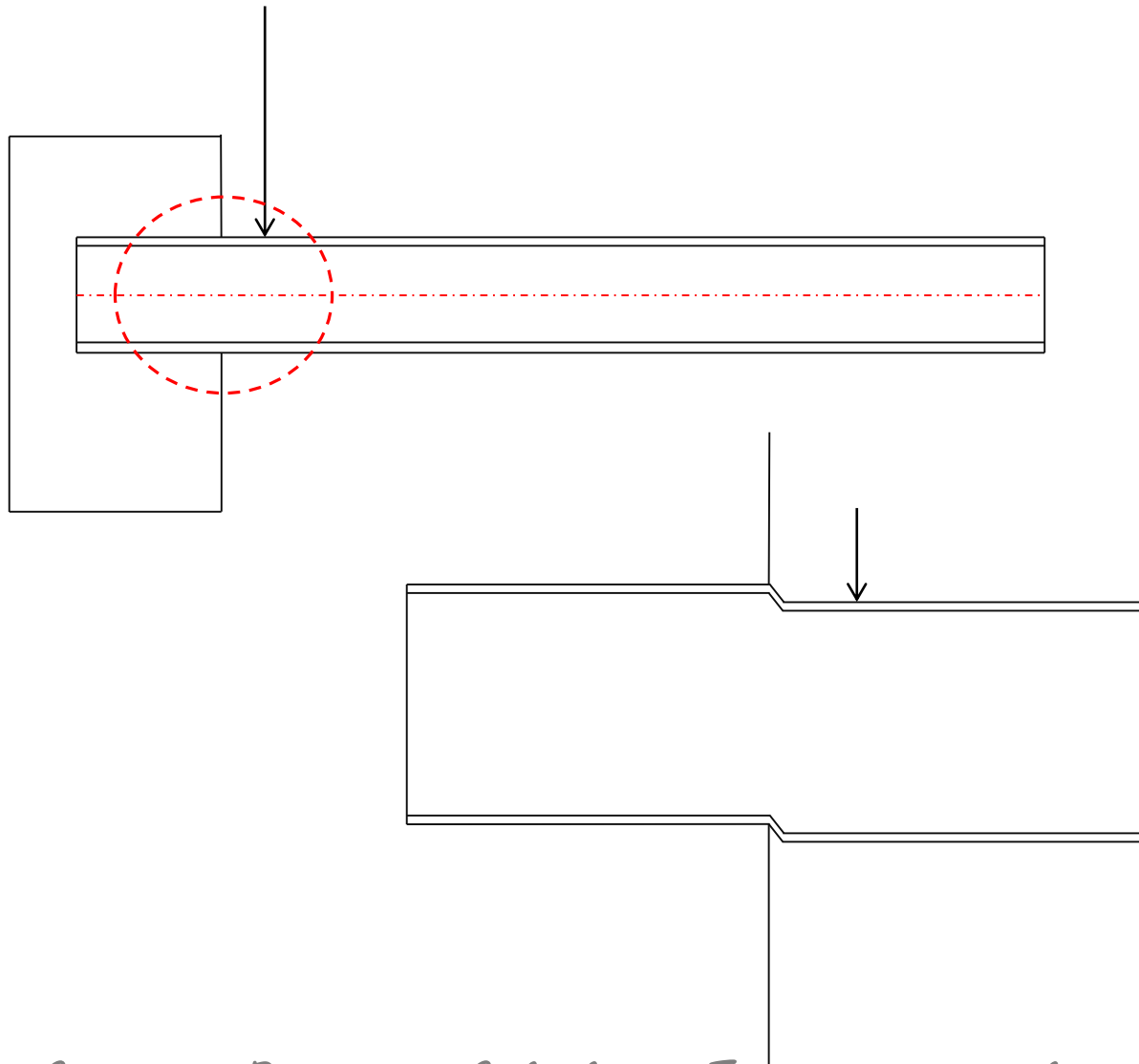


Força Cortante Combinação de Esforços

Curso de Projeto e Cálculo de Estruturas metálicas

Força Cortante



Força cortante resistente de cálculo:

Para perfis I, H e U fletidos em relação ao eixo de maior inércia

Passo 01: Comparar esbeltez da alma com dois limites (inferior e superior)

$$\lambda = \frac{h}{t_w}$$

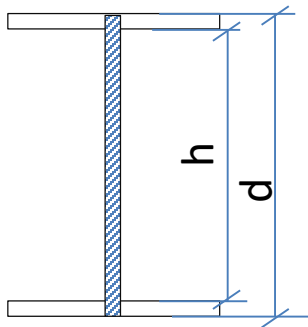
$$V_{Rd} = \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_p = 1,10 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

$$V_{Rd} = \frac{\lambda_p}{\lambda} \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_r = 1,37 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

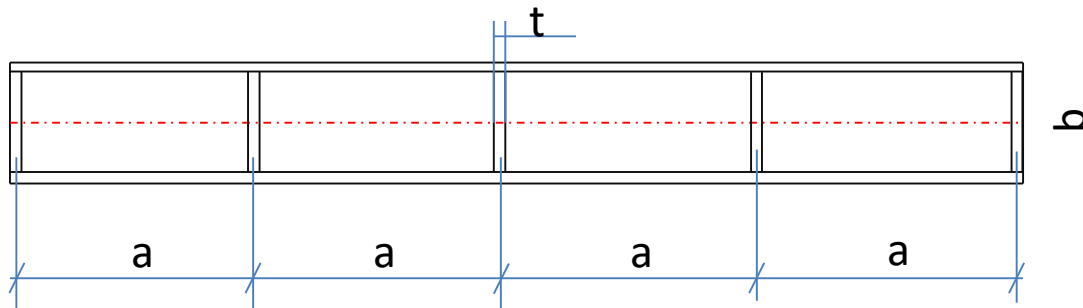
$$V_{Rd} = 1,24 \cdot \left(\frac{\lambda_p}{\lambda}\right)^2 \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$



$$A_w = d \cdot t_w$$

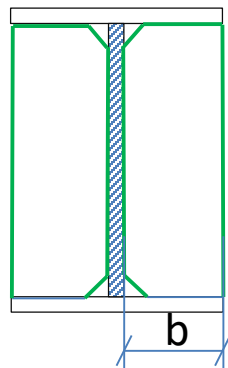
$$k_v = \begin{cases} 5,0 & \text{para almas sem enrijecedores transversais, para } \frac{a}{h} > 3 \text{ ou para } \frac{a}{h} > \left[\frac{260}{(h/t_w)} \right]^2 \\ 5 + \frac{5}{(a/h)^2} & \text{para todos os outros casos} \end{cases}$$

Força cortante resistente de cálculo:



Cálculo da espessura mínima do enrijecedor

$$\frac{b}{t} < 0,56 \sqrt{\frac{E}{F_y}}$$



Para ASTM A36 $\frac{b}{t} < 16$

Para ASTM A572 GR50 $\frac{b}{t} < 13,65$

Esforços Combinados

A norma exige que após a verificação dos esforços isolados, façamos a verificação dos perfis sujeitos a esforços combinados

5.5.1 Barras submetidas a momentos fletores, força axial e forças cortantes

5.5.1.1 Em 5.5.1.2 é apresentada a condição a ser atendida pelas barras submetidas aos efeitos combinados de força axial e momento fletor, carregadas de forma que não ocorra torção. Em 5.5.1.3 é apresentada a condição a ser atendida por essas barras para o efeito das forças cortantes.

a) para $\frac{N_{Sd}}{N_{Rd}} \geq 0,2$

$$\frac{N_{Sd}}{N_{Rd}} + \frac{8}{9} \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

b) para $\frac{N_{Sd}}{N_{Rd}} < 0,2$

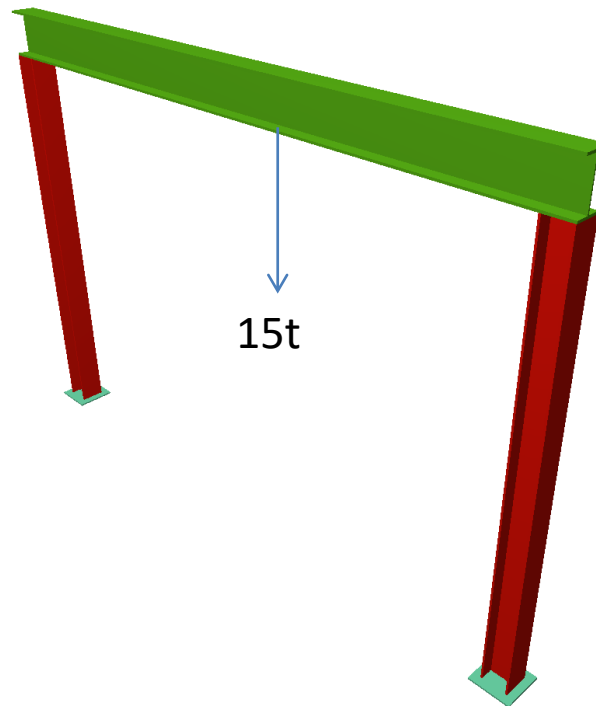
$$\frac{N_{Sd}}{2 N_{Rd}} + \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

Exercício Proposto 1

O pórtico da figura deve receber uma carga pontual de 15t no centro da viga. Admitindo que a flecha máxima admissível para este equipamento seja 15mm, determine se o pórtico está aprovado.

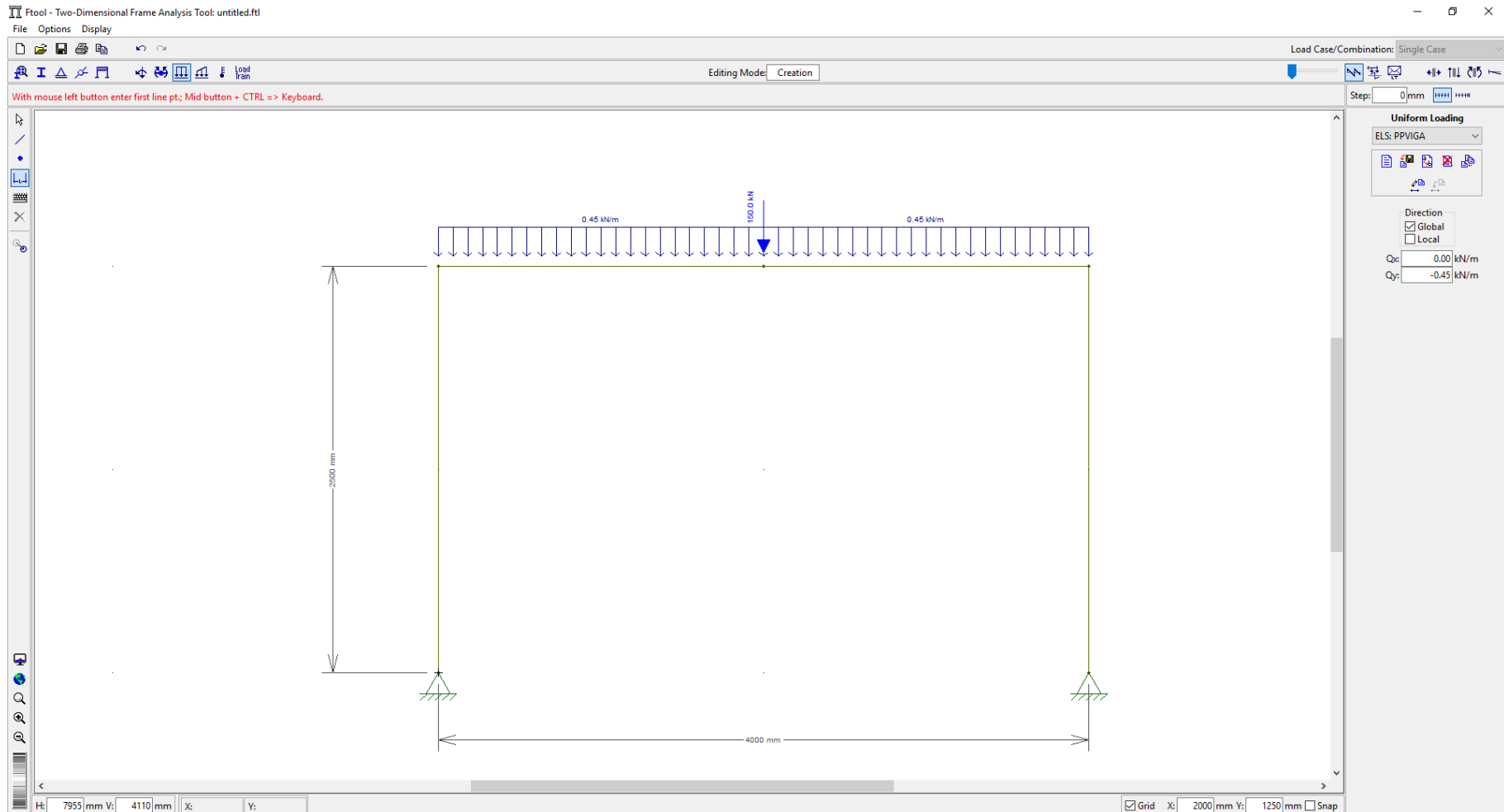
Dados: Viga = W250X44,8, Pilares = W150X37,1 – ASTM A572GR50

Considerar a base articulada. Altura 2,5m, vão livre: 4m

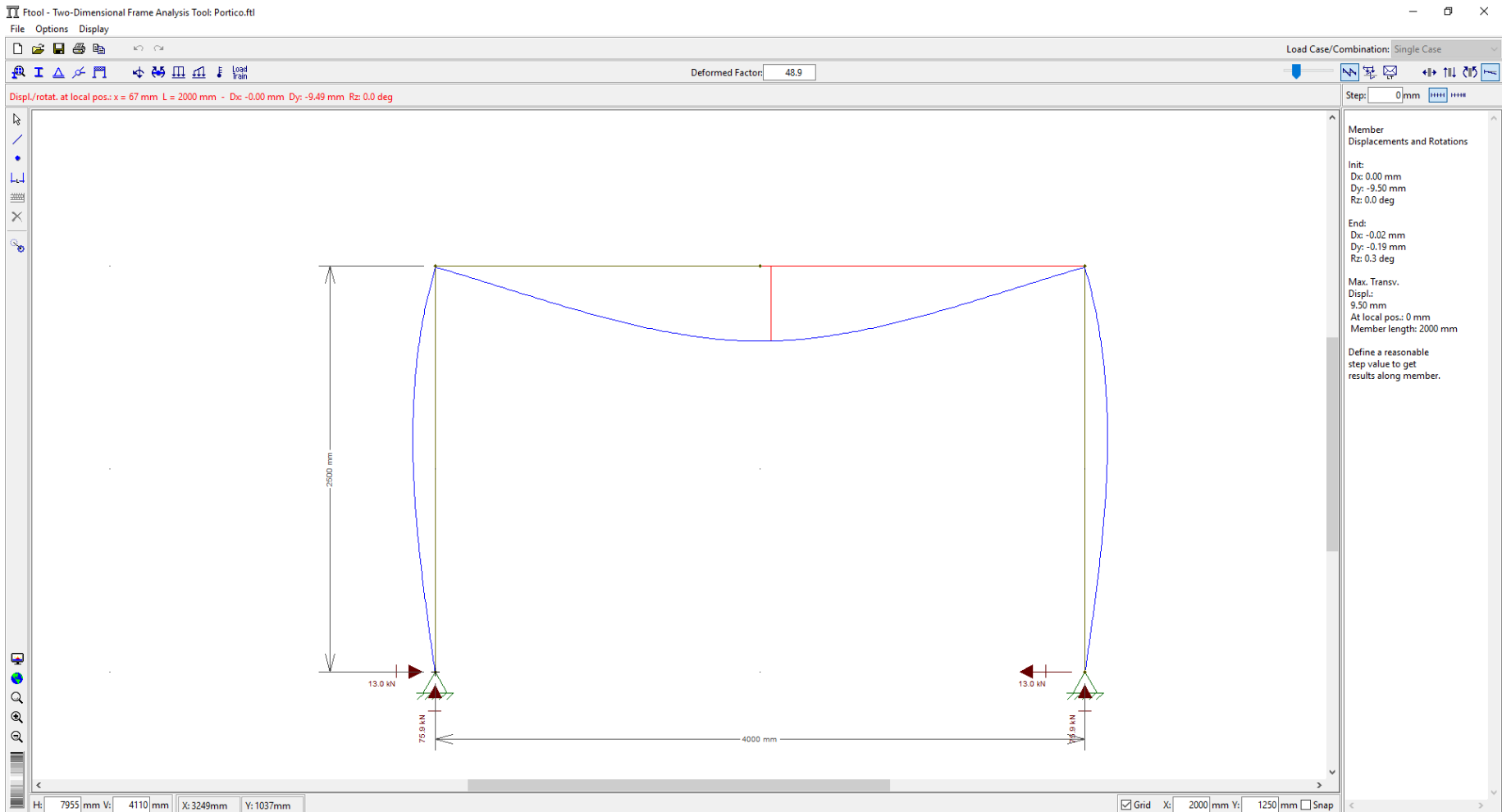


Curso de Projeto e Cálculo de Estruturas metálicas

Passo 1: Lançar no ftool sem majoração para cálculo de ELS

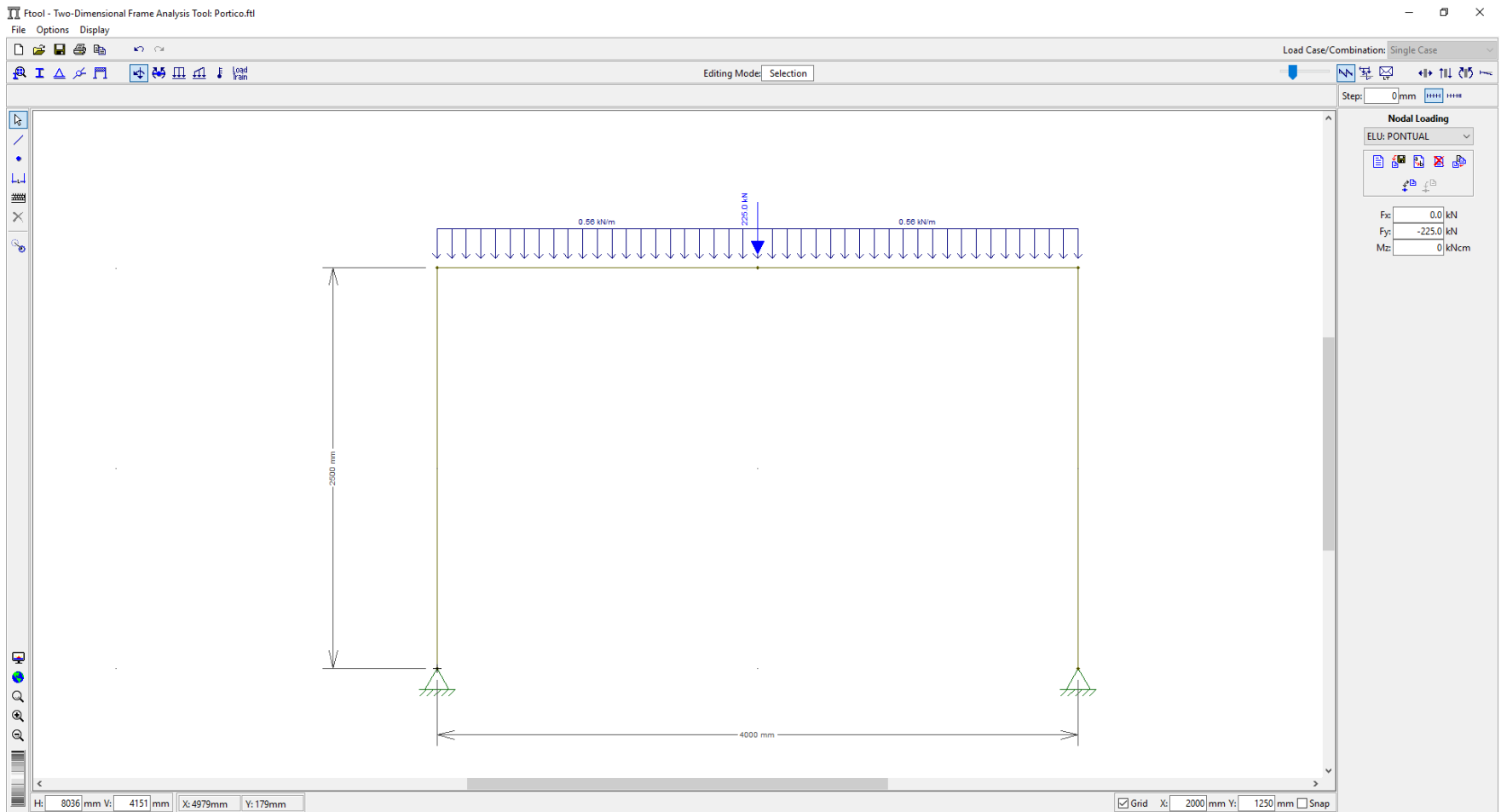


Passo 1: Lançar no ftool sem majoração para cálculo de ELS



Flecha na viga: 9,50mm < 15mm OK

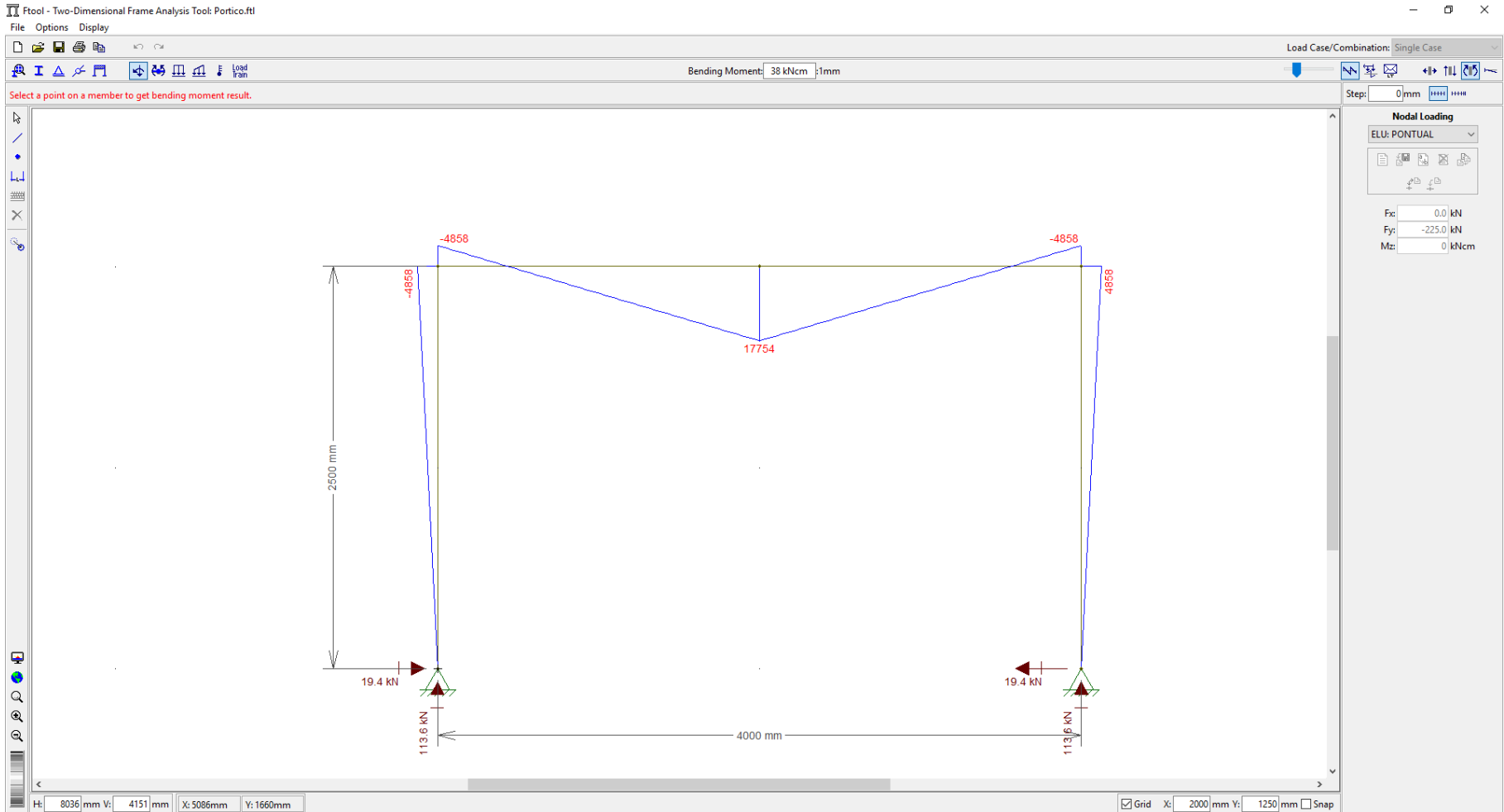
Passo 2: Lançar no ftool com majoração para cálculo de ELU



PP da viga: $= 1,25 \times 0,448 = 0,56 \text{ kN/m}$

SC $= 1,5 \times 150 = 225 \text{ kN pontual}$

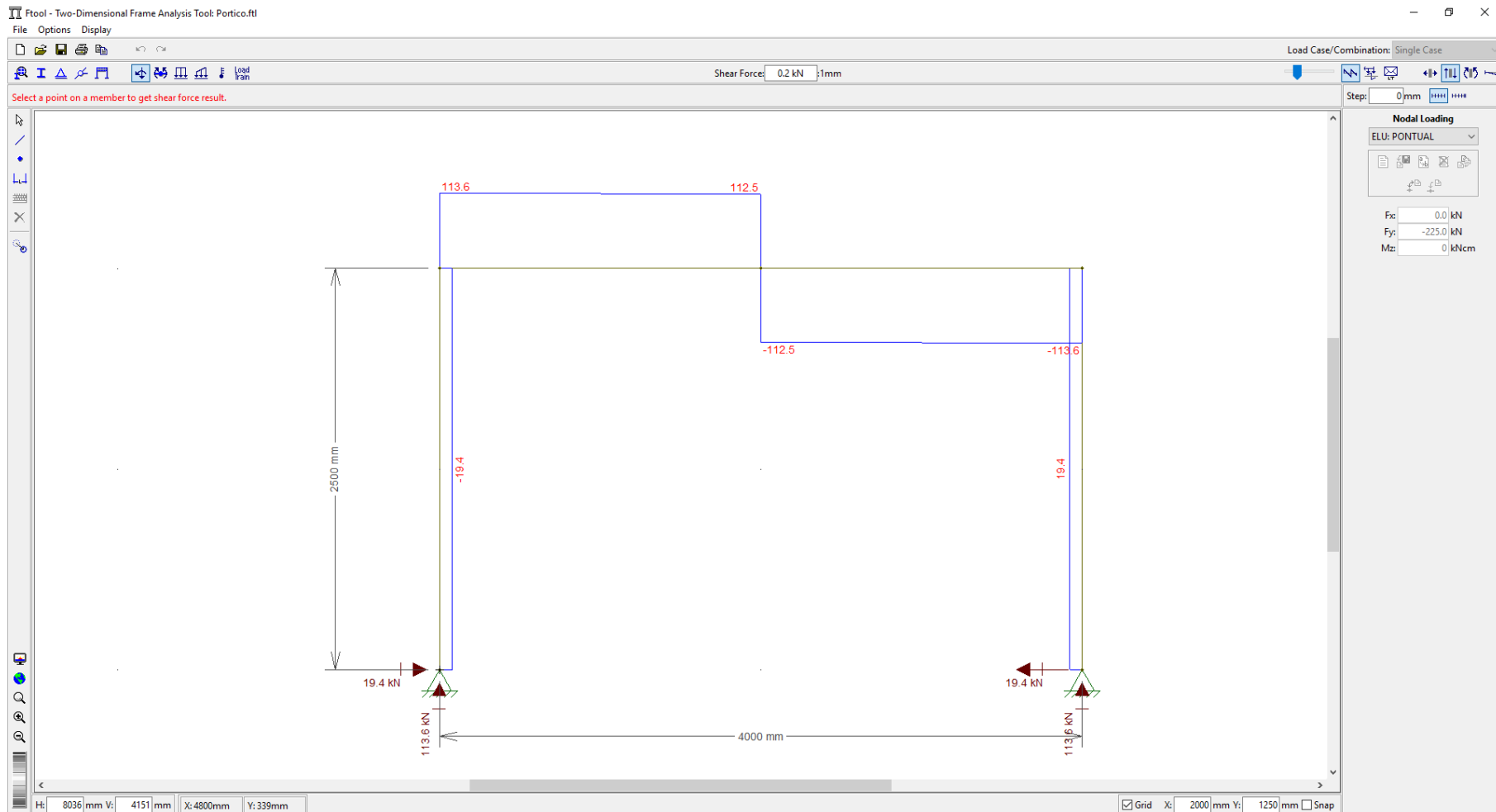
Passo 2: Lançar no ftool com majoração para cálculo de ELU



Momento Fletor máximo na viga: 17754 kN.cm

Momento Fletor Máximo no pilar: 4858 kN.cm

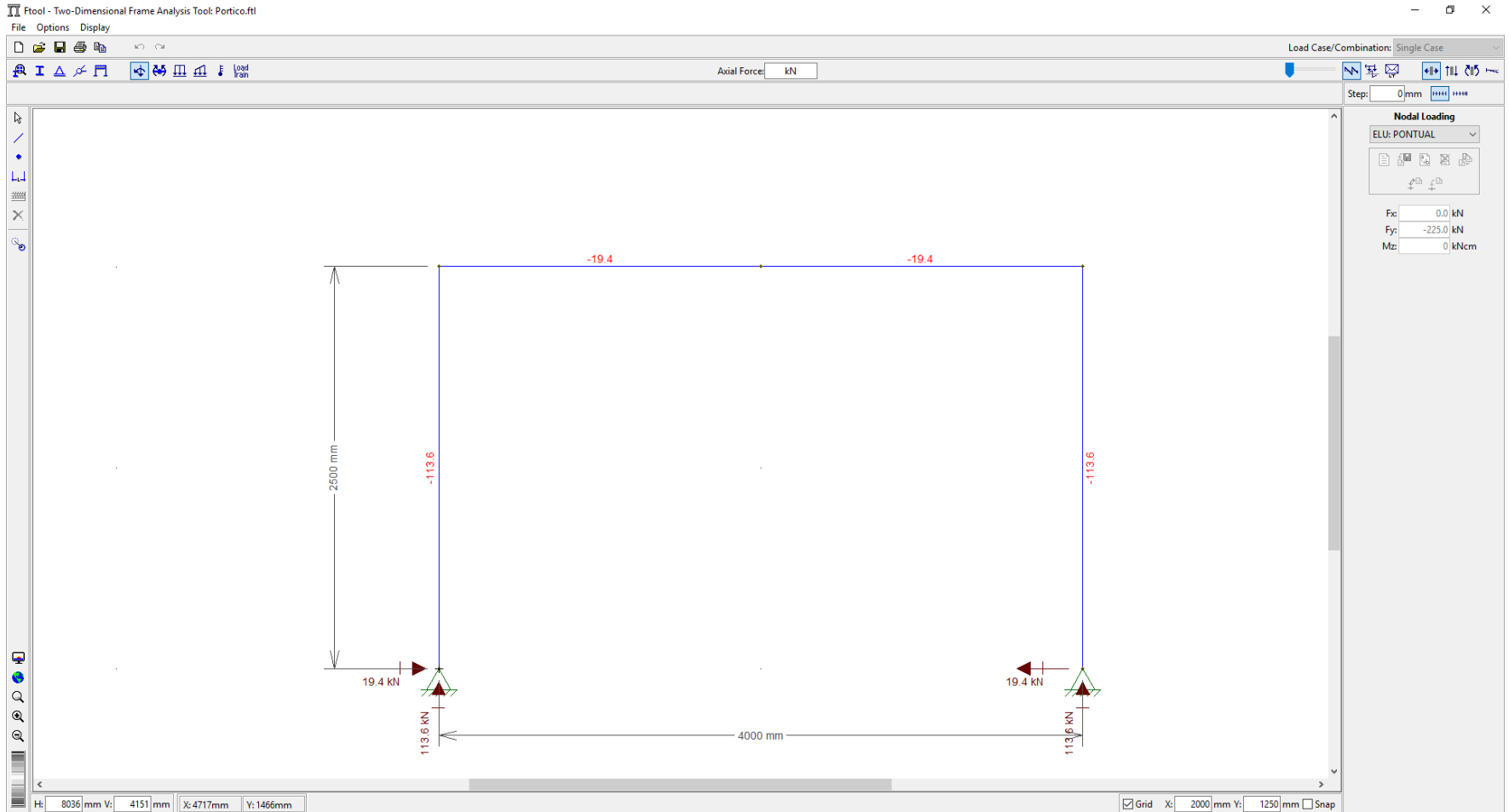
Passo 2: Lançar no ftool com majoração para cálculo de ELU



Cortante máxima na viga: 113,6 kN

Cortante Máxima no Pilar: 19,4 kN

Passo 2: Lançar no ftool com majoração para cálculo de ELU



Axial na viga: 19,4 kN COMPRESSÃO
Axial no Pilar: 113,6 kN COMPRESSÃO

TABELA DE BITOLAS

BITOLA mm x kg/m	Massa Linear kg/m	d mm	b ₁ mm	ESPESSURA		h mm	d' mm	Área cm²	EIXO X - X				EIXO Y - Y				r _i cm	I _y cm⁴	ESBELTEZ		C _w cm⁴	u m²/m	BITOLA in x lb/ft
				t ₁ mm	t ₂ mm				I _x cm⁴	W _x cm³	r _x cm	Z _x cm³	I _y cm⁴	W _y cm³	r _y cm	Z _y cm³			MESA - λ ₁ b ₁ /2L	ALMA - λ ₂ d'/L			
W 150 x 13,0	13,0	148	100	4,3	4,9	138	118	16,6	635	85,8	6,18	96,4	82	16,4	2,22	25,5	2,60	1,72	10,20	27,49	4,181	0,67	W 6 x 8,5
W 150 x 18,0	18,0	153	102	5,8	7,1	139	119	23,4	939	122,8	6,34	139,4	126	24,7	2,32	38,5	2,69	4,34	7,18	20,48	6,683	0,69	W 6 x 12
W 150 x 22,5 (H)	22,5	152	152	5,8	6,6	139	119	29,0	1229	161,7	6,51	179,6	387	50,9	3,65	77,9	4,10	4,75	11,52	20,48	20,417	0,88	W 6 x 15
W 150 x 24,0	24,0	160	102	6,6	10,3	139	115	31,5	1384	173,0	6,63	197,6	183	35,9	2,41	55,8	2,73	11,08	4,95	17,48	10,206	0,69	W 6 x 16
W 150 x 29,8 (H)	29,8	157	153	6,6	9,3	138	118	38,5	1739	221,5	6,72	247,5	556	72,6	3,80	110,8	4,18	10,95	8,23	17,94	30,277	0,90	W 6 x 20
W 150 x 37,1 (H)	37,1	162	154	8,1	11,6	139	119	47,8	2244	277,0	6,85	313,5	707	91,8	3,84	140,4	4,22	20,58	6,64	14,67	39,930	0,91	W 6 x 25
W 200 x 15,0	15,0	200	100	4,3	5,2	190	170	19,4	1305	130,5	8,20	147,9	87	17,4	2,12	27,3	2,55	2,05	9,62	39,44	8,222	0,77	W 8 x 10
W 200 x 19,3	19,3	203	102	5,8	6,5	190	170	25,1	1686	166,1	8,19	190,6	116	22,7	2,14	35,9	2,59	4,02	7,85	29,31	11,098	0,79	W 8 x 13
W 200 x 22,5	22,5	206	102	6,2	8,0	190	170	29,0	2029	197,0	8,37	225,5	142	27,9	2,22	43,9	2,63	6,18	6,38	27,42	13,868	0,79	W 8 x 15
W 200 x 26,6	26,6	207	133	5,8	8,4	190	170	34,2	2611	252,3	8,73	282,3	330	49,6	3,10	76,3	3,54	7,65	7,92	29,34	32,477	0,92	W 8 x 18
W 200 x 31,3	31,3	210	134	6,4	10,2	190	170	40,3	3168	301,7	8,86	338,6	410	61,2	3,19	94,0	3,60	12,59	6,57	26,50	40,822	0,93	W 8 x 21
W 200 x 35,9 (H)	35,9	201	165	6,2	10,2	181	161	45,7	3437	342,0	8,67	379,2	764	92,6	4,09	141,0	4,50	14,51	8,09	25,90	69,502	1,03	W 8 x 24
W 200 x 41,7 (H)	41,7	205	166	7,2	11,8	181	157	53,5	4114	401,4	8,77	448,6	901	108,5	4,10	165,7	4,53	23,19	7,03	21,86	83,948	1,04	W 8 x 28
W 200 x 46,1 (H)	46,1	203	203	7,2	11,0	181	161	58,6	4543	447,6	8,81	495,3	1535	151,2	5,12	229,5	5,58	22,01	9,23	22,36	141,342	1,19	W 8 x 31
W 200 x 52,0 (H)	52,0	206	204	7,9	12,6	181	157	66,9	5298	514,4	8,90	572,5	1784	174,9	5,16	265,8	5,61	33,34	8,10	19,85	166,710	1,19	W 8 x 35
HP 200 x 53,0 (H)	53,0	204	207	11,3	11,3	181	161	68,1	4977	488,0	8,55	551,3	1673	161,7	4,96	248,6	5,57	31,93	9,16	14,28	155,075	1,20	HP 8 x 36
W 200 x 59,0 (H)	59,0	210	205	9,1	14,2	182	158	76,0	6140	584,8	8,99	655,9	2041	199,1	5,18	303,0	5,64	47,69	7,22	17,32	195,418	1,20	W 8 x 40
W 200 x 71,0 (H)	71,0	216	206	10,2	17,4	181	161	91,0	7660	709,2	9,17	803,2	2537	246,3	5,28	374,5	5,70	81,66	5,92	15,80	249,976	1,22	W 8 x 48
W 200 x 86,0 (H)	86,0	222	209	13,0	20,6	181	157	110,9	9498	855,7	9,26	984,2	3139	300,4	5,32	458,7	5,77	142,19	5,07	12,06	317,844	1,23	W 8 x 58
W 200 x 100,0 (H)★	100,0	229	210	14,5	23,7	182	158	127,1	11355	991,7	9,45	1152,2	3664	349,0	5,37	533,4	5,80	212,61	4,43	10,87	385,454	1,25	W 8 x 67
W 250 x 17,9	17,9	251	101	4,8	5,3	240	220	23,1	2291	182,6	9,96	211,0	91	18,1	1,99	28,8	2,48	2,54	9,53	45,92	13,735	0,88	W 10 x 12
W 250 x 22,3	22,3	254	102	5,8	6,9	240	220	28,9	2939	231,4	10,09	267,7	123	24,1	2,06	38,4	2,54	4,77	7,39	37,97	18,629	0,89	W 10 x 15
W 250 x 25,3	25,3	257	102	6,1	8,4	240	220	32,6	3473	270,2	10,31	311,1	149	29,3	2,14	46,4	2,58	7,06	6,07	36,10	22,955	0,89	W 10 x 17
W 250 x 28,4	28,4	260	102	6,4	10,0	240	220	36,6	4046	311,2	10,51	357,3	178	34,8	2,20	54,9	2,62	10,34	5,10	34,38	27,636	0,90	W 10 x 19
W 250 x 32,7	32,7	258	146	6,1	9,1	240	220	42,1	4937	382,7	10,83	428,5	473	64,8	3,35	99,7	3,86	10,44	8,02	36,03	73,104	1,07	W 10 x 22
W 250 x 38,5	38,5	262	147	6,6	11,2	240	220	49,6	6057	462,4	11,05	517,8	594	80,8	3,46	124,1	3,93	17,63	6,56	33,27	93,242	1,08	W 10 x 26
W 250 x 44,8	44,8	266	148	7,6	13,0	240	220	57,6	7158	538,2	11,15	606,3	704	95,1	3,50	146,4	3,96	27,14	5,69	28,95	112,398	1,09	W 10 x 30
HP 250 x 62,0 (H)	62,0	246	256	10,5	10,7	225	201	79,6	8728	709,6	10,47	790,5	2995	234,0	6,13	357,8	6,89	33,46	11,96	19,10	414,130	1,47	HP 10 x 42
W 250 x 73,0 (H)	73,0	253	254	8,6	14,2	225	201	92,7	11257	889,9	11,02	983,3	3880	305,5	6,47	463,1	7,01	56,94	8,94	23,33	552,900	1,48	W 10 x 49
W 250 x 80,0 (H)	80,0	256	255	9,4	15,6	225	201	101,9	12550	980,5	11,10	1088,7	4313	338,3	6,51	513,1	7,04	75,02	8,17	21,36	622,878	1,49	W 10 x 54
HP 250 x 85,0 (H)	85,0	254	260	14,4	14,4	225	201	108,5	12280	966,9	10,64	1093,2	4225	325,0	6,24	499,6	7,00	82,07	9,03	13,97	605,403	1,50	HP 10 x 57
W 250 x 89,0 (H)	89,0	260	256	10,7	17,3	225	201	113,9	14237	1095,1	11,18	1224,4	4841	378,2	6,52	574,3	7,06	102,81	7,40	18,82	712,351	1,50	W 10 x 60
W 250 x 101,0 (H)	101,0	264	257	11,9	19,6	225	201	128,7	16352	1238,8	11,27	1395,0	5549	431,8	6,57	656,3	7,10	147,70	6,56	16,87	828,031	1,51	W 10 x 68
W 250 x 115,0 (H)	115,0	269	259	13,5	22,1	225	201	146,1	18920	1406,7	11,38	1597,4	6405	494,6	6,62	752,7	7,16	212,00	5,86	14,87	975,265	1,53	W 10 x 77
W 250 x 131,0 (H)★	131,0	275	261	15,4	25,1	225	193	167,8	22243	1617,7	11,51	1855,6	7448	570,7	6,66	870,7	7,21	321,06	5,20	12,52	1,161,225	1,54	W 10 x 88
W 250 x 149,0 (H)★	149,0	282	263	17,3	28,4	225	193	190,5	26027	1845,9	11,69	2137,5	8624	655,8	6,73	1001,7	7,27	462,06	4,63	11,17	1,384,436	1,55	W 10 x 100
W 250 x 167,0 (H)★	167,0	289	265	19,2	31,8	225	193	214,0	30110	2083,7	11,86	2435,3	9880	745,7	6,79	1140,2	7,33	644,95	4,17	10,07	1,631,156	1,57	W 10 x 112

Curso de Projeto e Cálculo de Estruturas metálicas

Passo 3: Verificar pilar quanto aos ELU

PERFIL W150X37,1 ASTM A572GR50

VERIFICAÇÃO À COMPRESSÃO SIMPLES

Verificação da Esbeltez:

$$\lambda_x = \frac{K_x \cdot L_x}{r_x} \quad \lambda_x = \frac{1,0 \cdot 250}{6,85} = 36,49 < 200 \text{ OK}$$

$$\lambda_y = \frac{K_y \cdot L_y}{r_y} \quad \lambda_y = \frac{1,0 \cdot 250}{3,84} = 65,10 < 200 \text{ OK}$$

Calcular fator de redução para flambagem local Q:

Esbeltez da alma:

$$\frac{b}{t} = \frac{d'}{tw} = 14,67 \quad \frac{b}{t} \lim = 1,49 \cdot \sqrt{\frac{E}{F_y}} \quad \frac{b}{t} \lim = 1,49 \cdot \sqrt{\frac{20500}{34,5}} = 36,32$$

$$Q_a = 1,00$$

Esbeltez da mesa:

$$\frac{b}{t} = \frac{(\frac{bf}{2})}{tf} = 6,64 \quad \frac{b}{t} \lim = 0,56 \cdot \sqrt{\frac{E}{F_y}} \quad \frac{b}{t} \lim = 0,56 \cdot \sqrt{\frac{20500}{34,5}} = 13,65$$

$$Q_s = 1,00$$

$$Q = Q_a \cdot Q_s = 1,00$$

Calcular fator de redução X para flambagem Global:

$$N_{ex} = \frac{\pi^2 \cdot E \cdot I_x}{(k_x \cdot L_x)^2} = \frac{\pi^2 \cdot 20500 \cdot 2244}{(1,0 \cdot 250)^2} = 7264,35 kN$$

$$N_{ey} = \frac{\pi^2 \cdot E \cdot I_y}{(k_y \cdot L_y)^2} = \frac{\pi^2 \cdot 20500 \cdot 707}{(1,0 \cdot 250)^2} = 2288,72 kN$$

$$r_0 = \sqrt{r_x^2 + r_y^2 + x^2 + y^2} = \sqrt{6,85^2 + 3,84^2} = 7,85 cm$$

$$N_{Ez} = \frac{\frac{\pi^2 \cdot E \cdot C_w}{(K_z L_z)^2} + G \cdot I_t}{(r_0)^2} = \frac{\frac{\pi^2 \cdot 20500 \cdot 39930}{(1,0 \cdot 250)^2} + 7700 \cdot 20,58}{(7,85)^2} = 4669,21 kN$$

$$\lambda_0 = \sqrt{\frac{Q \cdot A_g \cdot F_y}{N_e}} = \sqrt{\frac{1.47,8 \cdot 34,5}{2288,72}} = 0,85$$

5.3.3 Fator de redução χ

5.3.3.1 O fator de redução associado à resistência à compressão, χ , é dado por:

$$\text{- para } \lambda_0 \leq 1,5: \chi = 0,658^{\lambda_0^2}$$

$$\text{- para } \lambda_0 > 1,5: \chi = \frac{0,877}{\lambda_0^2}$$

$$\chi = 0,658^{0,85^2} = 0,739$$

$$N_{c,Rd} = \frac{\chi \cdot Q \cdot A_g \cdot F_y}{1,1} = \frac{0,739 \cdot 1 \cdot 47,8 \cdot 34,5}{1,1} = 1107,89 \text{ kN} < 113,6 \text{ OK}$$

VERIFICAÇÃO À FORÇA CORTANTE

Para perfis I, H e U fletidos em relação ao eixo de maior inércia

Passo 01: Comparar esbeltez da alma com dois limites (inferior e superior)

$$\lambda = \frac{h}{tw}$$

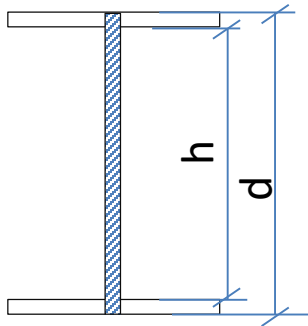
$$V_{Rd} = \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_p = 1,10 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

$$V_{Rd} = \frac{\lambda_p}{\lambda} \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_r = 1,37 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

$$V_{Rd} = 1,24 \cdot \left(\frac{\lambda_p}{\lambda} \right)^2 \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$



$$A_w = d \cdot t_w$$

$$k_v = \begin{cases} 5,0 & \text{para almas sem enrijecedores transversais, para } \frac{a}{h} > 3 \text{ ou para } \frac{a}{h} > \left[\frac{260}{(h/t_w)} \right]^2 \\ 5 + \frac{5}{(a/h)^2} & \text{, para todos os outros casos} \end{cases}$$

$$\lambda = \frac{h}{tw} = \frac{162 - 2 \cdot 11,6}{8,1} = 17,13$$

$$V_{Rd} = \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_p = 1,10 \cdot \sqrt{\frac{k_v \cdot E}{F_y}} = 1,10 \cdot \sqrt{\frac{5 \cdot 20500}{34,5}} = 59,95 > 16,14$$

$$V_{Rd} = \frac{0,60 \cdot 15,4 \cdot 0,81 \cdot 34,5}{1,1} = 234,74 \text{ kN}$$

VERIFICAÇÃO AO MOMENTO FLETOR

Verificação Flambagem Lateral com Torção (FLT)

$$\frac{Lb}{ry} = \frac{250}{3,84} = 65,10 \quad \lambda_p = 1,76 \sqrt{\frac{E}{F_y}} = 1,76 \sqrt{\frac{20500}{34,5}} = 42,90 \rightarrow \text{calcular } \lambda_r$$

As Notas relacionadas à Tabela G.1 são as seguintes:

$$\beta_1 = \frac{(34,5 - 0,3 \cdot 34,5) \cdot 277}{20500 \cdot 20,58} = 0,0158$$

$$1) \lambda_r = \frac{1,38 \sqrt{I_y J}}{r_y J \beta_1} \sqrt{1 + \sqrt{1 + \frac{27 C_w \beta_1^2}{I_y}}}$$

$$\lambda_r = \frac{1,38 \cdot \sqrt{707 \cdot 20,58}}{3,84 \cdot 20,58 \cdot 0,0158} \cdot \sqrt{1 + \sqrt{1 + \frac{27 \cdot 39930 \cdot 0,0158^2}{707}}} = 195,97$$

$$M_{cr} = \frac{C_b \pi^2 E I_y}{L_b^2} \sqrt{\frac{C_w}{I_y} \left(1 + 0,039 \frac{J L_b^2}{C_w} \right)}$$

onde:

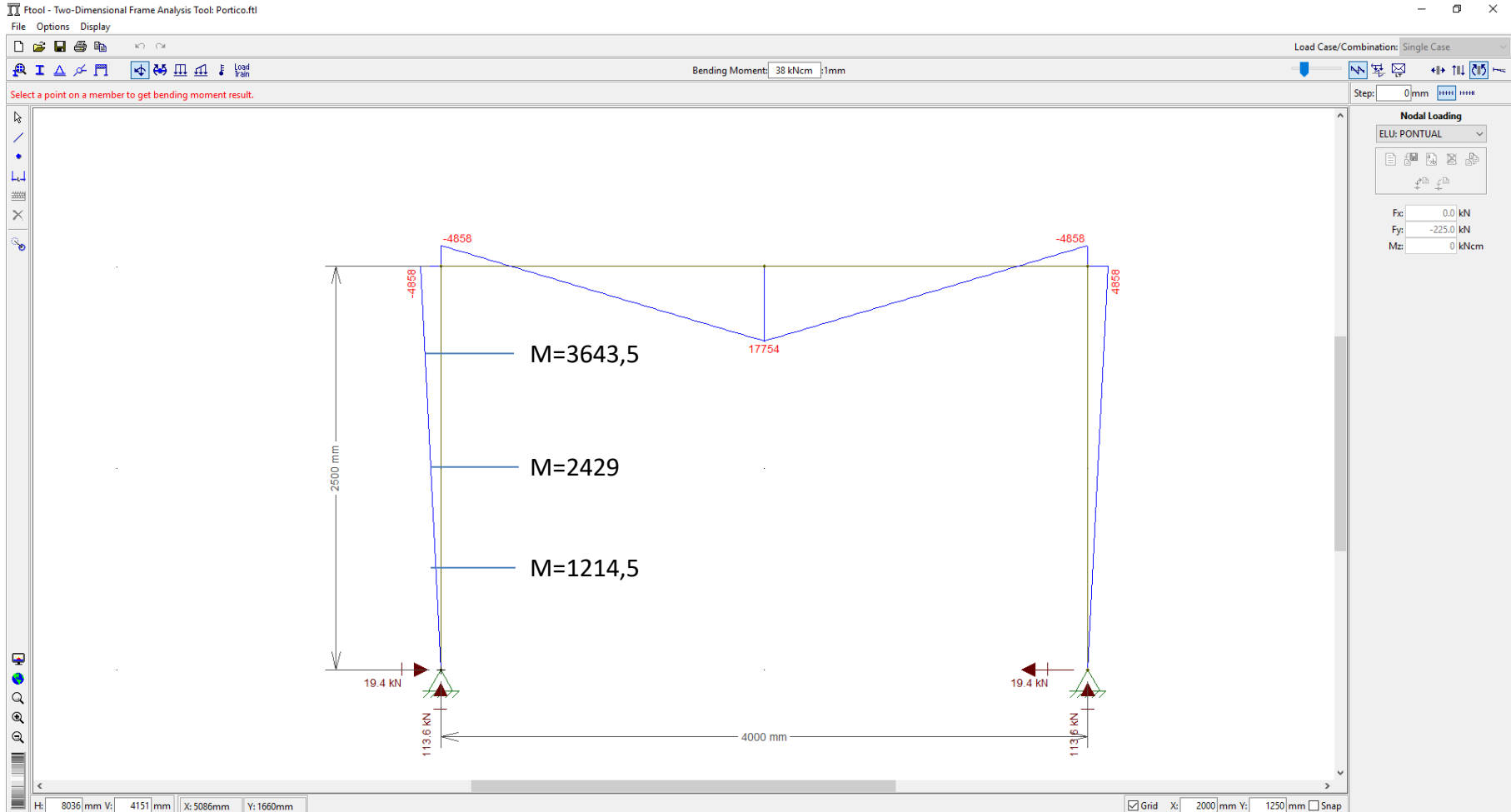
$$\beta_1 = \frac{(f_y - \sigma_t) W}{E J}$$

$$C_w = \frac{I_y (d - t_f)^2}{4}, \text{ para seções I}$$

$$C_w = \frac{t_f (b_f - 0,5 t_w)^3 (d - t_f)^2}{12} \left[\frac{3(b_f - 0,5 t_w) t_f + 2(d - t_f) t_w}{6(b_f - 0,5 t_w) t_f + (d - t_f) t_w} \right], \text{ para seções U}$$

VERIFICAÇÃO AO MOMENTO FLETOR

Como o FLT deve ser calculado pela equação B, podemos calcular o Coeficiente de Distribuição de Momentos C_b , ou adotar 1 de forma conservadora

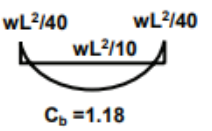
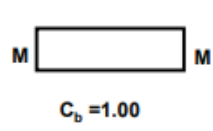
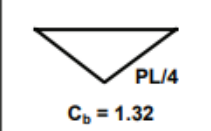
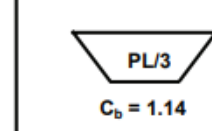
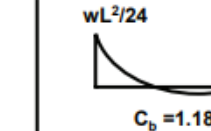
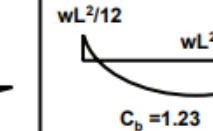
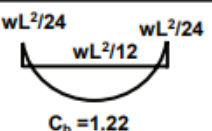
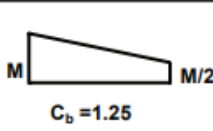
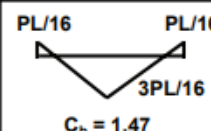
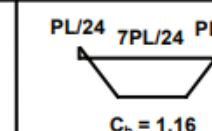
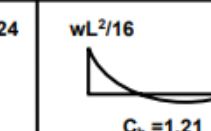
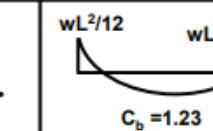
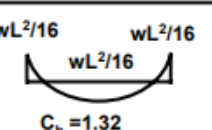
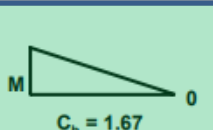
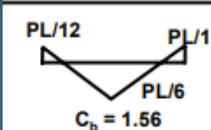
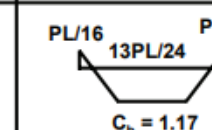
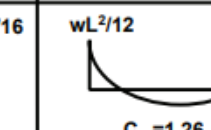
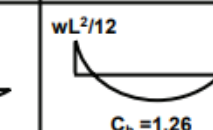
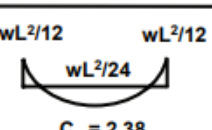
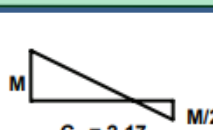
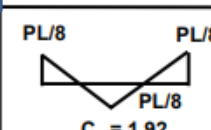
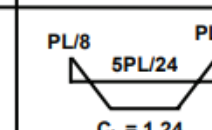

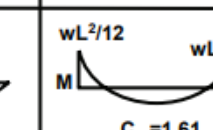
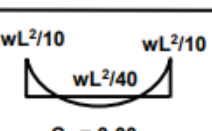
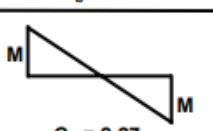
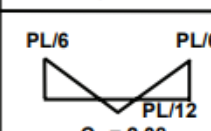
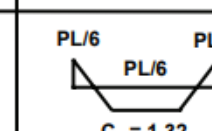

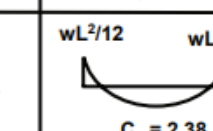


$$C_b = \frac{12,5 \cdot M_{Max}}{2,5 \cdot M_{max} + 3 \cdot M_A + 4 \cdot M_B + 3 \cdot M_B} \quad C_b = \frac{12,5 \cdot 4858}{2,5 \cdot 4858 + 3 \cdot 1214,5 + 4 \cdot 2429 + 3 \cdot 3643,5} = 1,67$$

Curso de Projeto e Cálculo de Estruturas metálicas

C_b Values for Different Load Cases

AISC Equation F1-1

 $C_b = 1.18$	 $C_b = 1.00$	 $C_b = 1.32$	 $C_b = 1.14$	 $C_b = 1.18$	 $C_b = 1.23$
 $C_b = 1.22$	 $C_b = 1.25$	 $C_b = 1.47$	 $C_b = 1.16$	 $C_b = 1.21$	 $C_b = 1.23$
 $C_b = 1.32$	 $C_b = 1.67$	 $C_b = 1.56$	 $C_b = 1.17$	 $C_b = 1.26$	 $C_b = 1.26$
 $C_b = 2.38$	 $C_b = 2.17$	 $C_b = 1.92$	 $C_b = 1.24$	 $C_b = 2.08$	 $C_b = 1.61$
 $C_b = 3.00$	 $C_b = 2.27$	 $C_b = 2.08$	 $C_b = 1.32$	 $C_b = 3.00$	 $C_b = 2.38$



VERIFICAÇÃO AO MOMENTO FLETOR

$M_{rd,FLT}$ é obtido pela equação B

$$a) \quad M_{Rd} = \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda \leq \lambda_p$$

$$b) \quad M_{Rd} = \frac{C_b}{\gamma_{a1}} \left[M_{p\ell} - (M_{p\ell} - M_r) \frac{\lambda - \lambda_p}{\lambda_r - \lambda_p} \right] \leq \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda_p < \lambda \leq \lambda_r$$

$$c) \quad M_{Rd} = \frac{M_{cr}}{\gamma_{a1}} \leq \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda > \lambda_r$$

$$M_{Rd,FLT} = \frac{1,67}{1,1} \cdot (313,5 \cdot 34,5 - (313,5 \cdot 34,5 - (0,7 \cdot 34,5 \cdot 277)) \cdot \frac{65,10 - 42,90}{195,97 - 42,90}) = 15512 \text{ kN.cm}$$

Verificação Flambagem local da Mesa (FLM)

$$\frac{b}{t} = \frac{bf}{2tf} = 6,64 \quad \lambda_p = 0,38 \sqrt{\frac{E}{F_y}} = 0,38 \sqrt{\frac{20500}{34,5}} = 9,26 \rightarrow \text{calcular pela equação a)}$$

Verificação Flambagem Local da Alma (FLA)

$$\frac{h}{tw} = \frac{d'}{tw} = 14,67 \quad \lambda_p = 3,76 \sqrt{\frac{E}{F_y}} = 3,76 \sqrt{\frac{20500}{34,5}} = 91,62 \rightarrow \text{calcular pela equação a)}$$

$$M_{Rd,FLM} = \frac{M_{pl}}{1,1} = \frac{Z_x \cdot F_y}{1,1} = \frac{313,5 \cdot 34,5}{1,1} = 9832,50 \text{ kN.cm}$$

VERIFICAÇÃO QUANTO À COMBINAÇÃO DE ESFORÇOS

a) para $\frac{N_{Sd}}{N_{Rd}} \geq 0,2$

b) para $\frac{N_{Sd}}{N_{Rd}} < 0,2$

$$\frac{N_{Sd}}{N_{Rd}} + \frac{8}{9} \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

$$\frac{N_{Sd}}{2 N_{Rd}} + \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

$$\frac{N_{Sd}}{N_{Rd}} = \frac{113,6}{1107,89} = 0,10 < 0,20$$

$$\frac{113,6}{2 \cdot 1107,89} + \left(\frac{4858}{9832,5} \right) = 0,55 < 1 \text{ PERFIL APROVADO}$$

Passo 3: Verificar Viga quanto aos ELU

PERFIL W250X44,8 ASTM A572GR50

VERIFICAÇÃO À COMPRESSÃO SIMPLES

Verificação da Esbeltez:

$$\lambda_x = \frac{K_x \cdot L_x}{r_x} \quad \lambda_x = \frac{1,0 \cdot 400}{11,15} = 35,87 < 200 \text{ OK}$$

$$\lambda_y = \frac{K_y \cdot L_y}{r_y} \quad \lambda_y = \frac{1,0 \cdot 400}{3,50} = 114,28 < 200 \text{ OK}$$

Calcular fator de redução para flambagem local Q:

Esbeltez da alma:

$$\frac{b}{t} = \frac{d'}{tw} = 28,95 \quad \frac{b}{t} \lim = 1,49 \cdot \sqrt{\frac{E}{F_y}} \quad \frac{b}{t} \lim = 1,49 \cdot \sqrt{\frac{20500}{34,5}} = 36,32$$

$$Q_a = 1,00$$

Esbeltez da mesa:

$$\frac{b}{t} = \frac{(\frac{bf}{2})}{tf} = 5,69 \quad \frac{b}{t} \lim = 0,56 \cdot \sqrt{\frac{E}{F_y}} \quad \frac{b}{t} \lim = 0,56 \cdot \sqrt{\frac{20500}{34,5}} = 13,65$$

$$Q_s = 1,00$$

$$Q = Q_a \cdot Q_s = 1,00$$

Calcular fator de redução X para flambagem Global:

$$N_{ex} = \frac{\pi^2 \cdot E \cdot I_x}{(k_x \cdot L_x)^2} = \frac{\pi^2 \cdot 20500 \cdot 7158}{(1,0 \cdot 400)^2} = 9052 kN$$

$$N_{ey} = \frac{\pi^2 \cdot E \cdot I_y}{(k_y \cdot L_y)^2} = \frac{\pi^2 \cdot 20500 \cdot 704}{(1,0 \cdot 400)^2} = 890,24 kN$$

$$r_0 = \sqrt{r_x^2 + r_y^2 + x^2 + y^2} = \sqrt{11,15^2 + 3,5^2} = 11,69 cm$$

$$N_{Ez} = \frac{\frac{\pi^2 \cdot E \cdot C_w}{(K_z L_z)^2} + G \cdot I_t}{(r_0)^2} = \frac{\frac{\pi^2 \cdot 20500 \cdot 112398}{(1,0 \cdot 400)^2} + 7700 \cdot 27,14}{(11,69)^2} = 2569,29 kN$$

$$\lambda_0 = \sqrt{\frac{Q \cdot A_g \cdot F_y}{N_e}} = \sqrt{\frac{1.57,6 \cdot 34,5}{890,24}} = 1,49$$

5.3.3 Fator de redução χ

5.3.3.1 O fator de redução associado à resistência à compressão, χ , é dado por:

$$\text{- para } \lambda_0 \leq 1,5: \chi = 0,658^{\lambda_0^2}$$

$$\text{- para } \lambda_0 > 1,5: \chi = \frac{0,877}{\lambda_0^2}$$

$$\chi = 0,658^{1,49^2} = 0,39$$

$$N_{c,Rd} = \frac{\chi \cdot Q \cdot A_g \cdot F_y}{1,1} = \frac{0,39 \cdot 1 \cdot 57,6 \cdot 34,5}{1,1} = 704,5 \text{ kN} < 19,4 \text{ OK}$$

VERIFICAÇÃO À FORÇA CORTANTE

Para perfis I, H e U fletidos em relação ao eixo de maior inércia

Passo 01: Comparar esbeltez da alma com dois limites (inferior e superior)

$$\lambda = \frac{h}{t_w}$$

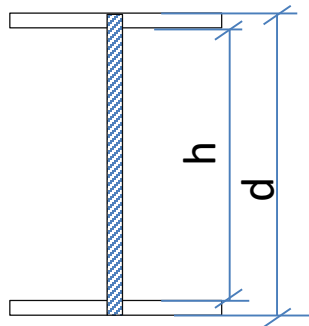
$$V_{Rd} = \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_p = 1,10 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

$$V_{Rd} = \frac{\lambda_p}{\lambda} \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_r = 1,37 \cdot \sqrt{\frac{k_v \cdot E}{F_y}}$$

$$V_{Rd} = 1,24 \cdot \left(\frac{\lambda_p}{\lambda}\right)^2 \cdot \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$



$$A_w = d \cdot t_w$$

$$k_v = \begin{cases} 5,0 & \text{para almas sem enrijecedores transversais, para } \frac{a}{h} > 3 \text{ ou para } \frac{a}{h} > \left[\frac{260}{(h/t_w)} \right]^2 \\ 5 + \frac{5}{(a/h)^2} & \text{, para todos os outros casos} \end{cases}$$

$$\lambda = \frac{h}{t_w} = \frac{266 - 2 \cdot 13}{7,6} = 31,57$$

$$V_{Rd} = \frac{0,60 \cdot A_w \cdot F_y}{1,1}$$

$$\lambda_p = 1,10 \cdot \sqrt{\frac{k_v \cdot E}{F_y}} = 1,10 \cdot \sqrt{\frac{5 \cdot 20500}{34,5}} = 59,95 > 31,57$$

$$V_{Rd} = \frac{0,60 \cdot 26 \cdot 60 \cdot 76 \cdot 34,5}{1,1} = 380 \text{ kN}$$

VERIFICAÇÃO AO MOMENTO FLETOR

Verificação Flambagem Lateral com Torção (FLT)

$$\frac{Lb}{r_y} = \frac{400}{3,5} = 114,28 \quad \lambda_p = 1,76 \sqrt{\frac{E}{F_y}} = 1,76 \sqrt{\frac{20500}{34,5}} = 42,90 \rightarrow \text{calcular } \lambda_r$$

As Notas relacionadas à Tabela G.1 são as seguintes:

$$\beta_1 = \frac{(34,5 - 0,3 \cdot 34,5) \cdot 538,2}{20500 \cdot 27,14} = 0,0233$$

$$1) \lambda_r = \frac{1,38 \sqrt{I_y J}}{r_y J \beta_1} \sqrt{1 + \sqrt{1 + \frac{27 C_w \beta_1^2}{I_y}}}$$

$$\lambda_r = \frac{1,38 \cdot \sqrt{704 \cdot 27,14}}{3,5 \cdot 27,14 \cdot 0,0233} \cdot \sqrt{1 + \sqrt{1 + \frac{27 \cdot 112398 \cdot 0,0233^2}{704}}} = 144,92$$

$$M_{cr} = \frac{C_b \pi^2 E I_y}{L_b^2} \sqrt{\frac{C_w}{I_y} \left(1 + 0,039 \frac{J L_b^2}{C_w} \right)}$$

onde:

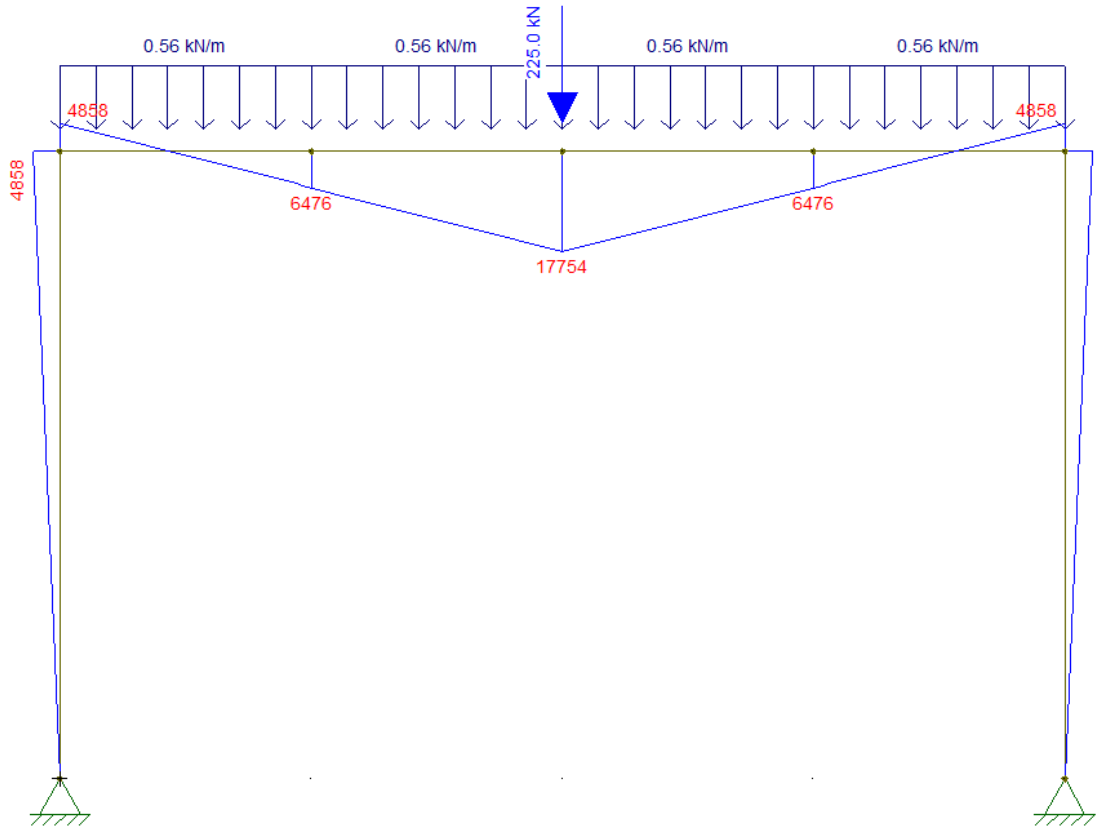
$$\beta_1 = \frac{(f_y - \sigma_t) W}{E J}$$

$$C_w = \frac{I_y (d - t_f)^2}{4}, \text{ para seções I}$$

$$C_w = \frac{t_f (b_f - 0,5 t_w)^3 (d - t_f)^2}{12} \left[\frac{3(b_f - 0,5 t_w) t_f + 2(d - t_f) t_w}{6(b_f - 0,5 t_w) t_f + (d - t_f) t_w} \right], \text{ para seções U}$$

VERIFICAÇÃO AO MOMENTO FLETOR

Como o FLT deve ser calculado pela equação B, podemos calcular o Coeficiente de Distribuição de Momentos C_b , ou adotar 1 de forma conservadora

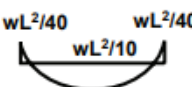
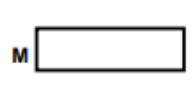
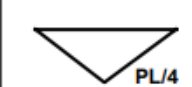
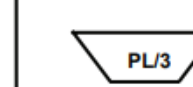
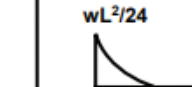

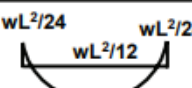
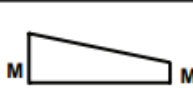
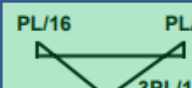
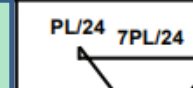
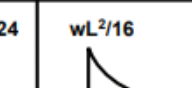

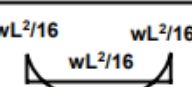

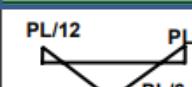
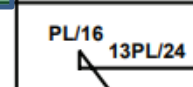

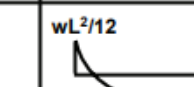
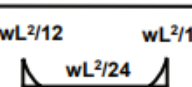
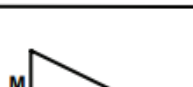
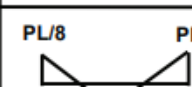
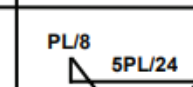
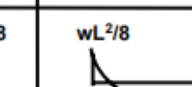
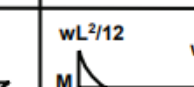
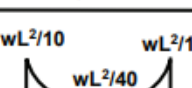
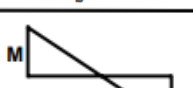
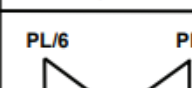
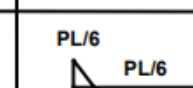
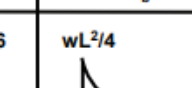
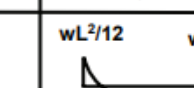


$$C_b = \frac{12,5 \cdot M_{Max}}{2,5 \cdot M_{max} + 3 \cdot M_A + 4 \cdot M_B + 3 \cdot M_B}$$

$$C_b = \frac{12,5 \cdot 17754}{2,5 \cdot 17754 + 3 \cdot 6476 + 4 \cdot 17754 + 3 \cdot 6476} = 1,44$$

C_b Values for Different Load Cases

AISC Equation F1-1

 $C_b = 1.18$	 $C_b = 1.00$	 $C_b = 1.32$	 $C_b = 1.14$	 $C_b = 1.18$	 $C_b = 1.23$
 $C_b = 1.22$	 $C_b = 1.25$	 $C_b = 1.47$	 $C_b = 1.16$	 $C_b = 1.21$	 $C_b = 1.23$
 $C_b = 1.32$	 $C_b = 1.67$	 $C_b = 1.56$	 $C_b = 1.17$	 $C_b = 1.26$	 $C_b = 1.26$
 $C_b = 2.38$	 $C_b = 2.17$	 $C_b = 1.92$	 $C_b = 1.24$	 $C_b = 2.08$	 $C_b = 1.61$
 $C_b = 3.00$	 $C_b = 2.27$	 $C_b = 2.08$	 $C_b = 1.32$	 $C_b = 3.00$	 $C_b = 2.38$



VERIFICAÇÃO AO MOMENTO FLETOR

$M_{rd,FLT}$ é obtido pela equação B

$$a) \quad M_{Rd} = \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda \leq \lambda_p$$

$$b) \quad M_{Rd} = \frac{C_b}{\gamma_{a1}} \left[M_{p\ell} - (M_{p\ell} - M_r) \frac{\lambda - \lambda_p}{\lambda_r - \lambda_p} \right] \leq \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda_p < \lambda \leq \lambda_r$$

$$c) \quad M_{Rd} = \frac{M_{cr}}{\gamma_{a1}} \leq \frac{M_{p\ell}}{\gamma_{a1}}, \text{ para } \lambda > \lambda_r$$

$$M_{Rd,FLT} = \frac{1,44}{1,1} \cdot (606,334,5 - (606,334,5 - (0,734,5538,2)) \cdot \frac{114,28 - 42,90}{144,92 - 42,90}) = 20128,72 \text{ kN.cm}$$

Verificação Flambagem local da Mesa (FLM)

$$\frac{b}{t} = \frac{bf}{2tf} = 5,69 \quad \lambda_p = 0,38 \sqrt{\frac{E}{F_y}} = 0,38 \sqrt{\frac{20500}{34,5}} = 9,26 \rightarrow \text{calcular pela equação a)}$$

Verificação Flambagem Local da Alma (FLA)

$$\frac{h}{tw} = \frac{d'}{tw} = 28,95 \quad \lambda_p = 3,76 \sqrt{\frac{E}{F_y}} = 3,76 \sqrt{\frac{20500}{34,5}} = 91,62 \rightarrow \text{calcular pela equação a)}$$

$$M_{Rd,FLM} = \frac{M_{pl}}{1,1} = \frac{Z_x \cdot F_y}{1,1} = \frac{606,3 \cdot 34,5}{1,1} = 20917,35 \text{ kN.cm}$$

VERIFICAÇÃO QUANTO À COMBINAÇÃO DE ESFORÇOS

a) para $\frac{N_{Sd}}{N_{Rd}} \geq 0,2$

b) para $\frac{N_{Sd}}{N_{Rd}} < 0,2$

$$\frac{N_{Sd}}{N_{Rd}} + \frac{8}{9} \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

$$\frac{N_{Sd}}{2 N_{Rd}} + \left(\frac{M_{x,Sd}}{M_{x,Rd}} + \frac{M_{y,Sd}}{M_{y,Rd}} \right) \leq 1,0$$

$$\frac{N_{Sd}}{N_{Rd}} = \frac{19,4}{1306,99} = 0,015 < 0,20$$

$$\frac{19,4}{2.704,5} + \left(\frac{17754}{20128,72} \right) = 0,89 < 1 \text{ PERFIL APROVADO COM } C_b$$

AUTOMAÇÃO DE CÁLCULO PLANILHA

Dimensionamento de Perfis I e H Laminados Padrão Açominas

Esforços e Distâncias	
Lx (mm)	4000
Ly (mm)	4000
N(kN)	-19,4
Vx(kN)	0
Vy(kN)	113,6
Mx(kN.cm)	17754
My(kN.cm)	0
kx	1
ky	1
kz	1
d (mm)	0
Cb	1,44
Lb (mm)	4000
Material	
ASTM A572GR50	
Fy (kN/cm²)	34,5

Dados para Cálculo de NRd			
Q	1,00		
Nex(kN)	9051,6	r0(cm)	11,7
Ney(kN)	890,2	Nez(kN)	2570,87
λ0	1,49		
χ	0,393		
Esbeltez Limite FLA X-X		Esbeltez Limite FLA Y-Y	
λalma	31,58	λalma	31,58
λb	24,85	λb	27,20

Resultado:

89,7%

W 250 x 44,8

d(mm)	266	Wx(cm³)	538,2	rx(cm)	11,15
bf(mm)	148	Wy(cm³)	95,1	ry(cm)	3,5
d'(mm)	220	Zx(cm³)	606,3	Área(cm²)	57,6
tw(mm)	7,6	Zy(cm³)	146,4	ho/tw	28,9
tf(mm)	13	Ix(cm⁴)	7158	b/tf	5,7
h(mm)	240	Iy(cm⁴)	704	Peso (kg/m)	44,8

Limite:

36,3

Compacta

Limite:

13,7

25,1

Compacta

1. Verificação da Esbeltez do perfil				
Limite	Real	Status	%	
200	36	OK	17,9%	λx
200	114	OK	57,1%	λy

2. Resistência à tração				
Nrd(kN)	Nsd(kN)	Status	%	Coef. S
N.A	0	N.A	0,0%	1,1

3. Resistência à Compressão				
Nrd(kN)	Nsd(kN)	Status	%	Coef. S
710	19,4	OK	2,7%	1,1

4. Resistência à Flexão eixo X-X				
Mrd(kN.cm)	Msd(kN.cm)	Status	%	Coef. S
20108	17754	OK	88,3%	1,1

5. Resistência à Flexão eixo Y-Y				
Mrd(kN.cm)	Msd(kN.cm)	Status	%	Coef. S
2415	0	N.A	0,0%	1,1

Listar Perfis que atendem		
Perfil	Peso	%
W 310 x 38,7	38,70	99,31%
W 360 x 44,0	44,00	83,22%
W 310 x 44,5	44,50	85,42%
W 250 x 44,8	44,80	94,95%
W 200 x 46,1 (H)	46,10	89,90%
W 410 x 46,1	46,10	88,30%
W 360 x 51,0	51,00	71,67%
W 200 x 52,0 (H)	52,00	77,77%
W 310 x 52,0	52,00	71,75%
W 460 x 52,0	52,00	75,05%
HP 200 x 53,0 (H)	53,00	81,06%
W 410 x 53,0	53,00	65,66%
W 360 x 57,8	57,80	63,15%
W 200 x 59,0 (H)	59,00	67,95%
W 410 x 60,0	60,00	56,59%
W 460 x 60,0	60,00	61,88%
HP 250 x 62,0 (H)	62,00	65,81%
W 360 x 64,0	64,00	51,15%
W 530 x 66,0	66,00	57,03%
W 410 x 67,0	67,00	49,71%
W 460 x 68,0	68,00	52,95%
W 200 x 71,0 (H)	71,00	55,42%
W 360 x 72,0	72,00	45,41%
W 530 x 72,0	72,00	45,83%
W 250 x 73,0 (H)	73,00	49,23%
W 460 x 74,0	74,00	42,42%
W 530 x 74,0	74,00	49,98%

AUTOMAÇÃO DE CÁLCULO VISUAL METAL (Não Considera o C_b)

Laminado

Identificação
Perfil **W 250 x 44,8**

Dimensões

d	266 mm	A_g	57,6 cm ²	W_x	538,2 cm ³
tw	7,6 mm	P	44,8 kgf/m	W_y	95,1 cm ³
bf	148 mm	I_x	7158 cm ⁴	Z_x	606,3 cm ³
tf	13 mm	I_y	704 cm ⁴	Z_y	146,4 cm ³
		IT	27,14 cm ⁴		

Compr. Flambagem

Lflx	400 cm
Lfly	400 cm
Lb	400 cm

Solicitações

Nd	-19,4 kN
Vd	113,6 kN
Mdx	17754 kN.cm
Mdy	0,00 kN.cm

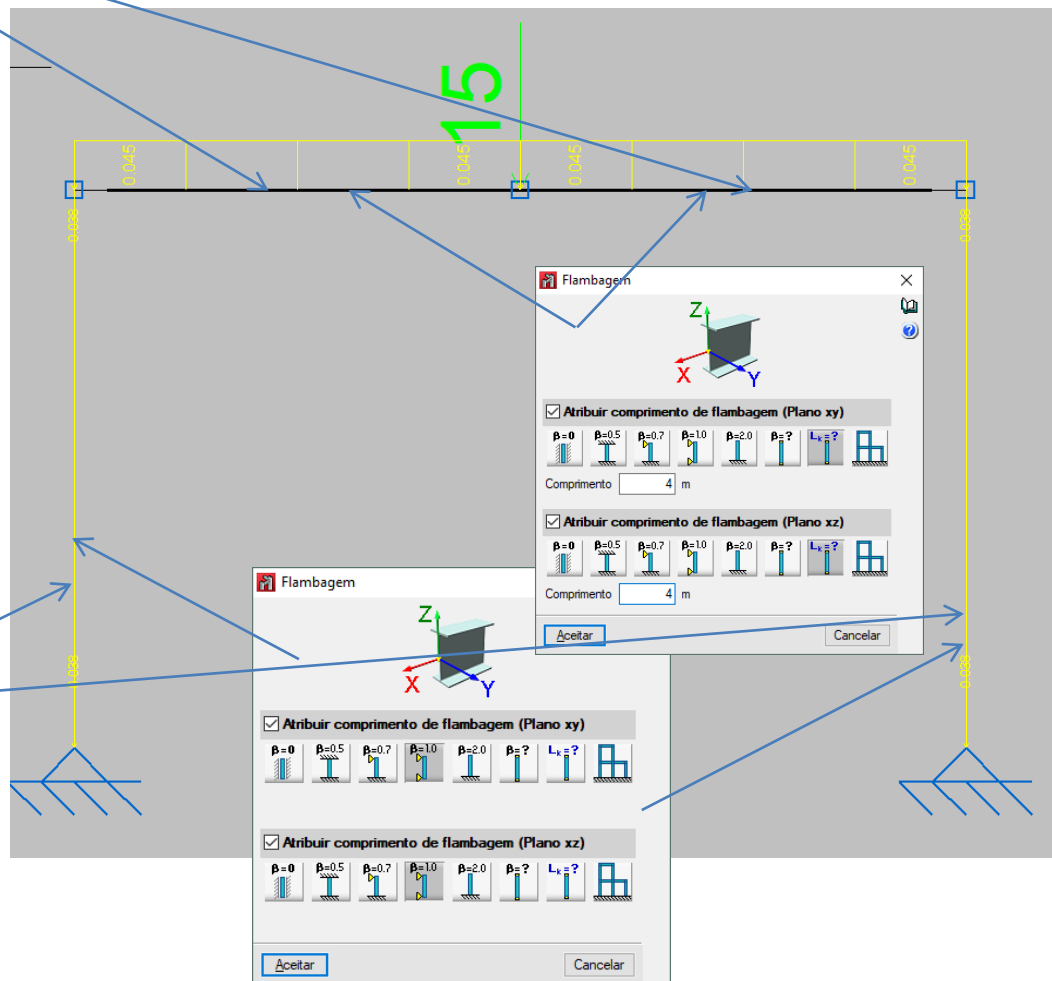
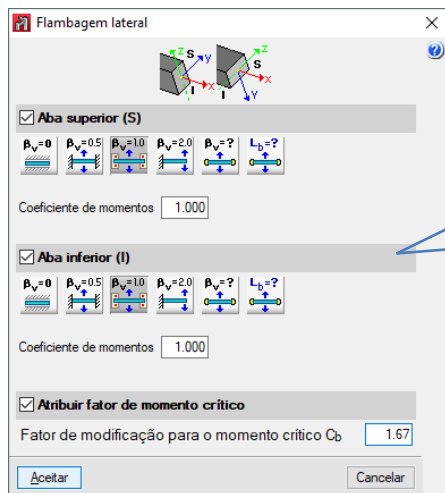
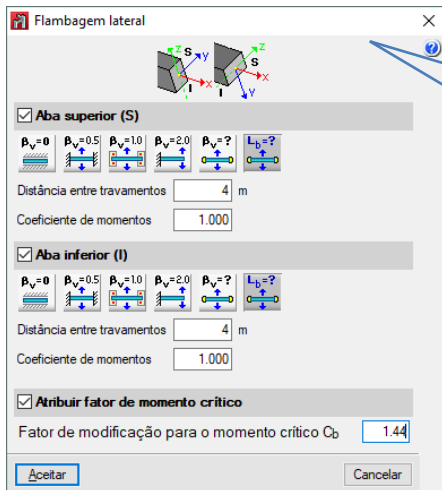
Resultados

Rd(Nd)	-581,66 kN	Ok!
Rd(Vd)	345,24 kN	Ok!
Rd(Mdx)	13699,10 kN.cm	Não Ok!
Rd(Mdy)	0,00 kN.cm	
Rd(Md+Nd)	1,33 <= 1	Não Ok!

Perfil indicado para elementos sujeitos à flexão composta (Ex.: vigas)

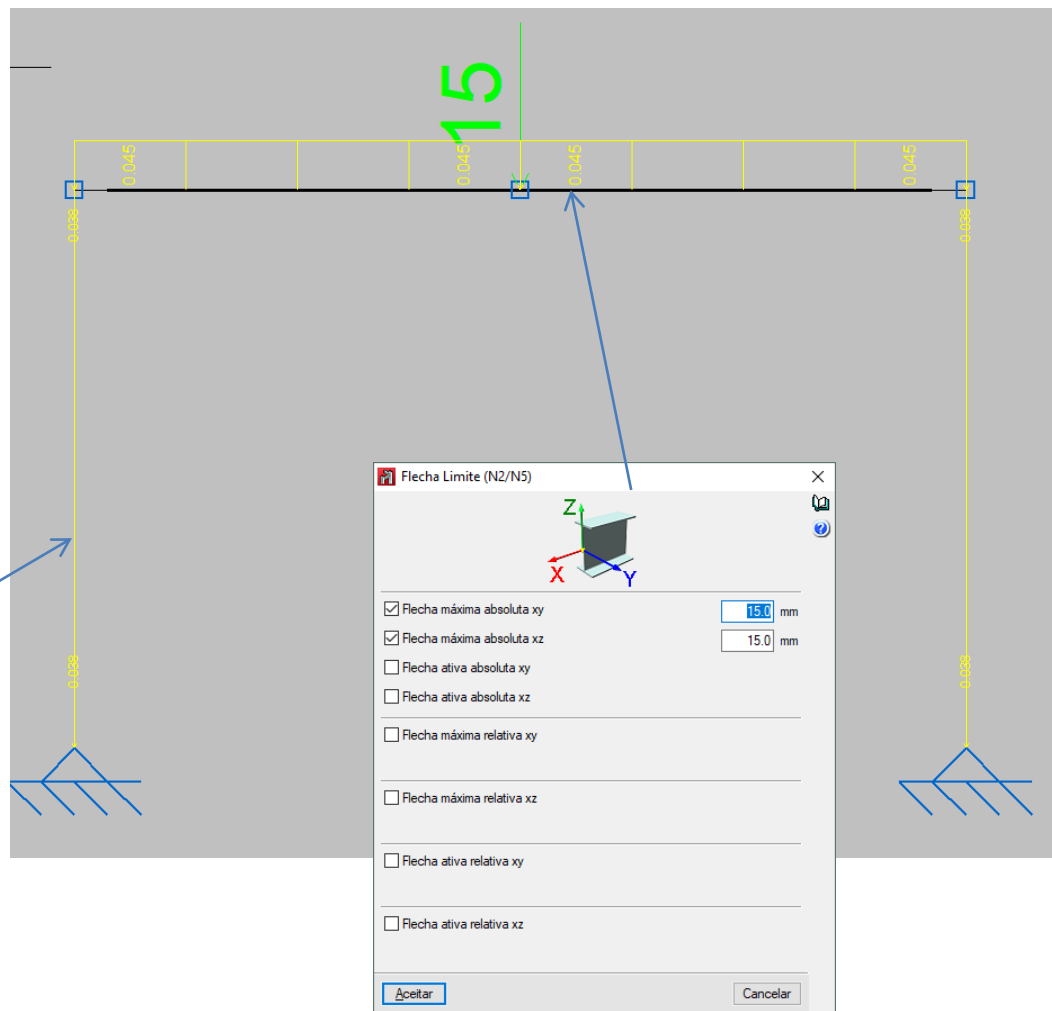
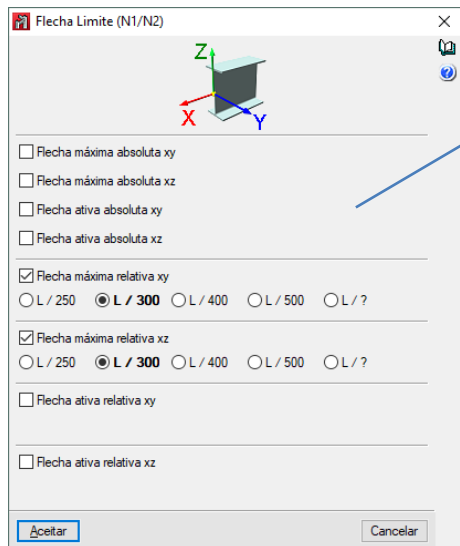
Calcular **Mais Leve** **Relatório** **Ok**

AUTOMAÇÃO DE CÁLCULO – CYPECAD METÁLICAS 3D



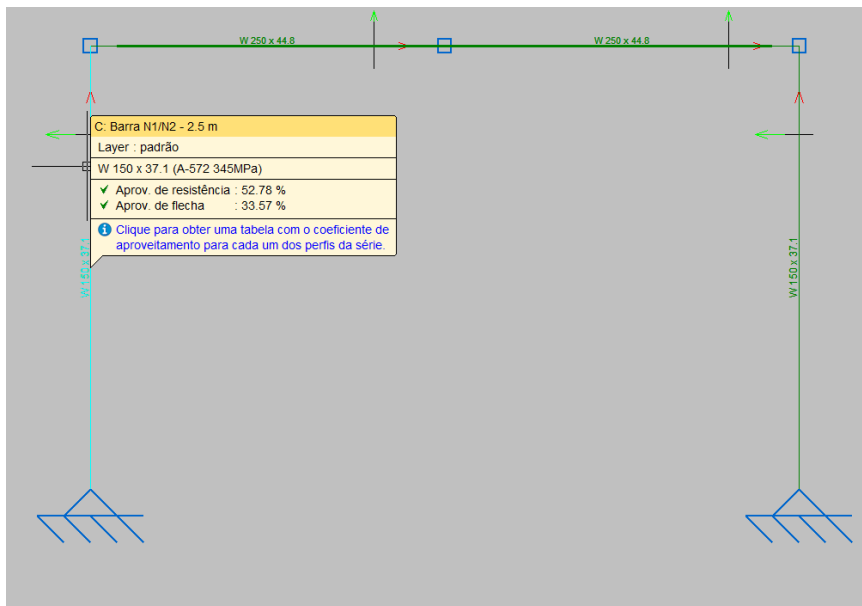
Curso de Projeto e Cálculo de Estruturas metálicas

AUTOMAÇÃO DE CÁLCULO – CYPECAD METALICAS 3D



Curso de Projeto e Cálculo de Estruturas metálicas

AUTOMAÇÃO DE CÁLCULO – CYPECAD METALICAS 3D



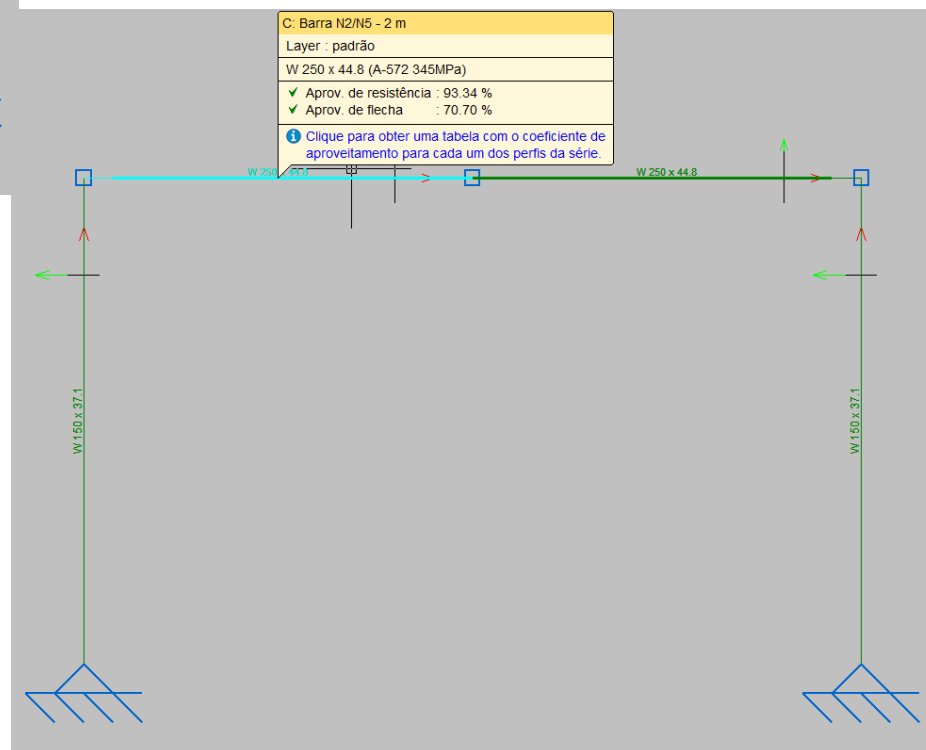
RELATÓRIO COMPLETO NA ÁREA DO
ALUNO – PÁG 37 a 95

Peso do Pórtico:

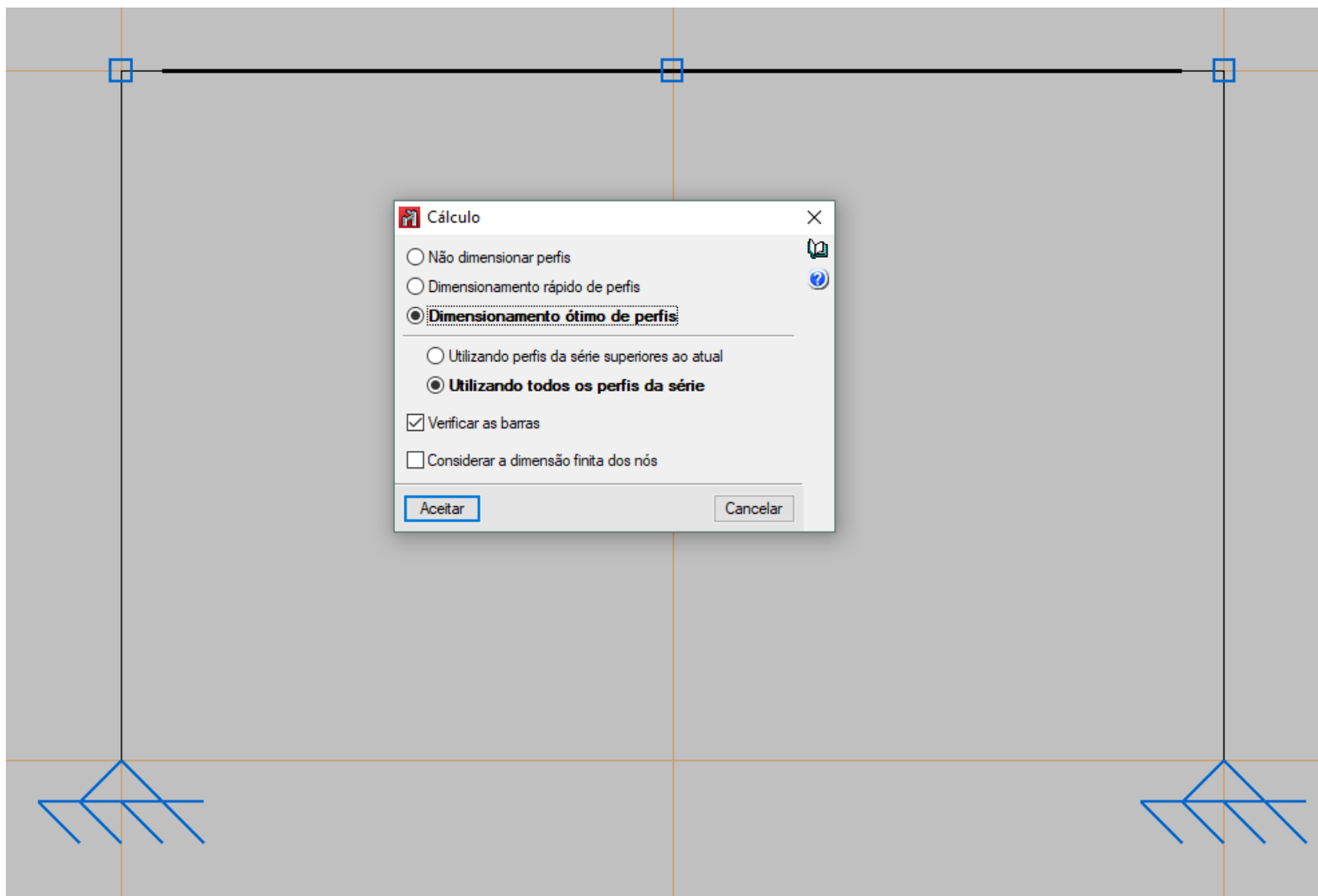
$$W150X37,1 = 5m = 37,1 \times 5 = 185,5kg$$

$$W250X44,8 = 4m = 44,8 \times 4 = 179,2kg$$

Peso Total = 364,7 kg

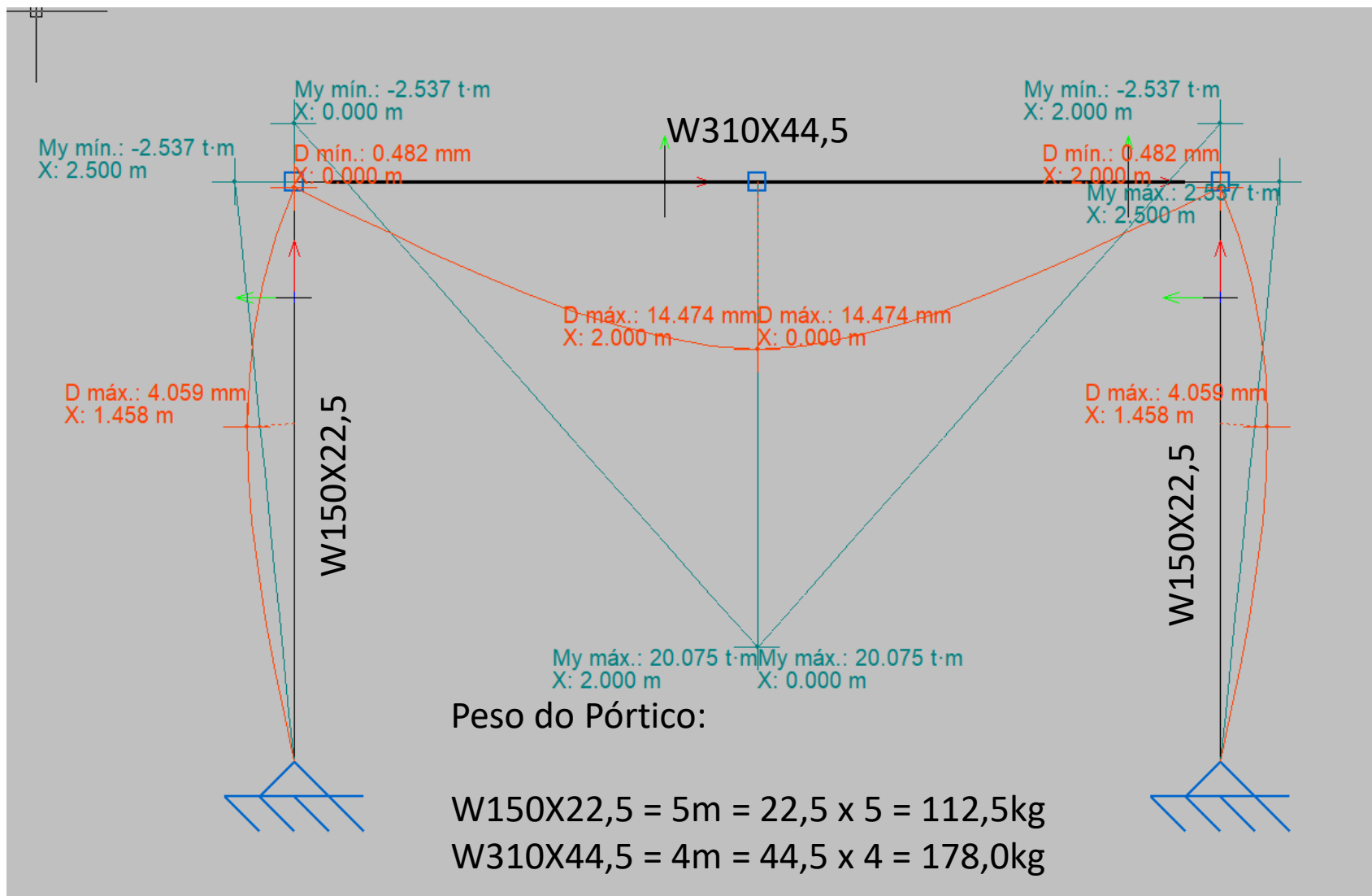


AUTOMAÇÃO DE CÁLCULO – CYPECAD METALICAS 3D



Curso de Projeto e Cálculo de Estruturas metálicas

AUTOMAÇÃO DE CÁLCULO – CYPECAD METALICAS 3D



Peso Total = 290,5 kg (-20%)

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