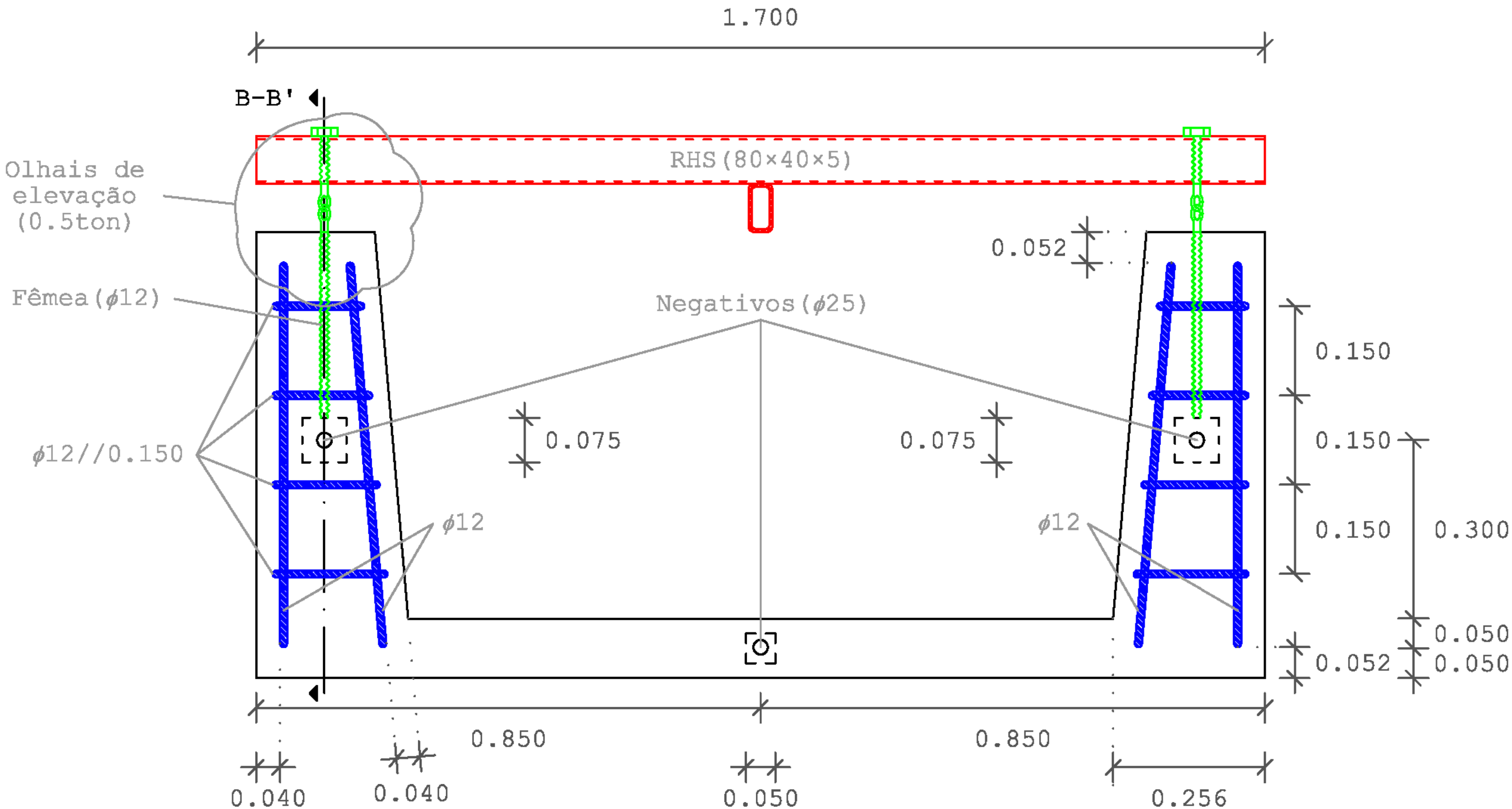
Exemplo da ligação pretendida (a) entre os pares de olhais e (b) entre o olhal e perfil tubular.

Estes elementos serão ligados ao betão por intermédio de uma ligação roscada.

O diâmetro nominal da rosca dos olhais deverá ser 12mm.

(a)

(b)

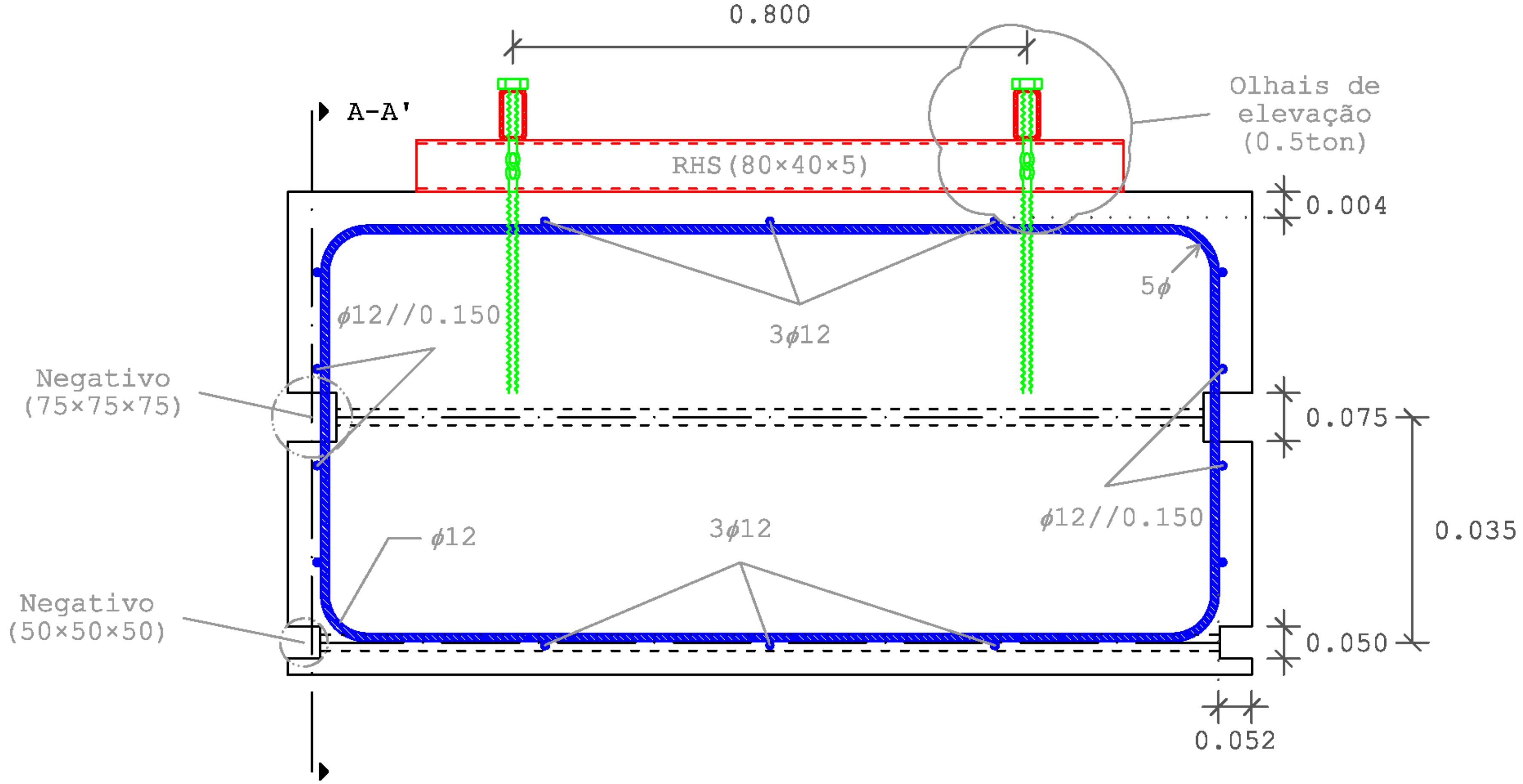


Obs.:

- **Dimensões cotadas em metros**
- **Betão: C30/37 ou superior**
- **Armaduras: A400NR**
- **Perfis e chapas: 355MPa**

Escola de Engenharia
Universidade do Minho

Pista de Pré-Esforço			
Requerente: DEC - Universidade do Minho		Local: Guimarães	
Peça: Módulo de Betão: Corte A-A'	Escala: 1/10 (A4)	Data: 13 Out. 2010	Desenho: 1.1



Obs.:

- **Dimensões cotadas em metros**
- **Betão: C30/37 ou superior**
- **Armaduras: A400NR**
- **Perfis e chapas: 355MPa**

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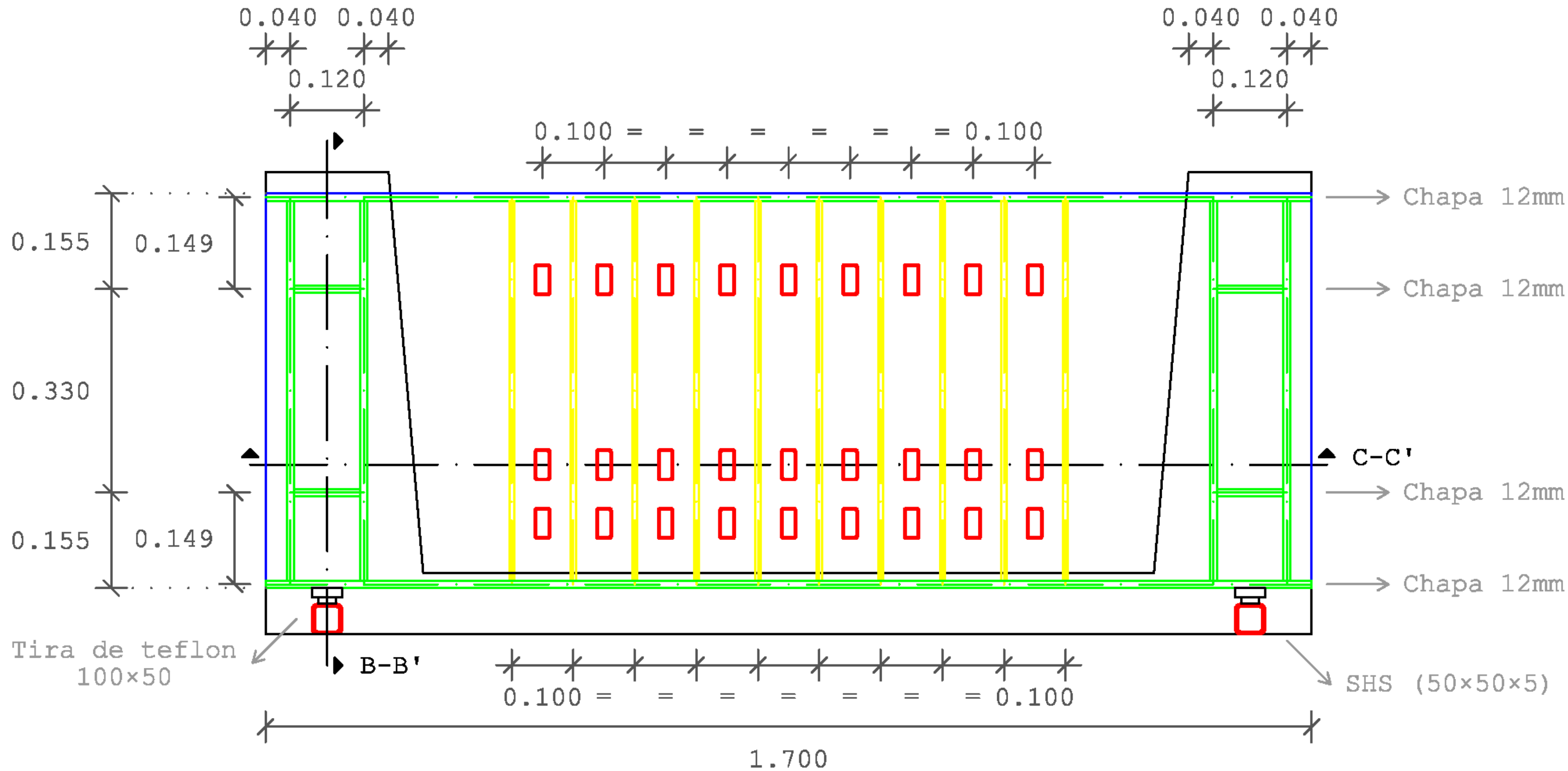
Pista de Pré-Esforço			
Requerente: DEC - Universidade do Minho		Local: Guimarães	
Peça: Módulo de Betão: Corte B-B'	Escala: 1/10 (A4)	Data: 13 Out. 2010	Desenho: 1.2



Obs.:

- **Dimensões cotadas em metros**
- **Betão: C30/37 ou superior**
- **Armaduras: A400NR**
- **Perfis e chapas: 355MPa**

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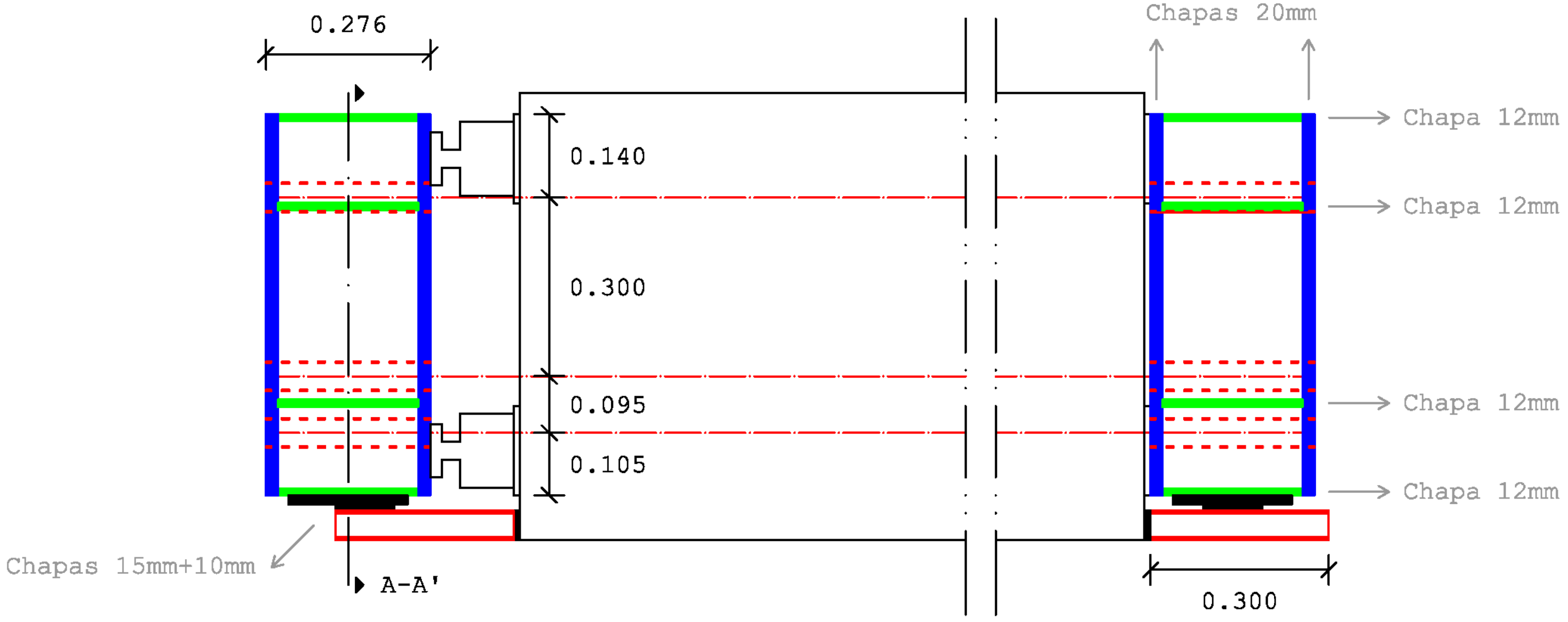
Pista de Pré-Esforço			
Requerente: DEC - Universidade do Minho		Local: Guimarães	
Peça: Cabeça de Pré-Esforço: Corte A-A'	Escala: 1/10 (A4)	Data: 13 Out. 2010	Desenho: 2.1



Obs.:

- **Dimensões cotadas em metros**
- **Betão: C30/37 ou superior**
- **Armaduras: A400NR**
- **Perfis e chapas: 355MPa**

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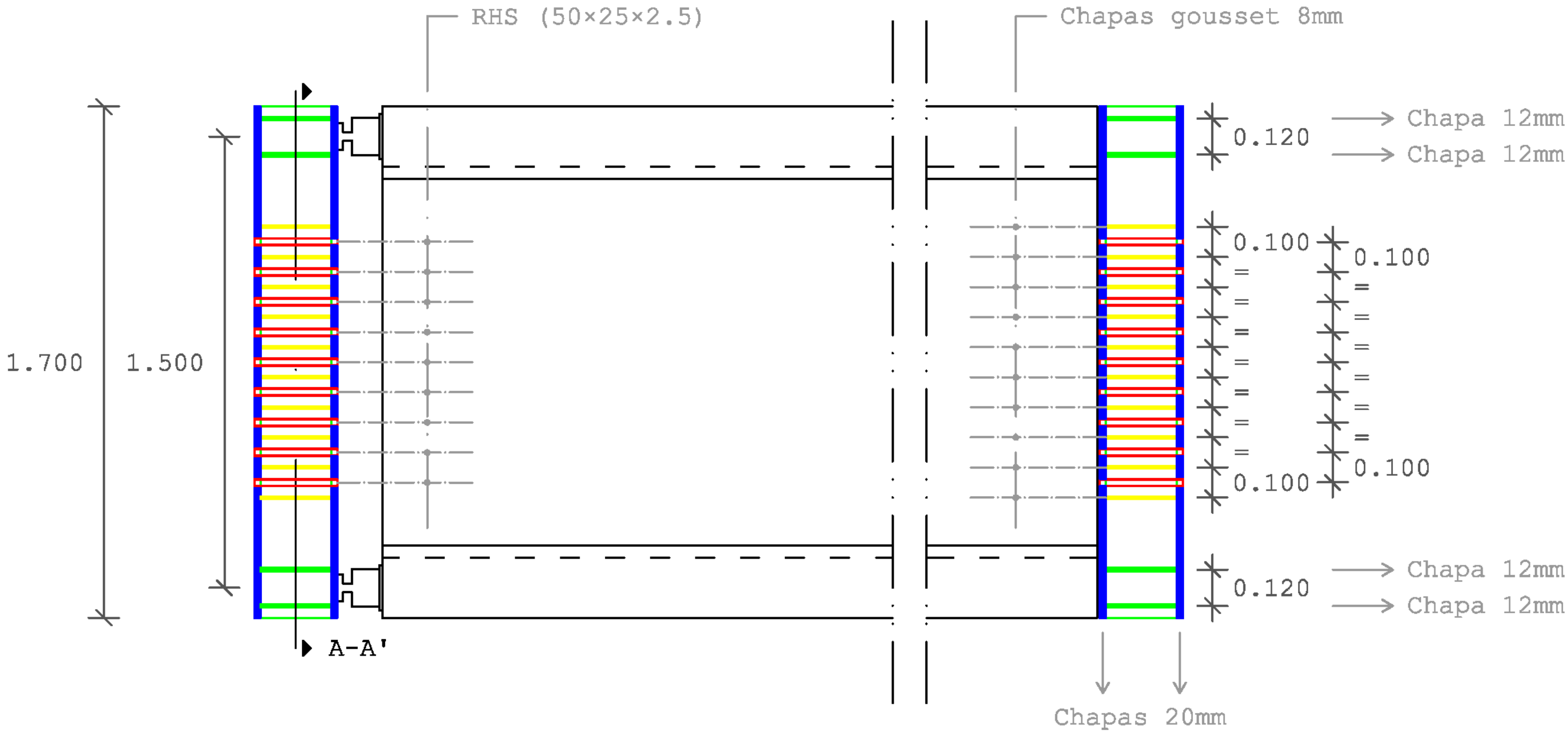
Pista de Pré-Esforço			
Requerente: DEC - Universidade do Minho		Local: Guimarães	
Peça: Cabeça de Pré-Esforço: Corte B-B'	Escala: 1/10 (A4)	Data: 13 Out. 2010	Desenho: 2.2



Obs.:

- **Dimensões cotadas em metros**
- **Betão: C30/37 ou superior**
- **Armaduras: A400NR**
- **Perfis e chapas: 355MPa**

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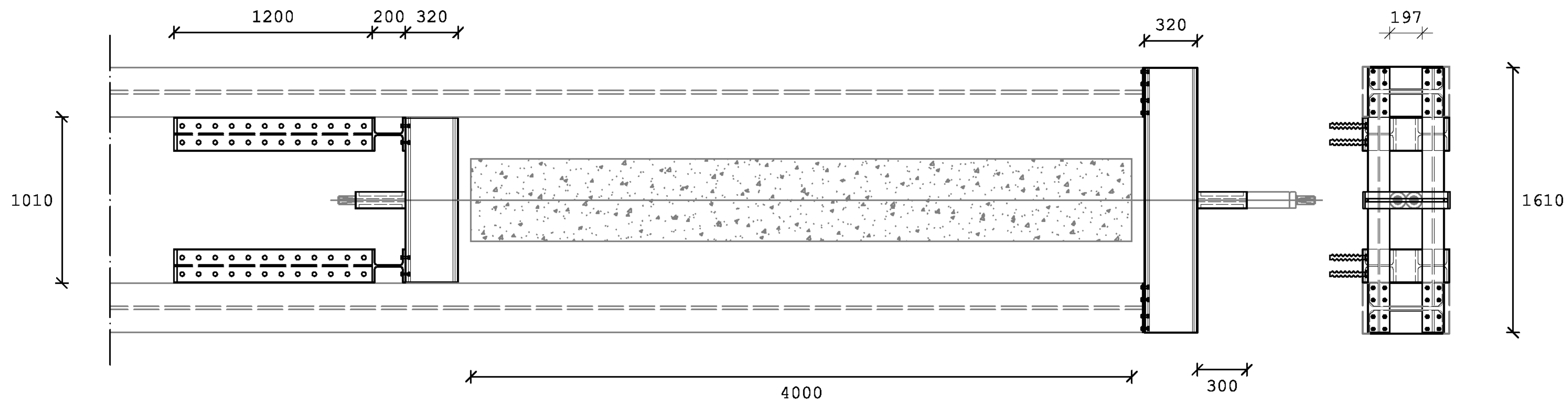
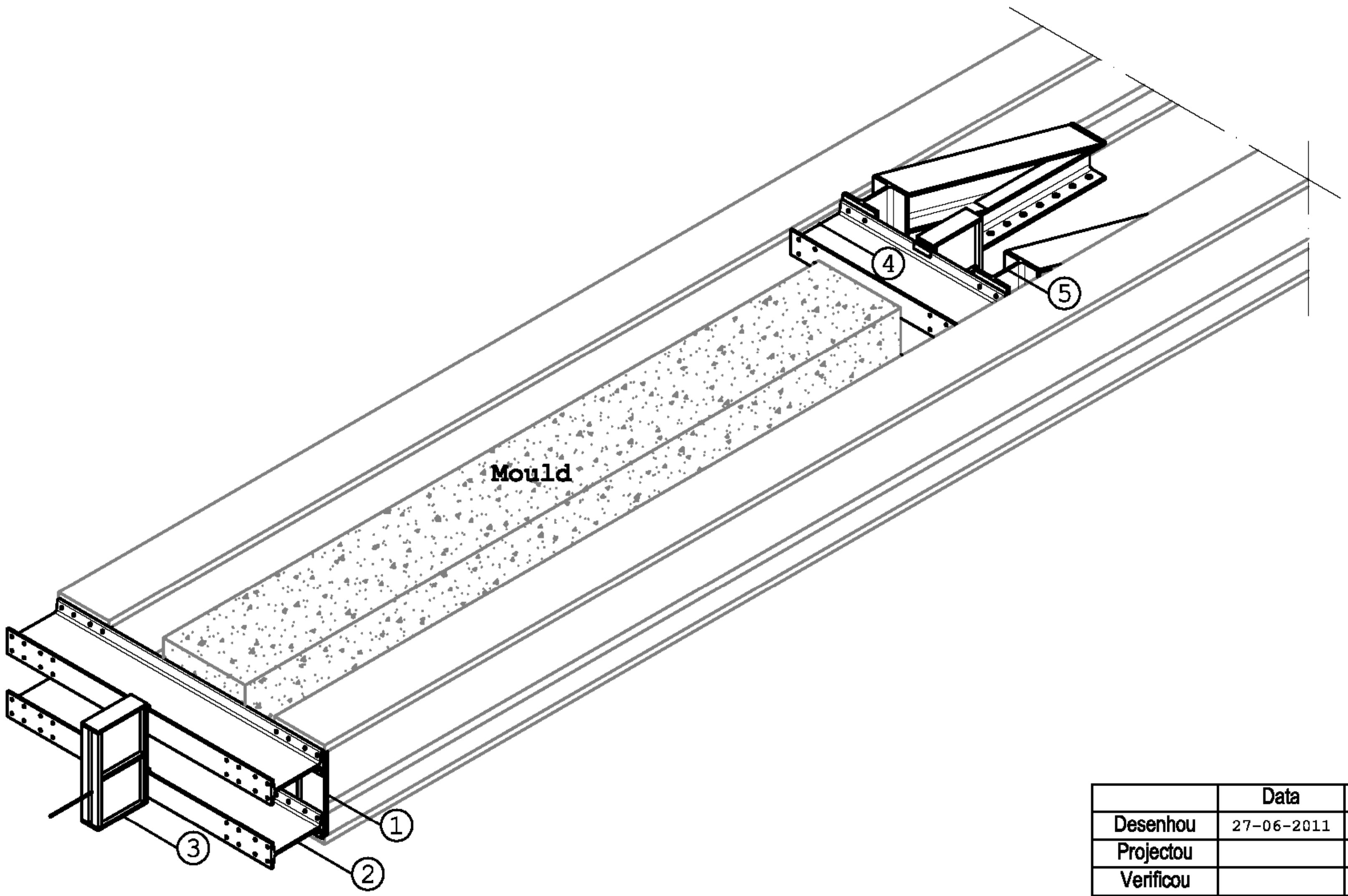
Universidade do Minho

Pista de Pré-Esforço			
Requerente: DEC - Universidade do Minho		Local: Guimarães	
Peça: Cabeça de Pré-Esforço: Corte C-C'	Escala: 1/20 (A4)	Data: 13 Out. 2010	Desenho: 2.3

ANNEX II – PRESTRESS SYSTEM EXECUTION DRAWINGS

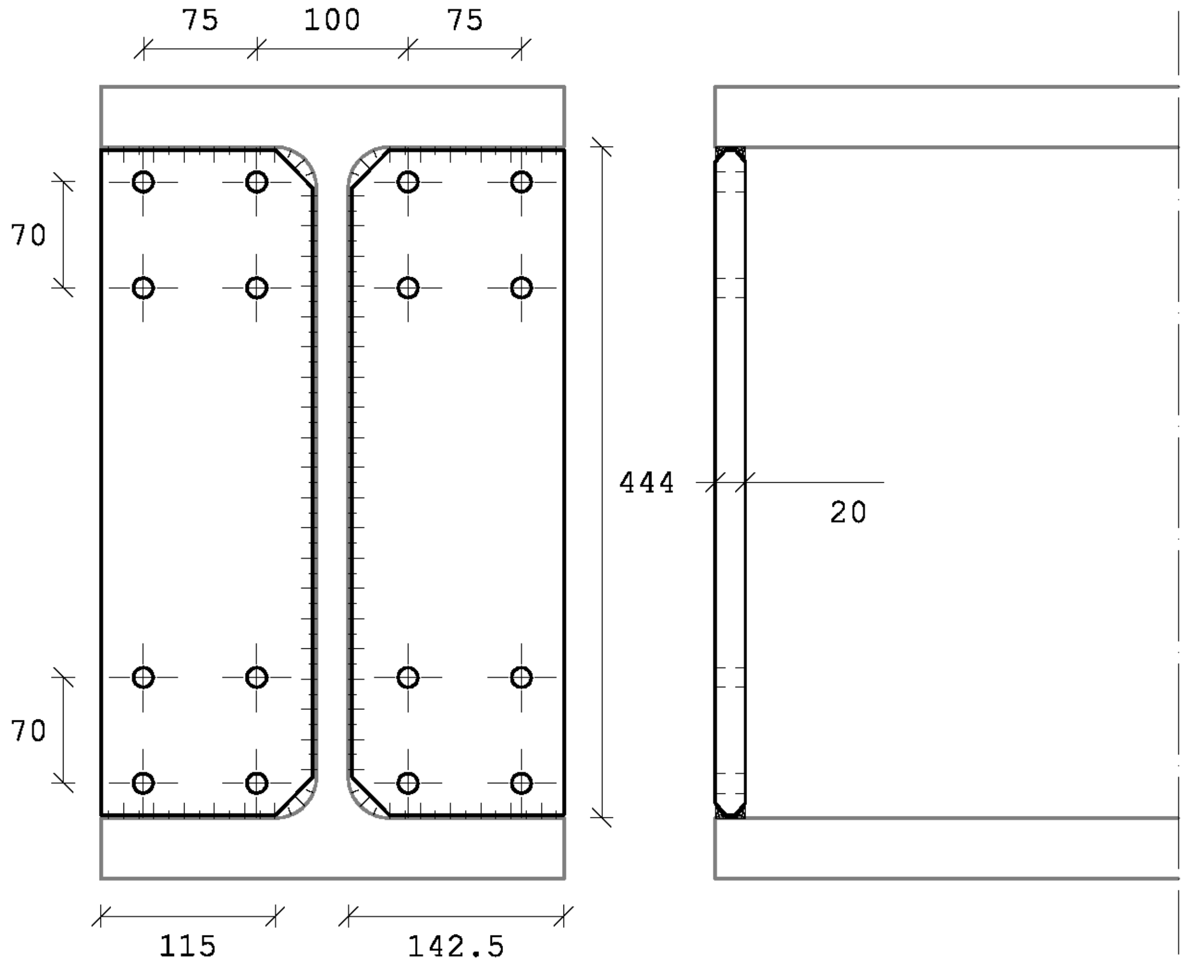


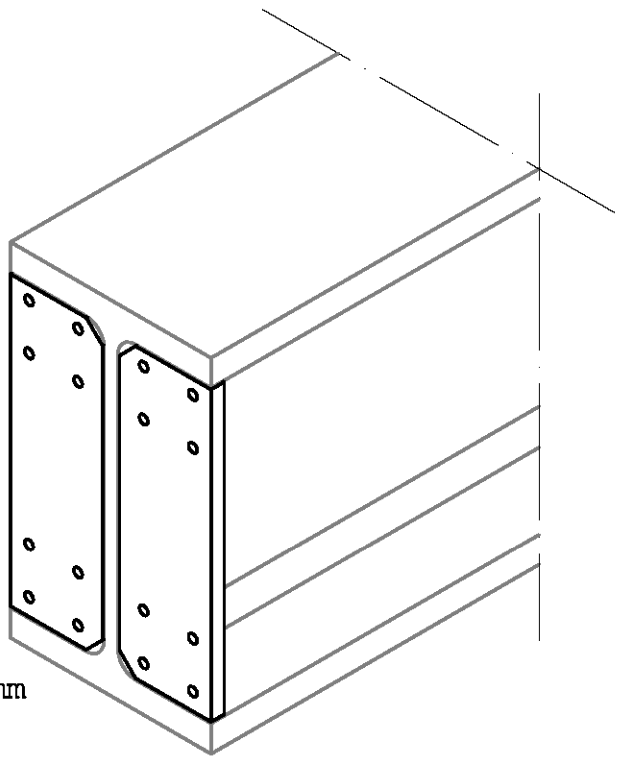


Item	Descrição	Qty.
1	Chapa 20mm	2
2	IPN320 topo	2
3	Encaixe topos	4
4	IPN320 medio	2
5	HEB200 esquadro	2
6	M12 (Aperto)	48
7	M24 (Ancoragem)	48

Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	27-06-2011	IC	Inês Costa	
Projectou				
Verificou				
Escala: 1/25 (A3)		Designação: Pista de Pré-esforço		Desenho no.: 1
Toler.:				Quantidade: ---





Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
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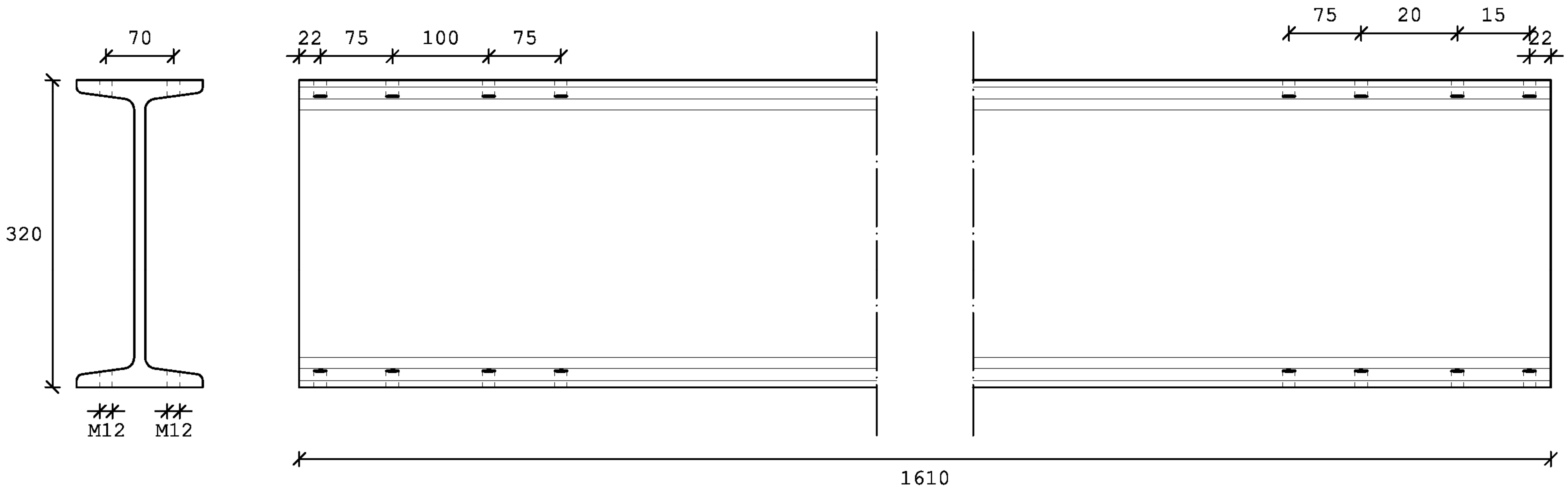
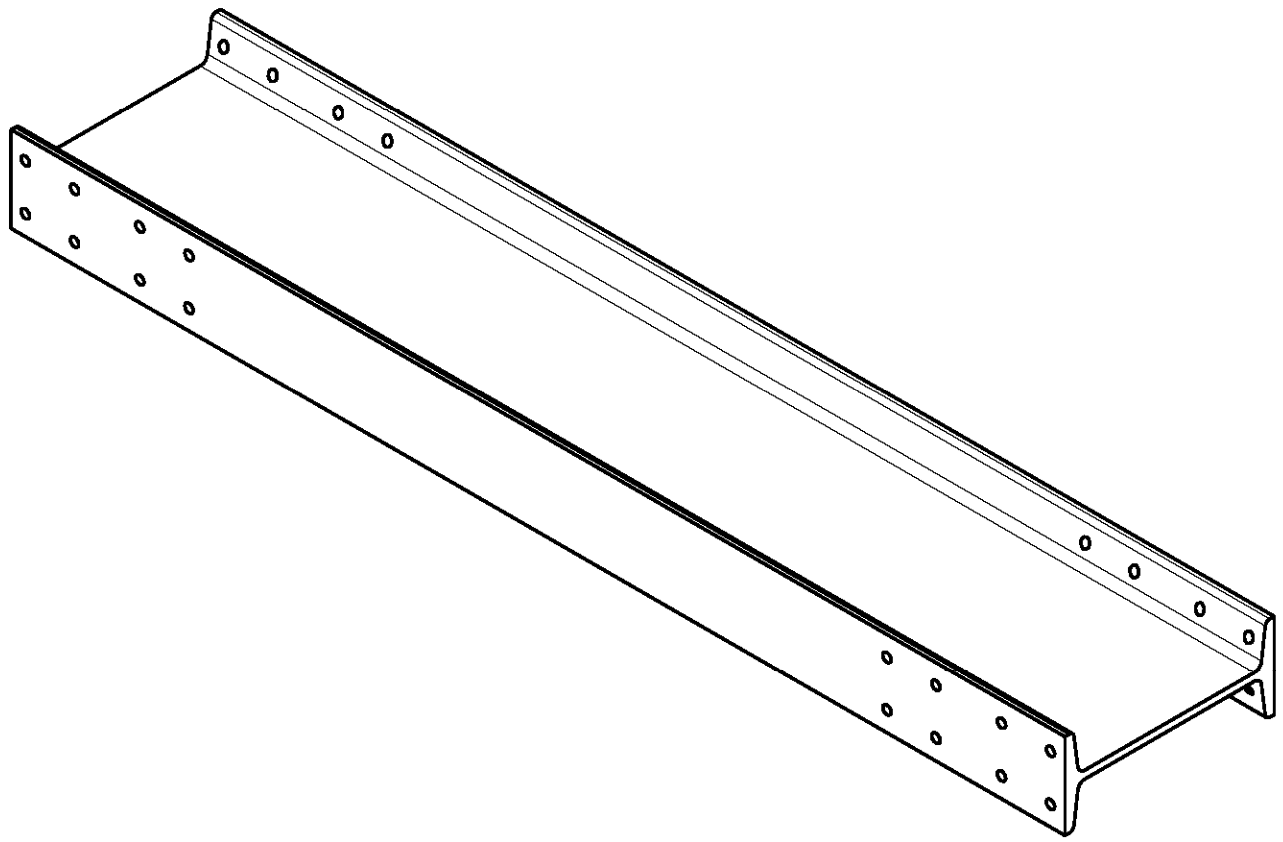
Verificou				
Escala: 1/5 (A4)	Designação: **Chapa 20mm**			Desenho no.: 1
Toler.:				Quantidade: 2





Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
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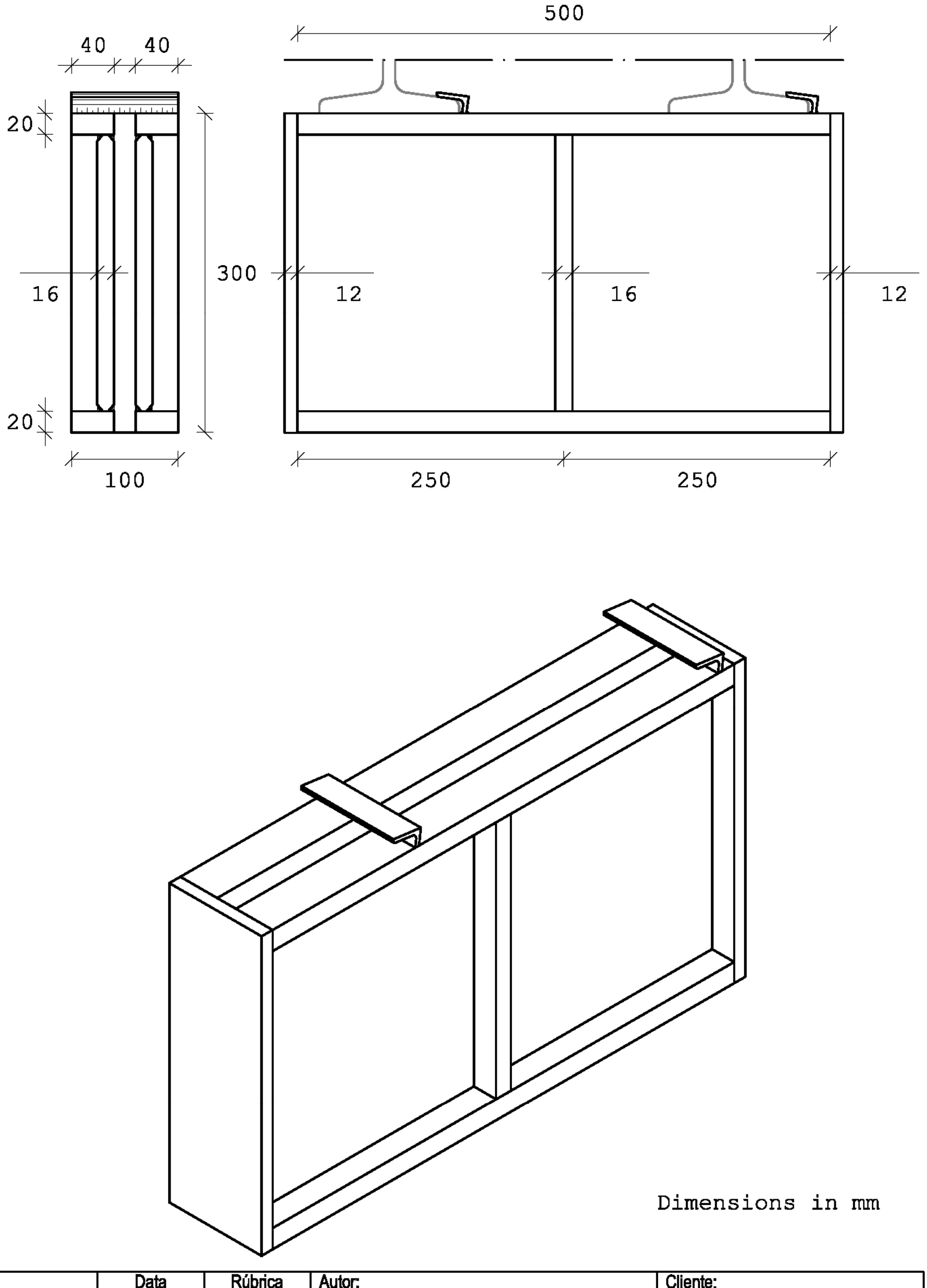
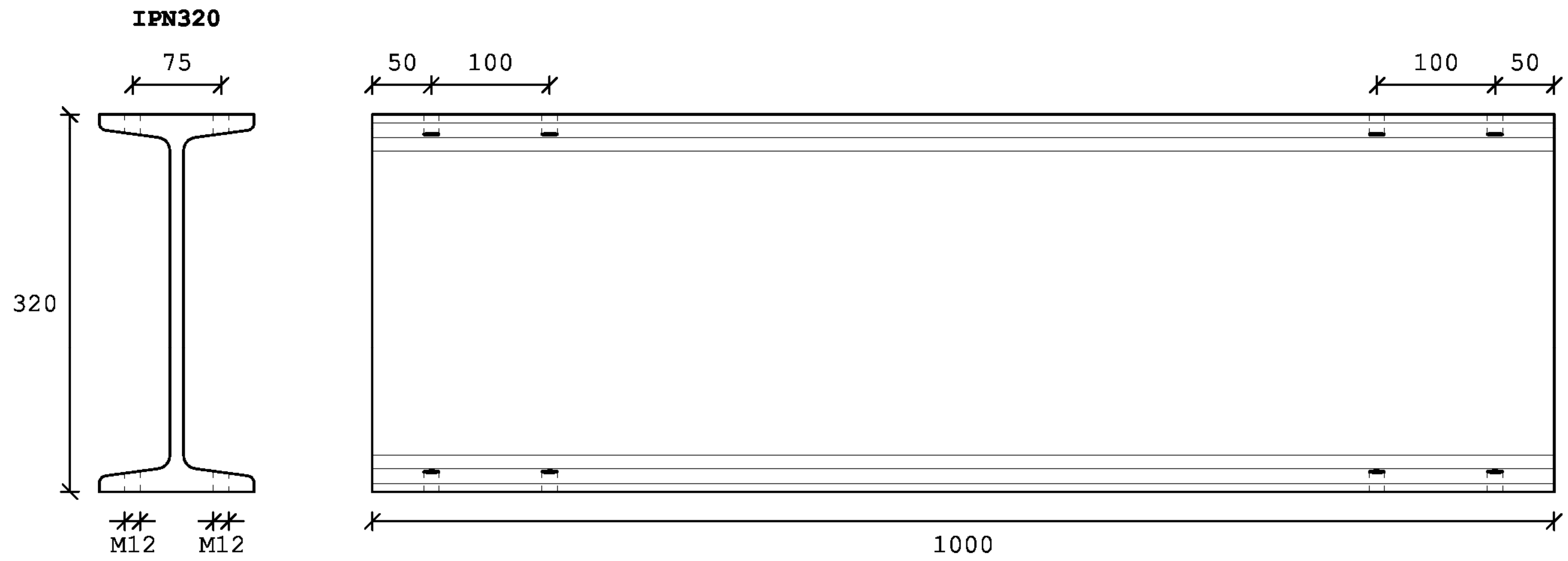
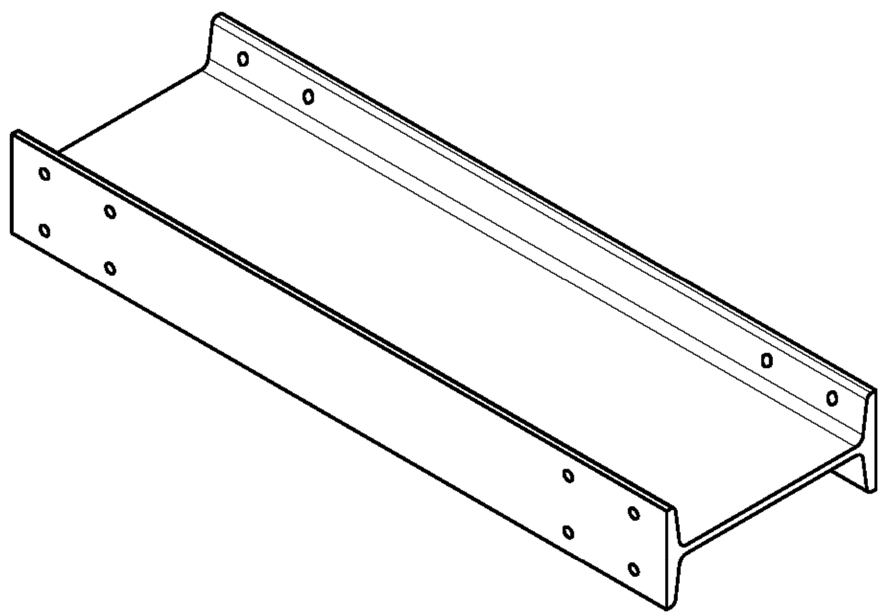
Projectou				
Verificou				
Escala: 1/5 (A3)	Designação: IPN320 topo			Desenho no.: 2
Toler.:				Quantidade: 2



Dimensions in mm

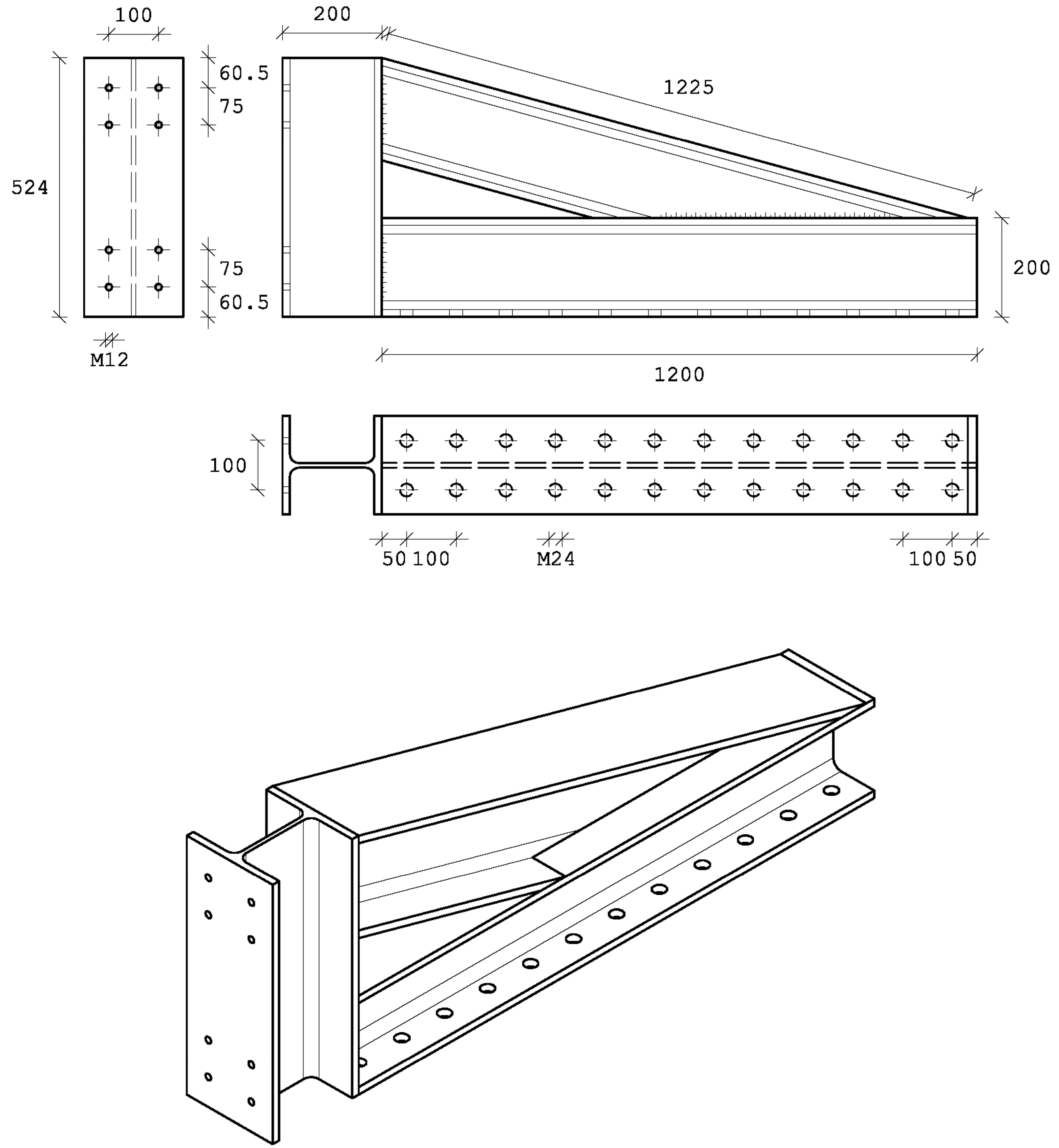
	Data	Rúbrica	Autor:	Cliente:
Desenhou	27-06-2011	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A4)	Designação: **Encaixe Topos**			Desenho no.: 3
Toler.:				Quantidade: 4





Dimensions in mm

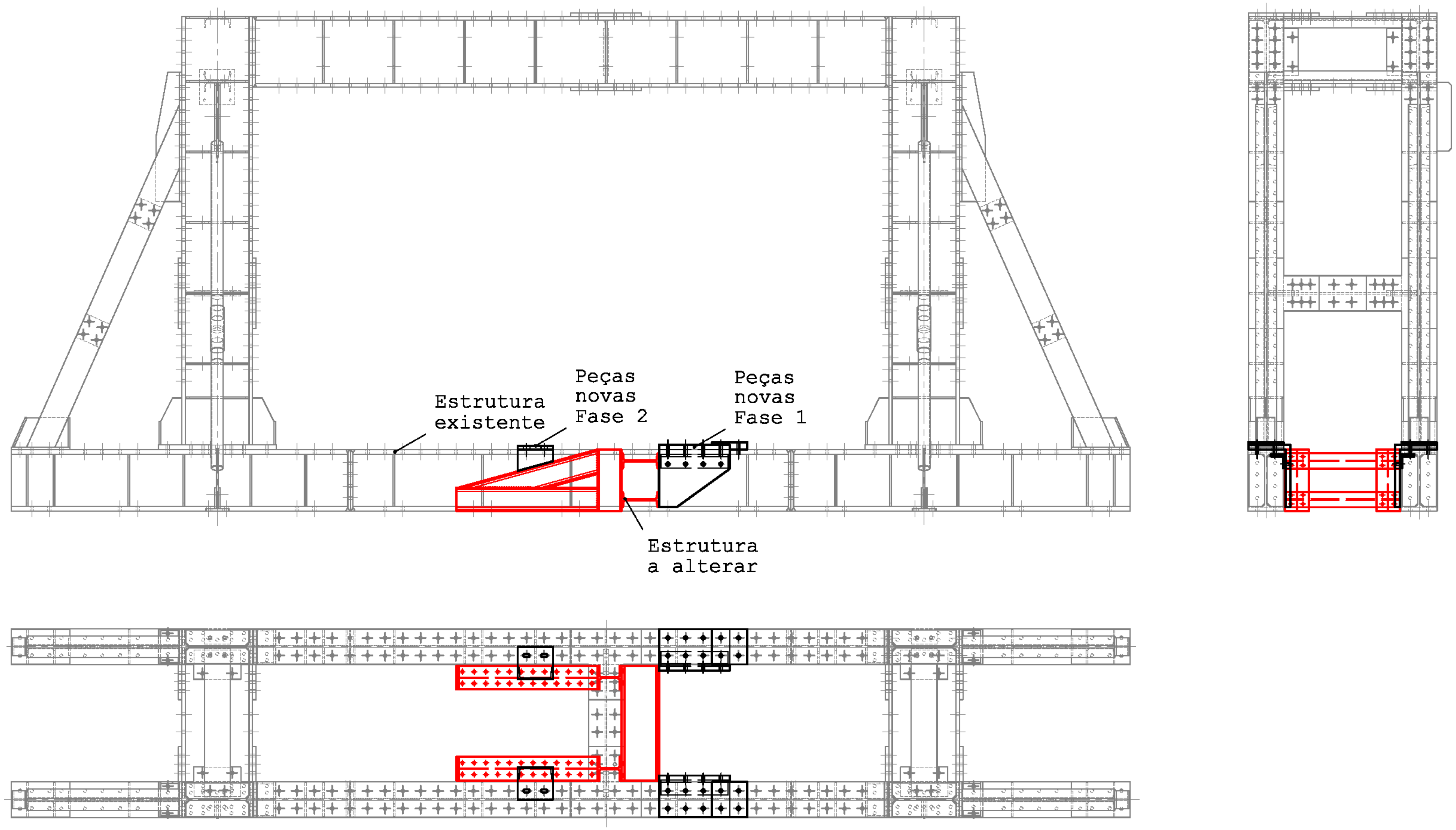
	Data	Rúbrica	Autor:	Cliente:
Desenhou	27-06-2011	IC	Inês Costa	
Projectou				
Verificou				
Escala: 1/5 (A3)	Designação: IPN320 medio			Desenho no.: 4
Toler.:				Quantidade: 2



Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	27-06-2011	IC	Inês Costa	
Projectou				
Verificou				
Escala: 1/10 (A3)		Designação: HEB200 esquadro		Desenho no.: 5
Toler.:				Quantidade: 2

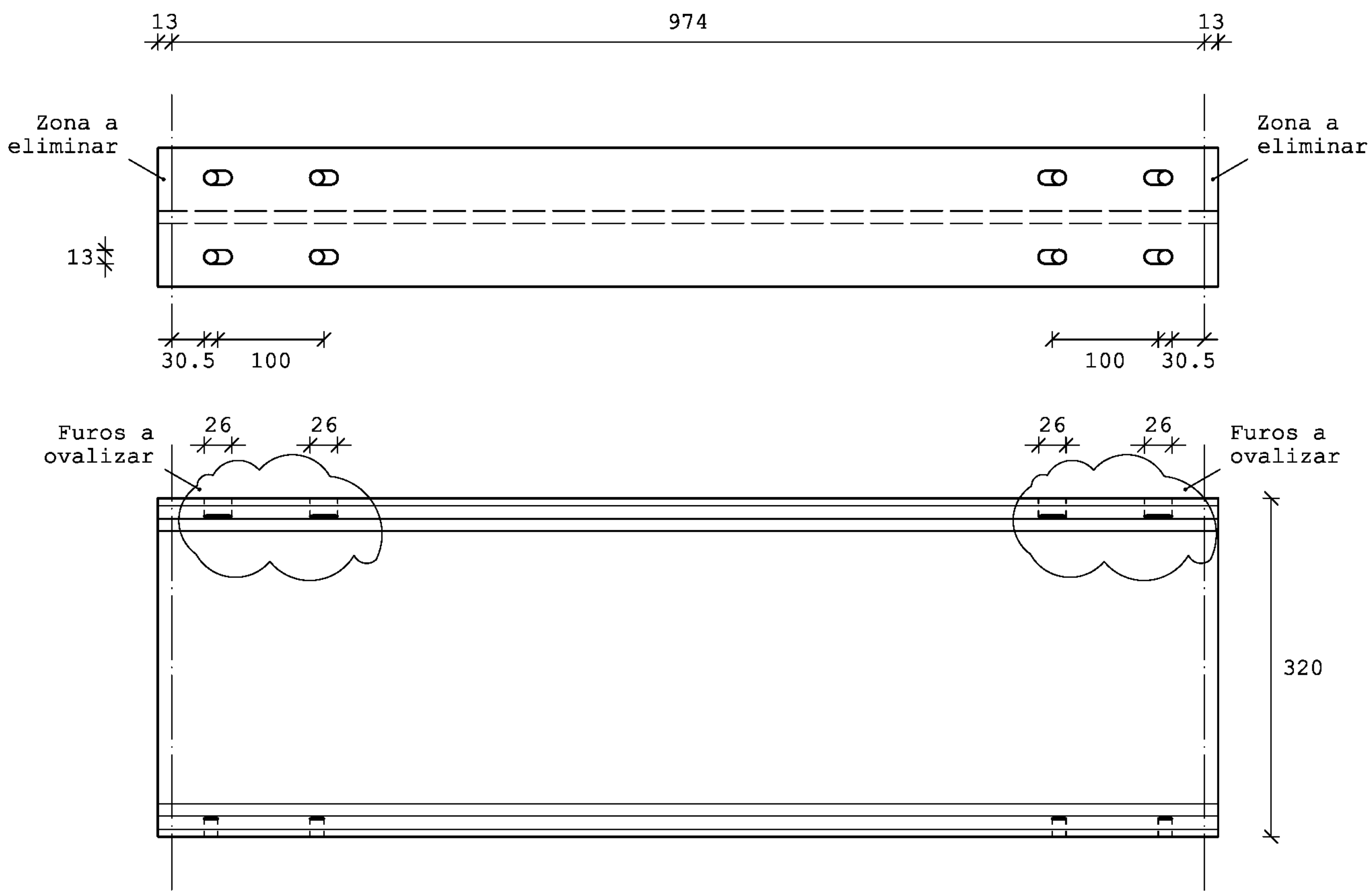
ANNEX III – PRESTRESS SYSTEM SUPPORT EXECUTION DRAWINGS



Material: S 235 JR

Dimensions in mm

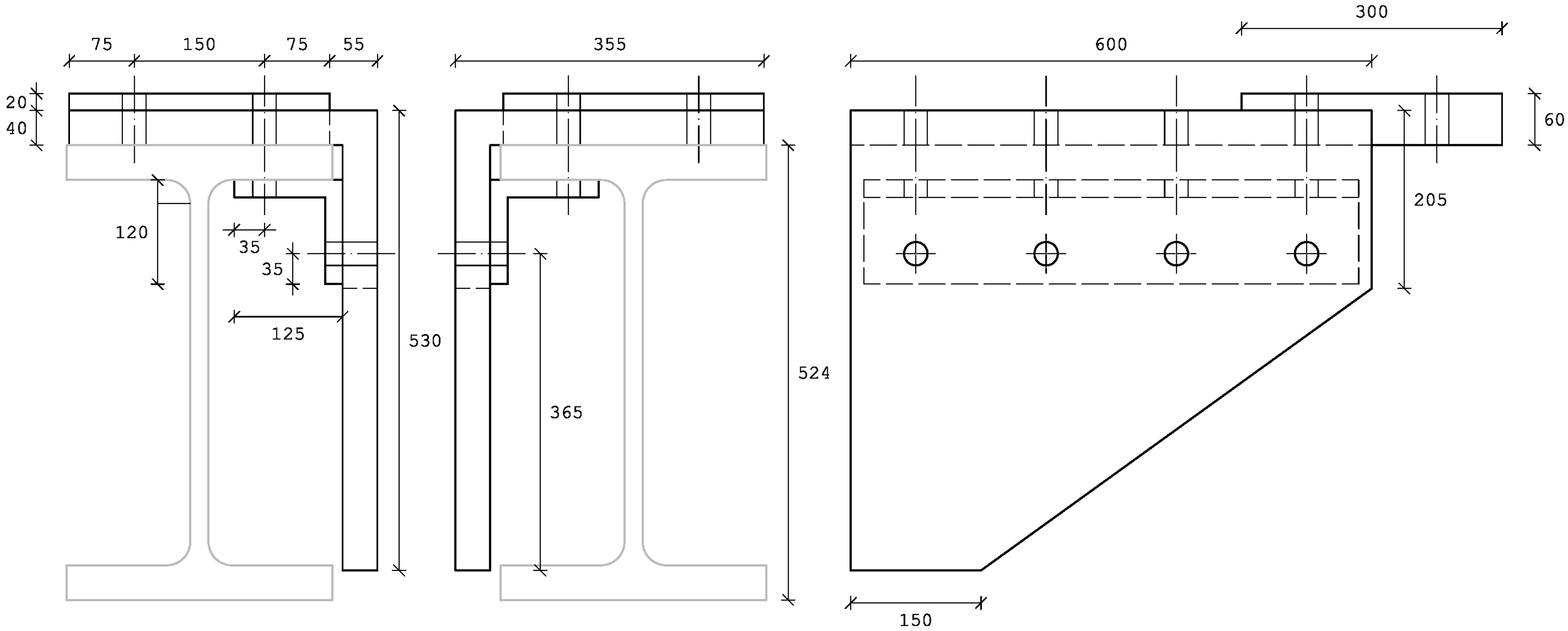
	Data	Rúbrica	Autor:	Cliente:
Desenhou	23-12-2011	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/40 (A3)	Designação:			Desenho no.: 1
Toler.:	**Pista de Pré-esforço - Extras**			Quantidade: ---

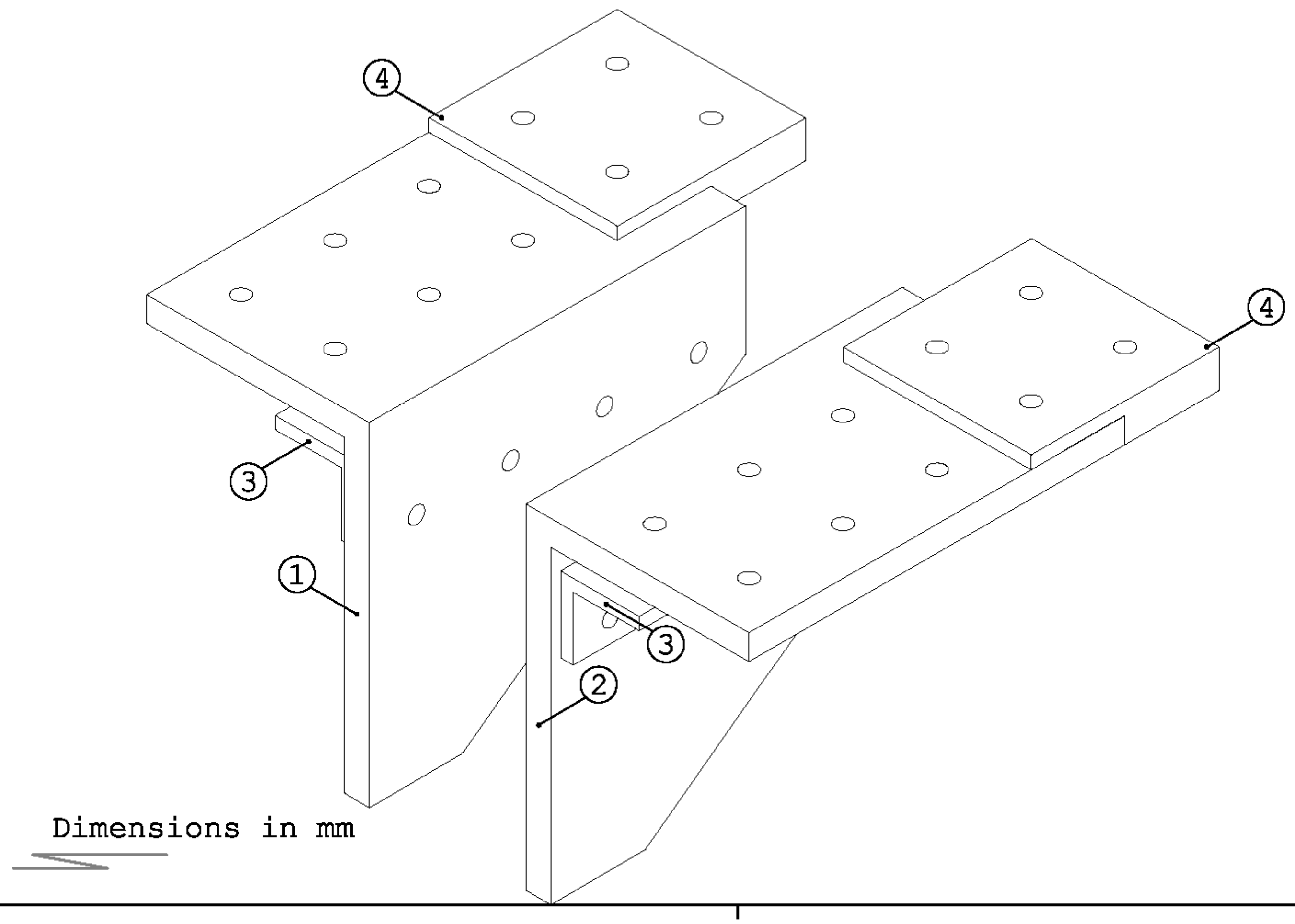


Estas vigas existem no LEST mas será necessário:
- ovalizar os furos em um dos banzos;
- cortar o perfil de modo a diminuir o seu comprimento de 1.000 m para 0.974 m

Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	23-12-2011	IC	Inês Costa	
Projectou				
Verificou				
Escala: 1/5 (A3)		Designação: Pista de Pré-esforço - Extras Estrutura a alterar		Desenho no.: 2
Toler.:				Quantidade: 2

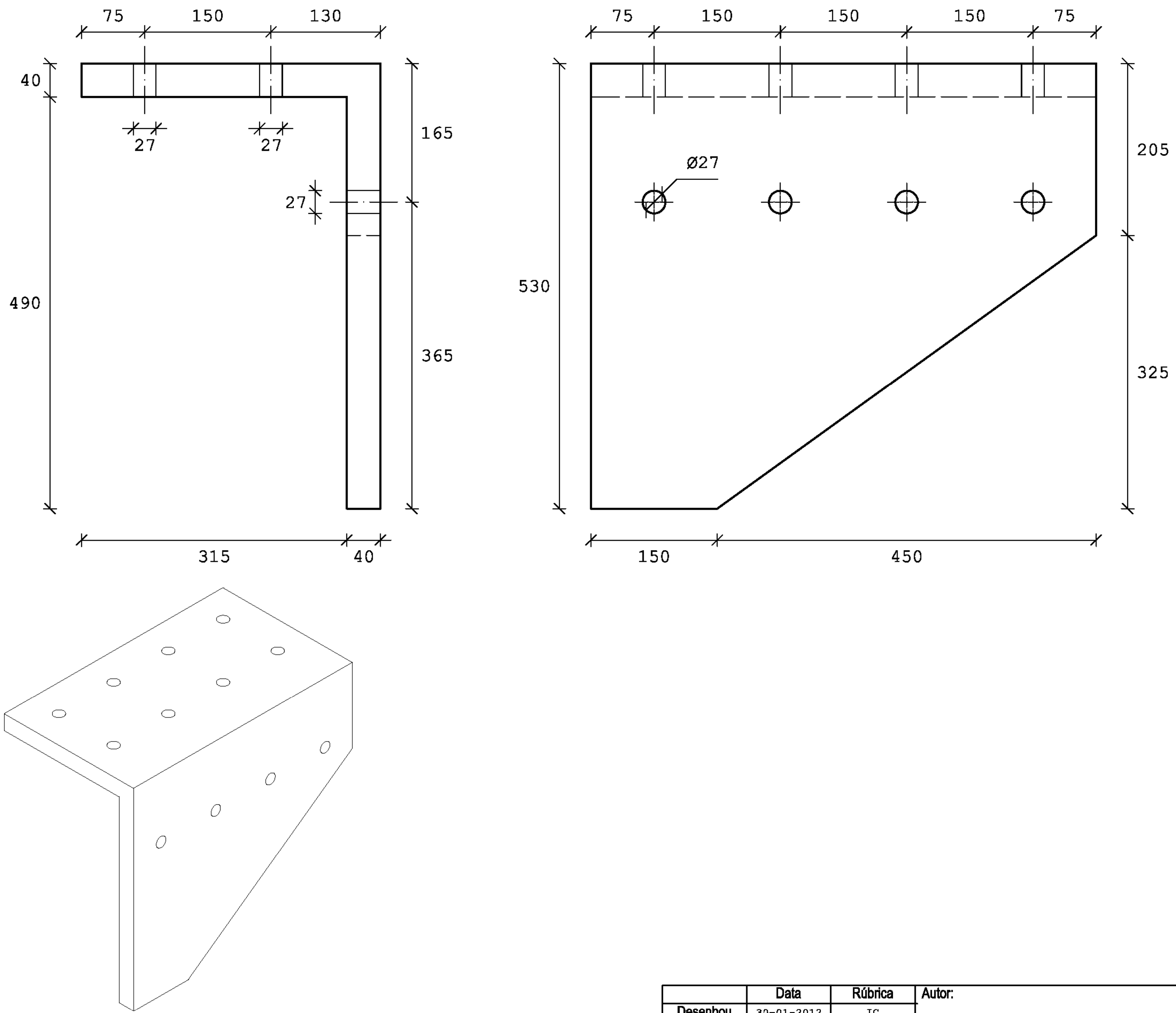




Dimensions in mm

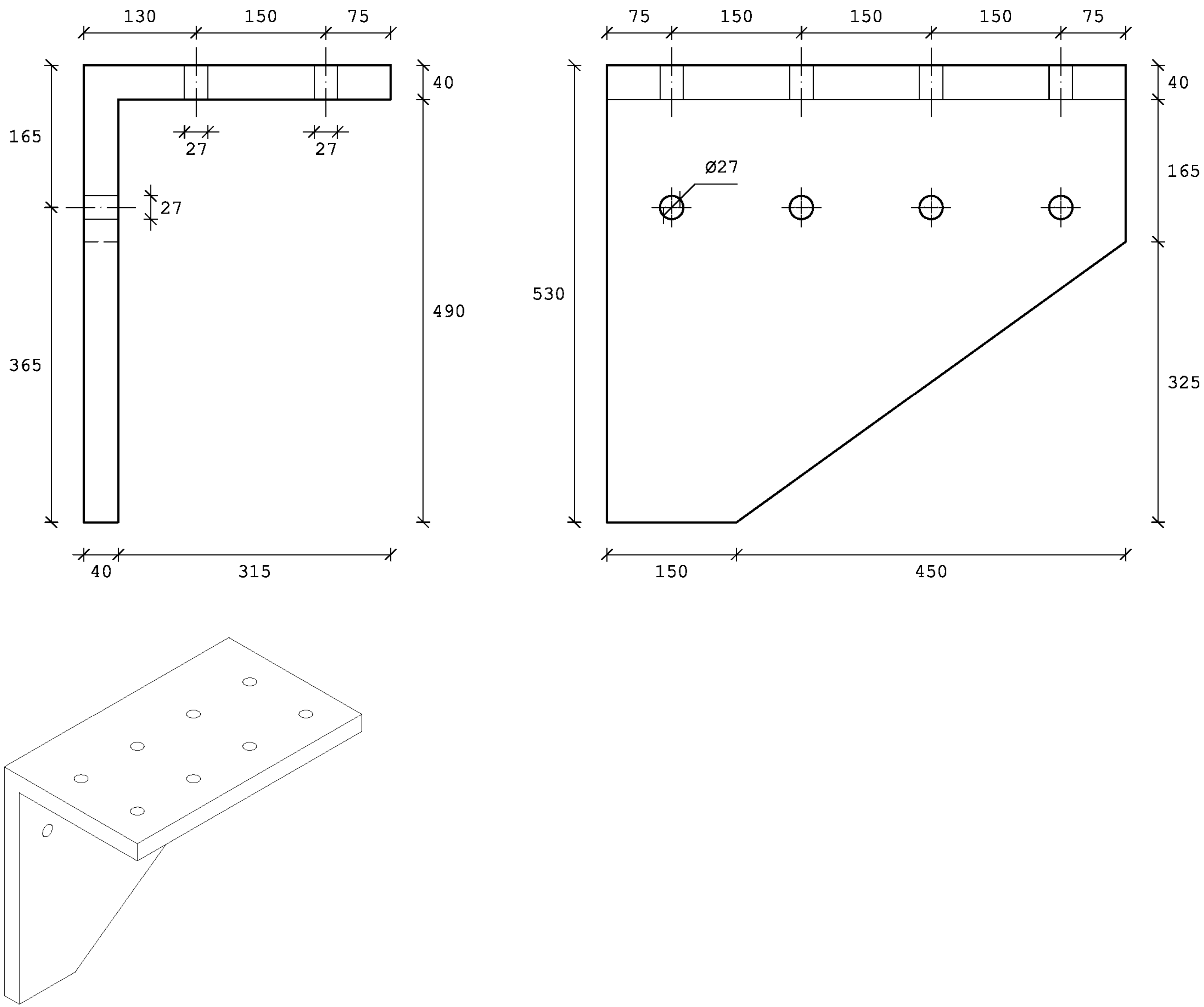
Item	Descrição	Qty.	W/un.	Des.
1	Chapa soldada 355×530×40 (esq) (S235JR)	1	157 kg	3.1
2	Chapa soldada 355×530×40 (dir) (S235JR)	1	157 kg	3.2
3	Chapa soldada 125×120×20 (S235JR)	2	19 kg	3.3
4	Chapa aperto 300×300 (S235JR)	2	28 kg	3.4
5	Parafuso/porca M24 (8.8, 100mm)	8	-	-
6	Parafuso/porca M24 (8.8, 160mm)	20	-	-

	Data	Rúbrica	Autor:	Cliente:
Desenhou	23-12-2011	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A3)		Designação: **Pista de Pré-esforço - Extras Peças novas : Fase 1**		Desenho no.: 3
Toler.:				Quantidade: ---



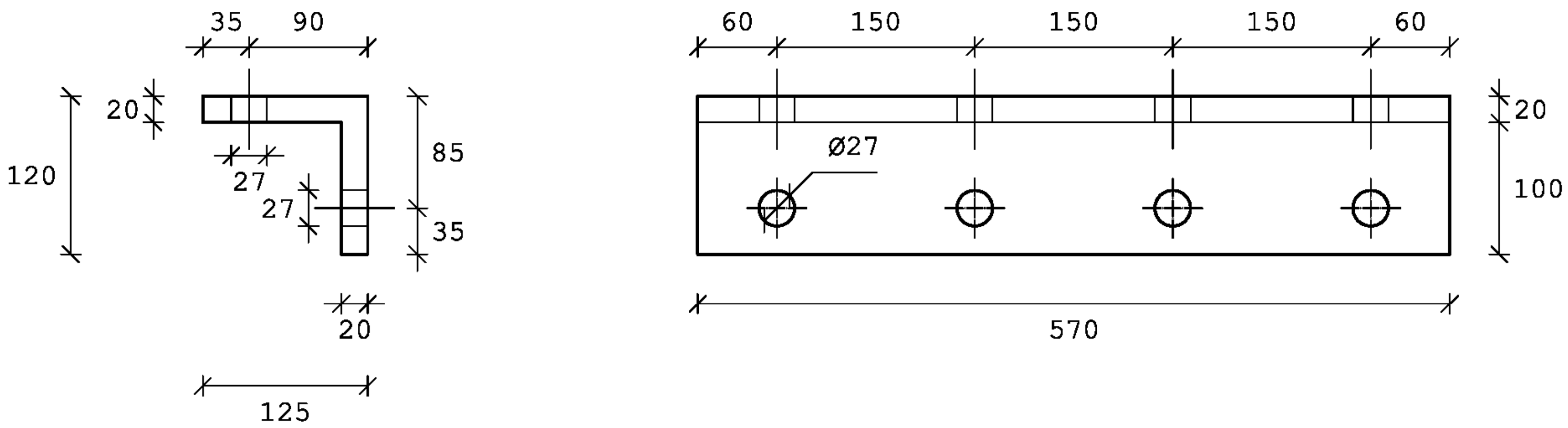
	Data	Rúbrica	Autor:	Cliente:
Desenhou	30-01-2012	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A3)		Designação: **Pista de Pré-esforço - Extras Peças novas : Fase 1**		Desenho no.: 3.1
Toler.:				Quantidade: 1

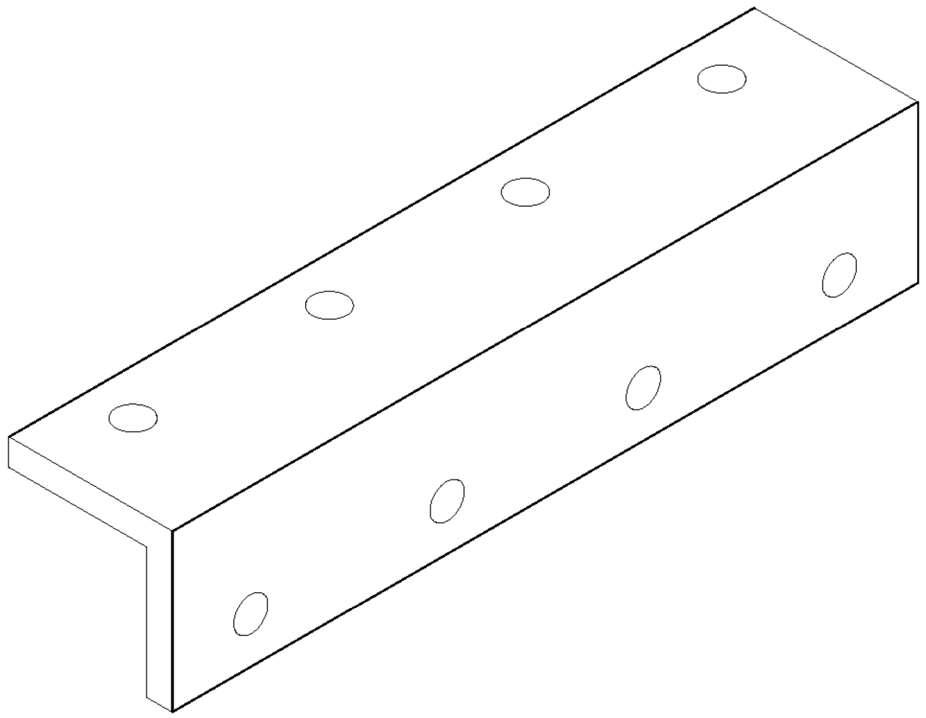
Dimensions in mm



Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	30-01-2012	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A3)	Designação:			Desenho no.: 3.2
Toler.:	**Pista de Pré-esforço - Extras Peças novas : Fase 1**			Quantidade: 1

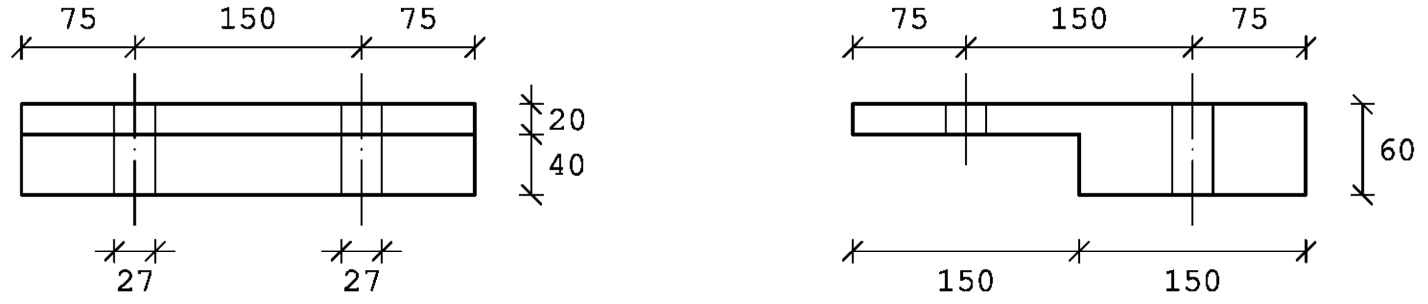


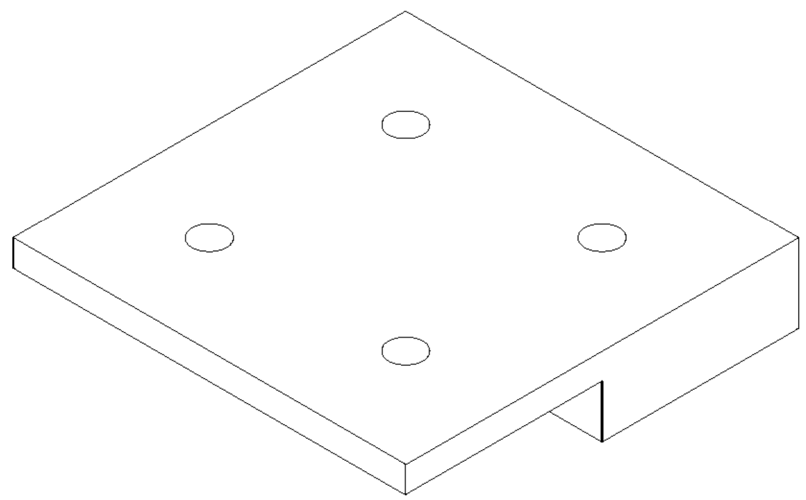


Material: S 235 JR

Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	30-01-2012	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A3)		Designação: **Pista de Pré-esforço - Extras Peças novas : Fase 1**		Desenho no.: 3.3
Toler.:				Quantidade: 2

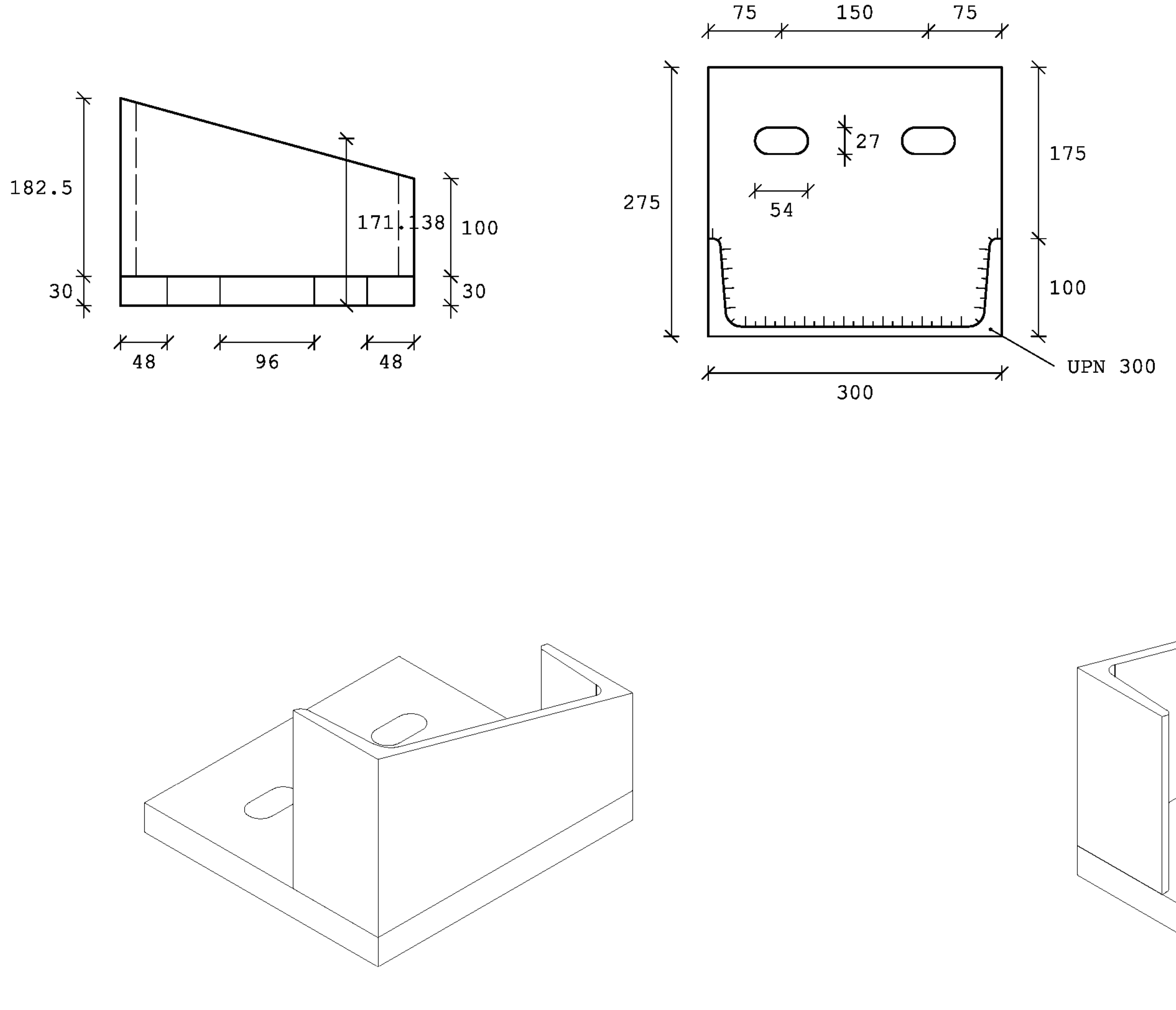




Material: S 235 JR

Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	30-01-2012	IC	Inês Costa	
Projectou				
Verificou				
Escala: 1/5 (A3)	Designação: Pista de Pré-esforço - Extras Peças novas : Fase 1			Desenho no.: 3.4
Toler.:				Quantidade: 2



Material: S 235 JR
Peso aproximado = 27 kg/cada
Serão necessários ainda 4
parafusos/anilha/porca M24 (8.8)

Dimensions in mm

	Data	Rúbrica	Autor:	Cliente:
Desenhou	30-01-2012	IC	**Inês Costa**	
Projectou				
Verificou				
Escala: 1/5 (A3)		Designação: **Pista de Pré-esforço - Extras Peças novas : Fase 2**		Desenho no.: 4.0
Toler.:				Quantidade: 2 (um de cada)