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Analysis and design diffrent soulutions of steel truss based on Continente Bom Dia project

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ERASMUS PROJECT •••••••••••••••••••••••••••••••••••• PROJECTO ERASMUS

Analysis and design of different steel truss solutions for a roof structure.

Thesis submitted to obtain the **Degree of Master of Science in Engineering Technology Construction**.

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SUMMARY

This project presents various design solutions for the roof structure of a Continente Bom Dia supermarket. In this project, was calculated the utilization of already built truss, checking the limit states according to Eurocode 3.

In the next part of the project four different solutions were designed, with the same height and span.

Calculated percentage of use of newly designed solutions (using Eurocode 3), results were compared with the truss built in the baseline construction of the Continente Bom Dia supermarket. In designing trusses it was important to maximize the percentage of using each cross-section and minimize the weight of the steel.

In the embodiment of structural steel, an important and costly element is also the fire retardant paint coating. The studied solutions have been compared due to the cost of steel and fire retardant paint.

Keywords: truss, steel construction, structure, structural mechanics

STRESZCZENIE

W niniejszej pracy zostały przedstawione różne rozwiązania projektu stalowej kratownicy. Projektem bazowym był projekt konstrukcji stalowej supermarketu Continente Bom Dia w Portugalii. Konstrukcja nośna dachu została wybudowana na stalowych kratownicach. W tym projekcie obliczono stopień wykorzystania wybudowanej już kratownicy, sprawdzając stany graniczne według Eurokodu 7.

W kolejnej części projektu przedstawiono 4 rozwiązania wybudowania kratownicy o tej samej wysokości oraz rozpiętości, używając różnych kształtowników, a następnie projektując kratownice o innym układzie prętów.

Obliczono procent użycia nowo zaprojektowanych rozwiązań oraz porównano wyniki z kratownicą wybudowaną w projekcie supermarketu. W projektowaniu kratownic dążyliśmy do jak największego wykożystania przekroju danego elementu kratownicy.

W wykonaniu stalowych elementów konstrukcyjnych, ważnym oraz kosztownym elementem jest pokrycie stali farbą ognioochronną. Przedstawione przez nas rozwiązania zostały porównane ze względu na koszt stali oraz farby ognioochronnej.

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1 INTRODUCTION

1.1 INITIAL CONSIDERATIONS

In this project different solutions for steel trusses are designed using Eurocode 3. The presented solutions are compared to truss from Continente Bom Dia supermarket. Every bar in each solution is checked for Ultimate Limit Stress for compression or tension, bending moment, buckling and bending moment with axial force. All necessary internal forces (N_{Ed} – normal force, M_{Ed} – bending moment) are obtained from Autodesk Robot Structural Analysis software.

The evaluated load equals 180 kN and it is applied on each joint of top chord. Wind load was not taken into account on the presented calculations, idea of this project is to compare single two-dimensional trusses in the same external conditions. Calculations are made for the given structure with original UPN, IPN and RHS cross-sections and for two trusses with different shape with IPN cross-sections. Span and height were kept the same on all cases for the sake of comparison. In every case steel S275 was used. Price of all of five structures are calculated taking into account steel price and fire-resistant paint.

2 CALCULATIONS AND DESIGN

2.1 CALCULATIONS OF A STEEL TRUSS BASED ON CONTINENTE BOM DIA CONSTRUCTION PROJECT.

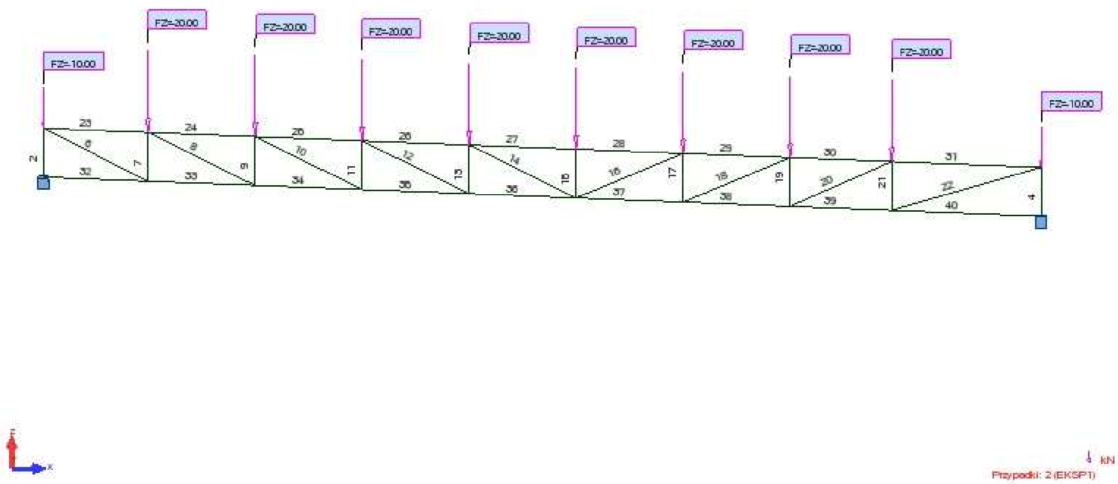


Figure 2.1.1 Original truss used in Continente Bom Dia construction.

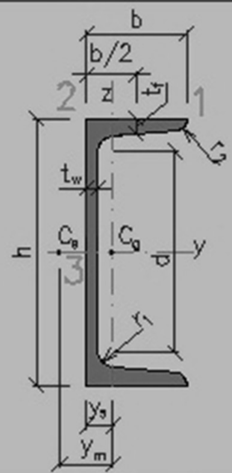
UPN 280			
Geometry		Section properties	
h = 28 cm		Axis y	Axis z
b = 9.5 cm		I_y = 6280 cm^4	I_z = 398.0 cm^4
t_f = 1.5 cm		W_y = 448.0 cm^3	W_{z1} = 57.10 cm^3
t_w = 1 cm			W_{z2} = 157.0 cm^3
r_1 = 1.5 cm		$W_{y,pl}$ = 532.0 cm^3	$W_{z,pl}$ = 108.0 cm^3
r_2 = 0.75 cm		i_y = 10.8 cm	i_z = 2.73 cm
y_s = 2.53 cm		S_y = 266.0 cm^3	
y_m = 5.09 cm		Warping and buckling	
d = 21.63 cm	G = 41.9 $kg.m^{-1}$	I_w = 4.86E+4 cm^6	I_t = 33.10 cm^4
A_L = 0.89 $m^2.m^{-1}$	A = 53.4 cm^2	i_w = 2.46 cm	i_{pc} = 11.2 cm

Figure 2.1.2 Top chord cross-section properties.

Compression – tension without considering the effect of buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN

  - Design compression resistance

$$N_{c,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{53,5 * 27,5}{1} = 1471,3kN \tag{2.1.}$$

  - Ultimate Limit Stress for compression

$$\frac{N_{Ed}}{N_{c,Rd}} < 1 \tag{2.2.}$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{338,40}{1471,3} = 0,230 < 1 - cross - section\ used\ in\ 23,0\ \% \tag{2.3.}$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.1.1.

Table 2.1.1 Calculations of Ultimate Limit Stress on compression and tension.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	Nt,Rd	Nc,Rd	NEd/Nt,Rd NEd/Nc,Rd
		kN		[m]		[cm^2]	[kN]	[kN]	[kN]
Diagonals	2	64,66	compression	0,91	UPN 240	42,1		1157,8	5,6%
	4	65,25	compression	0,91	UPN 240	42,1		1157,8	5,6%
	6	129,02	tension	2,16	UPN 180	27,83	765,3		16,9%
	7	82,69	compression	0,91	UPN 120	16,88		464,2	17,8%
	8	137,00	tension	2,19	UPN 160	23,89	657,0		20,9%
	9	53,72	tension	0,91	UPN 100	13,38	368,0		14,6%
	10	95,52	tension	2,19	UPN 140	20,27	557,4		17,1%
	11	39,92	compression	0,91	UPN 100	13,38		368,0	10,8%
	12	46,59	tension	2,19	UPN 100	13,38	368,0		12,7%
	13	20,24	compression	0,91	UPN 100	13,38		368,0	5,5%
	14	5,19	tension	2,19	UPN 100	13,38	368,0		1,4%
	15	16,48	compression	0,91	UPN 100	13,38		368,0	4,5%
	16	28,92	tension	2,13	UPN 120	16,88	464,2		6,2%
	17	32,63	compression	0,91	UPN 100	13,38		368,0	8,9%
	18	73,90	tension	2,13	UPN 140	20,27	557,4		13,3%
	19	50,20	compression	0,91	UPN 100	13,38		368,0	13,6%
	20	123,65	tension	2,04	UPN 160	23,89	657,0		18,8%
	21	74,66	compression	0,91	UPN 100	13,38		368,0	20,3%
	22	171,47	tension	2,85	UPN 220	37,27	1024,9		16,7%
Top chord	23	57,96	compression	1,92	UPN 280	53,5		1471,3	3,9%
	24	193,26	compression	1,96	UPN 280	53,5		1471,3	13,1%
	25	284,76	compression	1,96	UPN 280	53,5		1471,3	19,4%
	26	331,02	compression	1,96	UPN 280	53,5		1471,3	22,5%
	27	338,40	compression	1,96	UPN 280	53,5		1471,3	23,0%
	28	337,91	compression	1,96	UPN 280	53,5		1471,3	23,0%
	29	307,95	compression	1,96	UPN 280	53,5		1471,3	20,9%
	30	235,51	compression	1,86	UPN 280	53,5		1471,3	16,0%
	31	114,87	compression	2,74	UPN 280	53,5		1471,3	7,8%
Bottom chord	32	210,84	compression	1,92	UPN 240	42,1		1157,8	18,2%
	33	82,56	compression	1,96	UPN 240	42,1		1157,8	7,1%
	34	45,67	tension	1,96	UPN 240	42,1	1157,8		3,9%
	35	135,83	tension	1,96	UPN 240	42,1	1157,8		11,7%
	36	180,11	tension	1,96	UPN 240	42,1	1157,8		15,6%
	37	157,41	tension	1,96	UPN 240	42,1	1157,8		13,6%
	38	85,84	tension	1,96	UPN 240	42,1	1157,8		7,4%
	39	31,27	compression	1,86	UPN 240	42,1		1157,8	2,7%
	40	204,96	compression	2,74	UPN 240	42,1		1157,8	17,7%

Bending moment

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 53,03 kNm

  - Design bending resistance

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{74{,}0 * 27{,}5}{1 * 100} = 20{,}4\ kNm \qquad 2.4.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{c,Rd}} < 1 \qquad 2.5.$$

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{53{,}03}{20{,}4} = 2{,}606 > 1 - cross - section\ used\ in\ 260{,}6\ \% \qquad 2.6.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.1.2.

Table 2.1.2 Calculations of Ultimate Limit Stress on bending moment.

	Number	Med.	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mc,Rd	MEd/Mc,Rd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	UPN 240	42,1	74,0	20,4	260,6%
	4	51,07	compression	0,91	UPN 240	42,1	74,0	20,4	251,0%
	6	-4,79	tension	2,16	UPN 180	27,83	42,5	11,7	41,0%
	7	6,45	compression	0,91	UPN 120	16,88	21,1	5,8	111,2%
	8	0,24	tension	2,19	UPN 160	23,89	34,9	9,6	2,5%
	9	-2,67	tension	0,91	UPN 100	13,38	16,2	4,5	59,9%
	10	1,04	tension	2,19	UPN 140	20,27	28,1	7,7	13,5%
	11	2,12	compression	0,91	UPN 100	13,38	16,2	4,5	47,6%
	12	0,32	tension	2,19	UPN 100	13,38	16,2	4,5	7,2%
	13	-1,22	compression	0,91	UPN 100	13,38	16,2	4,5	27,4%
	14	0,33	tension	2,19	UPN 100	13,38	16,2	4,5	7,4%
	15	-0,3	compression	0,91	UPN 100	13,38	16,2	4,5	6,7%
	16	0,52	tension	2,13	UPN 120	16,88	21,1	5,8	9,0%
	17	1,55	compression	0,91	UPN 100	13,38	16,2	4,5	34,8%
	18	0,92	tension	2,13	UPN 140	20,27	28,1	7,7	11,9%
	19	-1,99	compression	0,91	UPN 100	13,38	16,2	4,5	44,7%
	20	1,04	tension	2,04	UPN 160	23,89	34,9	9,6	10,8%
	21	3,73	compression	0,91	UPN 100	13,38	16,2	4,5	83,7%
	22	-3,83	tension	2,85	UPN 220	37,27	63,5	17,5	21,9%
Top chord	23	-2,63	compression	1,92	UPN 280	53,5	108,0	29,7	8,9%
	24	7,82	compression	1,96	UPN 280	53,5	108,0	29,7	26,3%
	25	8,15	compression	1,96	UPN 280	53,5	108,0	29,7	27,4%
	26	11,35	compression	1,96	UPN 280	53,5	108,0	29,7	38,2%
	27	11,89	compression	1,96	UPN 280	53,5	108,0	29,7	40,0%
	28	12,17	compression	1,96	UPN 280	53,5	108,0	29,7	41,0%
	29	9,31	compression	1,96	UPN 280	53,5	108,0	29,7	31,3%
	30	7,62	compression	1,86	UPN 280	53,5	108,0	29,7	25,7%
	31	-6,36	compression	2,74	UPN 280	53,5	108,0	29,7	21,4%
Bottom chord	32	-45,88	compression	1,92	UPN 240	42,1	74,0	20,4	225,5%
	33	3,31	compression	1,96	UPN 240	42,1	74,0	20,4	16,3%
	34	5,46	tension	1,96	UPN 240	42,1	74,0	20,4	26,8%
	35	6,67	tension	1,96	UPN 240	42,1	74,0	20,4	32,8%
	36	6,9	tension	1,96	UPN 240	42,1	74,0	20,4	33,9%
	37	7,01	tension	1,96	UPN 240	42,1	74,0	20,4	34,4%
	38	5,8	tension	1,96	UPN 240	42,1	74,0	20,4	28,5%
	39	7,12	compression	1,86	UPN 240	42,1	74,0	20,4	35,0%
	40	-36,96	compression	2,74	UPN 240	42,1	74,0	20,4	181,6%

Buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN

  -Buckling curve

$For\ every\ chann\quad section \rightarrow \boldsymbol{buckling\ curve}$ „c"

- imperfection factor α

For buckling curve„c" imperfection parameter equals $\alpha = 0{,}49$

- Buckling length

$$L_{cr} = \mu * L = 1 * 1{,}96 = 1{,}96\ m$$

- Slenderness $\bar{\lambda}$

$$\lambda_1 = 93.9 * \varepsilon = 93.9 * 0{,}92 = 86{,}39 \qquad 2.7.$$

$$\bar{\lambda} = \frac{L_{c,r}}{i_z} * \frac{1}{\lambda_1} = \frac{1{,}96 * 100}{2{,}74} * \frac{1}{86{,}93} = 0{,}828 \qquad 2.8.$$

- Reduction factor χ

$$\phi = 0{,}5 * \left[1 + \alpha * \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0{,}5 * [1 + 0{,}49 * (0{,}828 - 0{,}2) + 0{,}828^2] = 0{,}997 \qquad 2.9.$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0{,}997 + \sqrt{0{,}997^2 - 0{,}828^2}} = 0{,}645 \qquad 2.10.$$

- Design buckling resistance

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} = \frac{0{,}645 * 53{,}5 * 27{,}5}{1} = 948{,}3kN \qquad 2.11.$$

- Ultimate Limit Stress for Buckling

$$\frac{N_{Ed}}{N_{b,Rd}} < 1 \qquad 2.12.$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{338{,}40}{948{,}3} = 0{,}357 < 1 - cross - section\ used\ in\ 35{,}7\ \% \qquad 2.13.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.1.3.

Table 2.1.3 Calculations of Ultimate Limit Stress on buckling.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	i	Normalized slenderness $\bar{\lambda}$	Parameter ϕ	Reduction factor χ	$N_{b,RdNb,Rd}$	$N_{Ed}/N_{b,RdNEd}$
		kN		[m]		[cm^2]	[cm]					
Diagonals	2	64,66	compression	0,91	UPN 240	42,1	2,42	0,435	0,652	0,878	1017,1	6,4%
	4	65,25	compression	0,91	UPN 240	42,1	2,42	0,435	0,652	0,878	1017,1	6,4%
	6	129,02	tension	2,16	UPN 180	27,83	2,01					
	7	82,69	compression	0,91	UPN 120	16,88	1,59	0,662	0,833	0,748	347,1	23,8%
	8	137	tension	2,19	UPN 160	23,89	1,88	1,348	1,690			
	9	53,72	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	20,4%
	10	95,52	tension	2,19	UPN 140	20,27	1,75					
	11	39,92	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	15,2%
	12	46,59	tension	2,19	UPN 100	13,38	1,47					
	13	20,24	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	7,7%
	14	5,19	tension	2,19	UPN 100	13,38	1,47					
	15	16,48	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	6,3%
	16	28,92	tension	2,13	UPN 120	16,88	1,59					
	17	32,63	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	12,4%
	18	73,9	tension	2,13	UPN 140	20,27	1,75					
	19	50,2	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	19,1%
	20	123,65	tension	2,04	UPN 160	23,89	1,88					
	21	74,66	compression	0,91	UPN 100	13,38	1,47	0,717	0,883	0,714	262,9	28,4%
	22	171,47	tension	2,85	UPN 220	37,27	2,29					
Top chord	23	57,96	compression	1,92	UPN 280	53,5	2,73	0,814	0,982	0,653	961,2	6,0%
	24	193,26	compression	1,96	UPN 280	53,5	2,73	0,831	1,000	0,643	945,5	20,4%
	25	284,76	compression	1,96	UPN 280	53,5	2,73	0,831	1,000	0,643	945,5	30,1%
	26	331,02	compression	1,96	UPN 280	53,5	2,73	0,831	1,000	0,643	945,5	35,0%
	27	338,4	compression	1,96	UPN 280	53,5	2,74	0,828	0,997	0,645	948,3	35,7%
	28	337,91	compression	1,96	UPN 280	53,5	2,73	0,831	1,000	0,643	945,5	35,7%
	29	307,95	compression	1,96	UPN 280	53,5	2,73	0,831	1,000	0,643	945,5	32,6%
	30	235,51	compression	1,86	UPN 280	53,5	2,73	0,789	0,955	0,669	984,7	23,9%
	31	114,87	compression	2,74	UPN 280	53,5	2,73	1,162	1,411	0,452	665,6	17,3%
Bottom chord	32	210,84	compression	1,92	UPN 240	42,1	2,42	0,918	1,098	0,589	681,4	30,9%
	33	82,56	compression	1,96	UPN 240	42,1	2,42	0,938	1,120	0,577	668,0	12,4%
	34	45,67	tension	1,96	UPN 240	42,1	2,42					
	35	135,83	tension	1,96	UPN 240	42,1	2,42					
	36	180,11	tension	1,96	UPN 240	42,1	2,42					
	37	157,41	tension	1,96	UPN 240	42,1	2,42					
	38	85,84	tension	1,96	UPN 240	42,1	2,42					
	39	31,27	compression	1,86	UPN 240	42,1	2,42	0,890	1,065	0,606	701,8	4,5%
	40	204,96	compression	2,74	UPN 240	42,1	2,42	1,311	1,631	0,384	445,0	46,1%

Bending moment and axial force

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 53,03 kNm

- Design bending resistance

$$N_{Ed} = 64{,}66\ kN \quad 2.14.$$

$$N_{pl,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{42{,}1 * 27{,}5}{1} = 1157{,}75\ kN \quad 2.15.$$

$$M_{pl,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{74{,}0 * 27{,}5}{1 * 100} = 20{,}4\ kNm \quad 2.16.$$

$$M_{N,Rd} = M_{pl,Rd} * \left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] = 20{,}4 * \ [1 - \left(\frac{64{,}66}{1157{,}75}\right)^2 = 20{,}3\ kN \quad 2.17.$$

- Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{N,Rd}} < 1 \quad 2.18.$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{53{,}03}{20{,}3} = 2{,}614 > 1 - cross - section\ used\ in\ 261{,}4\ \% \quad 2.19.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.1.4.

Table 2.1.4 Calculations of Ultimate Limit Stress on bending moment and axial force.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mpl,Rd	NEd/Npl,Rd	M N,Rd	MEd/MNRd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]		[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	UPN 240	42,1	74,0	20,4	0,06	20,3	261,4%
	4	51,07	compression	0,91	UPN 240	42,1	74,0	20,4	0,06	20,3	251,8%
	6	-4,79	tension	2,16	UPN 180	27,83	42,5	11,7	0,17	11,4	42,2%
	7	6,45	compression	0,91	UPN 120	16,88	21,1	5,8	0,18	5,6	114,8%
	8	0,24	tension	2,19	UPN 160	23,89	34,9	9,6	0,21	9,2	2,6%
	9	-2,67	tension	0,91	UPN 100	13,38	16,2	4,5	0,15	4,4	61,2%
	10	1,04	tension	2,19	UPN 140	20,27	28,1	7,7	0,17	7,5	13,9%
	11	2,12	compression	0,91	UPN 100	13,38	16,2	4,5	0,11	4,4	48,2%
	12	0,32	tension	2,19	UPN 100	13,38	16,2	4,5	0,13	4,4	7,3%
	13	-1,22	compression	0,91	UPN 100	13,38	16,2	4,5	0,06	4,4	27,5%
	14	0,33	tension	2,19	UPN 100	13,38	16,2	4,5	0,01	4,5	7,4%
	15	-0,3	compression	0,91	UPN 100	13,38	16,2	4,5	0,04	4,4	6,7%
	16	0,52	tension	2,13	UPN 120	16,88	21,1	5,8	0,06	5,8	9,0%
	17	1,55	compression	0,91	UPN 100	13,38	16,2	4,5	0,09	4,4	35,1%
	18	0,92	tension	2,13	UPN 140	20,27	28,1	7,7	0,13	7,6	12,1%
	19	-1,99	compression	0,91	UPN 100	13,38	16,2	4,5	0,14	4,4	45,5%
	20	1,04	tension	2,04	UPN 160	23,89	34,9	9,6	0,19	9,3	11,2%
	21	3,73	compression	0,91	UPN 100	13,38	16,2	4,5	0,20	4,3	87,3%
	22	-3,83	tension	2,85	UPN 220	37,27	63,5	17,5	0,17	17,0	22,6%
Top chord	23	-2,63	compression	1,92	UPN 280	53,5	108,0	29,7	0,04	29,7	8,9%
	24	7,82	compression	1,96	UPN 280	53,5	108,0	29,7	0,13	29,2	26,8%
	25	8,15	compression	1,96	UPN 280	53,5	108,0	29,7	0,19	28,6	28,5%
	26	11,35	compression	1,96	UPN 280	53,5	108,0	29,7	0,22	28,2	40,3%
	27	11,89	compression	1,96	UPN 280	53,5	108,0	29,7	0,23	28,1	42,3%
	28	12,17	compression	1,96	UPN 280	53,5	108,0	29,7	0,23	28,1	43,3%
	29	9,31	compression	1,96	UPN 280	53,5	108,0	29,7	0,21	28,4	32,8%
	30	7,62	compression	1,86	UPN 280	53,5	108,0	29,7	0,16	28,9	26,3%
	31	-6,36	compression	2,74	UPN 280	53,5	108,0	29,7	0,08	29,5	21,5%
Bottom chord	32	-45,88	compression	1,92	UPN 240	42,1	74,0	20,4	0,18	19,7	233,2%
	33	3,31	compression	1,96	UPN 240	42,1	74,0	20,4	0,07	20,2	16,3%
	34	5,46	tension	1,96	UPN 240	42,1	74,0	20,4	0,04	20,3	26,9%
	35	6,67	tension	1,96	UPN 240	42,1	74,0	20,4	0,12	20,1	33,2%
	36	6,9	tension	1,96	UPN 240	42,1	74,0	20,4	0,16	19,9	34,7%
	37	7,01	tension	1,96	UPN 240	42,1	74,0	20,4	0,14	20,0	35,1%
	38	5,8	tension	1,96	UPN 240	42,1	74,0	20,4	0,07	20,2	28,7%
	39	7,12	compression	1,86	UPN 240	42,1	74,0	20,4	0,03	20,3	35,0%
	40	-36,96	compression	2,74	UPN 240	42,1	74,0	20,4	0,18	19,7	187,5%

2.2 Calculations of a steel truss with original structure topology using IPN cross-sections.

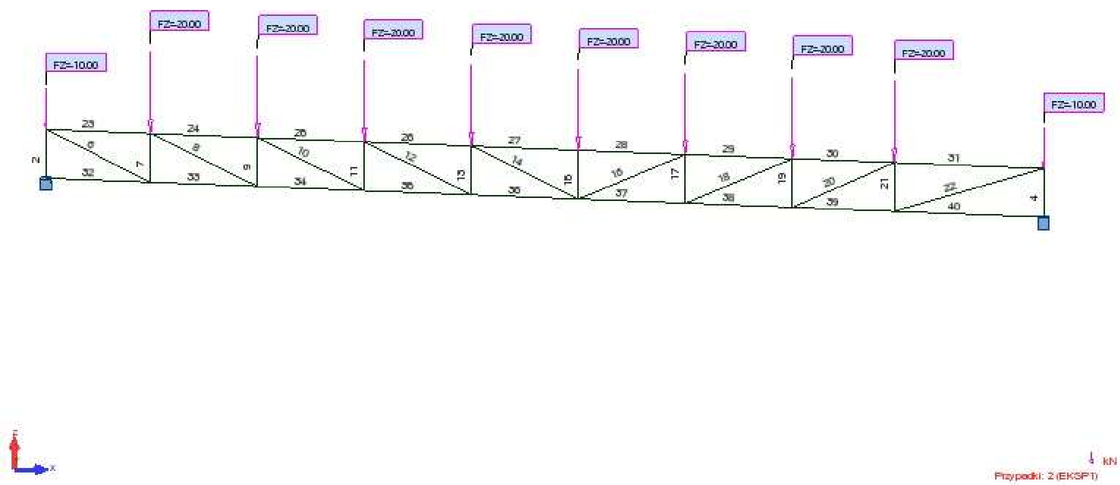


Figure 2.2.1 Truss with original shape and IPN cross-sections.

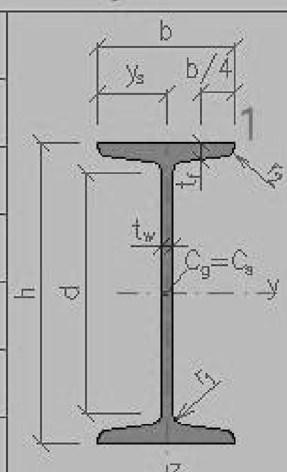
IPN 200			
Geometry		Section properties	
$h = 20$ cm		Axis y	Axis z
$b = 9$ cm		$I_y = 2140$ cm^4	$I_z = 116.0$ cm^4
$t_f = 1.13$ cm		$W_{y1} = 214.0$ cm^3	$W_{z1} = 25.90$ cm^3
$t_w = 0.75$ cm		$W_{y,pl} = 248.0$ cm^3	$W_{z,pl} = 42.70$ cm^3
$r_1 = 0.75$ cm		$i_y = 8$ cm	$i_z = 1.87$ cm
$r_2 = 0.45$ cm		$S_y = 124.0$ cm^3	$S_z = 21.40$ cm^3
$y_s = 4.5$ cm		Warping and buckling	
$d = 15.91$ cm	$G = 26.2$ kg.m^{-1}	$I_w = 9980$ cm^6	$I_t = 13.60$ cm^4
$A_L = 0.71$ m^2.m^{-1}	$A = 33.4$ cm^2	$i_w = 2.1$ cm	$i_{pc} = 8.21$ cm

Figure 2.2.2 Top chord cross-section properties.

Compression - tension without considering the effect of buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN

  - Design compression resistance

$$N_{c,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{33,4 * 27,5}{1} = 918,5 kN \qquad 2.20.$$

  - Ultimate Limit Stress for compression

$$\frac{N_{Ed}}{N_{c,Rd}} < 1 \qquad 2.21.$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{338,40}{918,5} = 0,368 < 1 - cross - section\ used\ in\ 36,8\ \% \qquad 2.22.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.2.1.

Table 2.2.1 Calculations of Ultimate Limit Stress on compression and tension.

	Number	NEd	Compression / Tension	Length	Type of profile		Area of cross-section	Nt,Rd	Nc,Rd	NEd/Nt,Rd NEd/Nc,Rd
		kN		[m]			[cm^2]	[kN]	[kN]	[kN]
Diagonals	2	64,66	compression	0,91	IPN	200	33,4		918,5	7,0%
	4	65,25	compression	0,91	IPN	200	33,4		918,5	7,1%
	6	129,02	tension	2,16	IPN	80	7,57	208,2		62,0%
	7	82,69	compression	0,91	IPN	100	10,6		291,5	28,4%
	8	137	tension	2,19	IPN	80	7,57	208,2		65,8%
	9	53,72	tension	0,91	IPN	80	7,57	208,2		25,8%
	10	95,52	tension	2,19	IPN	80	7,57	208,2		45,9%
	11	39,92	compression	0,91	IPN	80	7,57		208,2	19,2%
	12	46,59	tension	2,19	IPN	80	7,57	208,2		22,4%
	13	20,24	compression	0,91	IPN	80	7,57		208,2	9,7%
	14	5,19	tension	2,19	IPN	80	7,57	208,2		2,5%
	15	16,48	compression	0,91	IPN	80	7,57		208,2	7,9%
	16	28,92	tension	2,13	IPN	80	7,57	208,2		13,9%
	17	32,63	compression	0,91	IPN	80	7,57		208,2	15,7%
	18	73,9	tension	2,13	IPN	80	7,57	208,2		35,5%
	19	50,2	compression	0,91	IPN	80	7,57		208,2	24,1%
	20	123,65	tension	2,04	IPN	80	7,57	208,2		59,4%
	21	74,66	compression	0,91	IPN	80	7,57		208,2	35,9%
	22	171,47	tension	2,85	IPN	80	7,57	208,2		82,4%
Top chord	23	57,96	compression	1,92	IPN	200	33,4		918,5	6,3%
	24	193,26	compression	1,96	IPN	200	33,4		918,5	21,0%
	25	284,76	compression	1,96	IPN	200	33,4		918,5	31,0%
	26	331,02	compression	1,96	IPN	200	33,4		918,5	36,0%
	27	338,4	compression	1,96	IPN	200	33,4		918,5	36,8%
	28	337,91	compression	1,96	IPN	200	33,4		918,5	36,8%
	29	307,95	compression	1,96	IPN	200	33,4		918,5	33,5%
	30	235,51	compression	1,86	IPN	200	33,4		918,5	25,6%
	31	114,87	compression	2,74	IPN	200	33,4		918,5	12,5%
Bottom chord	32	210,84	compression	1,92	IPN	200	33,4		918,5	23,0%
	33	82,56	compression	1,96	IPN	200	33,4		918,5	9,0%
	34	45,67	tension	1,96	IPN	200	33,4	918,5		5,0%
	35	135,83	tension	1,96	IPN	200	33,4	918,5		14,8%
	36	180,11	tension	1,96	IPN	200	33,4	918,5		19,6%
	37	157,41	tension	1,96	IPN	200	33,4	918,5		17,1%
	38	85,84	tension	1,96	IPN	200	33,4	918,5		9,3%
	39	31,27	compression	1,86	IPN	200	33,4		918,5	3,4%
	40	204,96	compression	2,74	IPN	200	33,4		918,5	22,3%

Bending moment

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 53,03 kNm

  - Design bending resistance

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{248{,}0 * 27{,}5}{1 * 100} = 68{,}2kNm \quad 2.23.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{c,Rd}} < 1 \quad 2.24.$$

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{53{,}03}{68{,}2} = 0{,}778 < 1 - cross - section\ used\ in\ 77{,}8\ \% \quad 2.25.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.2.2.

Table 2.2.2 Calculations of Ultimate Limit Stress on bending moment.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mc,Rd	MEd/Mc,Rd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	IPN 200	33,4	248,0	68,2	77,8%
	4	51,07	compression	0,91	IPN 200	33,4	248,0	68,2	74,9%
	6	-4,79	tension	2,16	IPN 80	7,57	22,8	6,3	76,4%
	7	6,45	compression	0,91	IPN 100	10,6	39,8	10,9	58,9%
	8	0,24	tension	2,19	IPN 80	7,57	22,8	6,3	3,8%
	9	-2,67	tension	0,91	IPN 80	7,57	22,8	6,3	42,6%
	10	1,04	tension	2,19	IPN 80	7,57	22,8	6,3	16,6%
	11	2,12	compression	0,91	IPN 80	7,57	22,8	6,3	33,8%
	12	0,32	tension	2,19	IPN 80	7,57	22,8	6,3	5,1%
	13	-1,22	compression	0,91	IPN 80	7,57	22,8	6,3	19,5%
	14	0,33	tension	2,19	IPN 80	7,57	22,8	6,3	5,3%
	15	-0,3	compression	0,91	IPN 80	7,57	22,8	6,3	4,8%
	16	0,52	tension	2,13	IPN 80	7,57	22,8	6,3	8,3%
	17	1,55	compression	0,91	IPN 80	7,57	22,8	6,3	24,7%
	18	0,92	tension	2,13	IPN 80	7,57	22,8	6,3	14,7%
	19	-1,99	compression	0,91	IPN 80	7,57	22,8	6,3	31,7%
	20	1,04	tension	2,04	IPN 80	7,57	22,8	6,3	16,6%
	21	3,73	compression	0,91	IPN 80	7,57	22,8	6,3	59,5%
	22	-3,83	tension	2,85	IPN 80	7,57	22,8	6,3	61,1%
Top chord	23	-2,63	compression	1,92	IPN 200	33,4	532,0	146,3	1,8%
	24	7,82	compression	1,96	IPN 200	33,4	532,0	146,3	5,3%
	25	8,15	compression	1,96	IPN 200	33,4	532,0	146,3	5,6%
	26	11,35	compression	1,96	IPN 200	33,4	532,0	146,3	7,8%
	27	11,89	compression	1,96	IPN 200	33,4	532,0	146,3	8,1%
	28	12,17	compression	1,96	IPN 200	33,4	532,0	146,3	8,3%
	29	9,31	compression	1,96	IPN 200	33,4	532,0	146,3	6,4%
	30	7,62	compression	1,86	IPN 200	33,4	532,0	146,3	5,2%
	31	-6,36	compression	2,74	IPN 200	33,4	532,0	146,3	4,3%
Bottom chord	32	-45,88	compression	1,92	IPN 200	33,4	358,0	98,5	46,6%
	33	3,31	compression	1,96	IPN 200	33,4	358,0	98,5	3,4%
	34	5,46	tension	1,96	IPN 200	33,4	358,0	98,5	5,5%
	35	6,67	tension	1,96	IPN 200	33,4	358,0	98,5	6,8%
	36	6,9	tension	1,96	IPN 200	33,4	358,0	98,5	7,0%
	37	7,01	tension	1,96	IPN 200	33,4	358,0	98,5	7,1%
	38	5,8	tension	1,96	IPN 200	33,4	358,0	98,5	5,9%
	39	7,12	compression	1,86	IPN 200	33,4	358,0	98,5	7,2%
	40	-36,96	compression	2,74	IPN 200	33,4	358,0	98,5	37,5%

Buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN

-Buckling curve

$For\ every\ cha \qquad section \rightarrow \boldsymbol{buckling\ curve}$ „c"

- imperfection factor α

For buckling curve„c" imperfection parameter equals $\alpha = 0{,}49$

- Buckling length

$$L_{cr} = \mu * L = 1 * 1{,}96 = 1{,}96\ m \qquad 2.26.$$

- Slenderness $\bar{\lambda}$

$$\lambda_1 = 93.9 * \varepsilon = 93.9 * 0{,}92 = 86{,}39 \qquad 2.27.$$

$$\bar{\lambda} = \frac{L_{c,r}}{i_z} * \frac{1}{\lambda_1} = \frac{1{,}96 * 100}{2{,}74} * \frac{1}{86{,}93} = 0{,}828 \qquad 2.28.$$

- Reduction factor χ

$$\phi = 0{,}5 * \left[1 + \alpha * \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0{,}5 * [1 + 0{,}49 * (0{,}828 - 0{,}2) + 0{,}828^2] = 0{,}997 \qquad 2.29.$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0{,}997 + \sqrt{0{,}997^2 - 0{,}828^2}} = 0{,}645 \qquad 2.30.$$

- Design buckling resistance

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} = \frac{0{,}427 * 33{,}4 * 27{,}5}{1} = 392{,}7kN \qquad 2.31.$$

- Ultimate Limit Stress for Buckling

$$\frac{N_{Ed}}{N_{b,Rd}} < 1 \qquad 2.32.$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{338{,}40}{392{,}7} = 0{,}862 < 1 - cross - section\ used\ in\ 86{,}2\ \% \qquad 2.33.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.2.3.

Table 2.2.3 Calculations of Ultimate Limit Stress on buckling

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	i	Normalized slenderness $\bar{\lambda}$	Parameter ϕ	Reduction factor χ	$N_{b,RdNb,Rd}$	$N_{Ed}/N_{b,RdNEd}$
		kN		[m]		[cm^2]	[cm]					
Diagonals	2	64,66	compression	0,91	IPN 200	33,4	1,87	0,563	0,748	0,807	741,2	8,7%
	4	65,25	compression	0,91	IPN 200	33,4	1,87	0,563	0,748	0,807	741,2	8,8%
	6	129,02	tension	2,16	IPN 80	7,57	0,911					
	7	82,69	compression	0,91	IPN 100	10,6	1,07	0,984	1,177	0,549	160,0	51,7%
	8	137	tension	2,19	IPN 80	7,57	0,911					
	9	53,72	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	56,7%
	10	95,52	tension	2,19	IPN 80	7,57	0,911					
	11	39,92	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	42,1%
	12	46,59	tension	2,19	IPN 80	7,57	0,911					
	13	20,24	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	21,4%
	14	5,19	tension	2,19	IPN 80	7,57	0,911					
	15	16,48	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	17,4%
	16	28,92	tension	2,13	IPN 80	7,57	0,911					
	17	32,63	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	34,4%
	18	73,9	tension	2,13	IPN 80	7,57	0,911					
	19	50,2	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	53,0%
	20	123,65	tension	2,04	IPN 80	7,57	0,911					
	21	74,66	compression	0,91	IPN 80	7,57	0,911	1,156	1,403	0,455	94,8	78,8%
	22	171,47	tension	2,85	IPN 80	7,57	0,911					
Top chord	23	57,96	compression	1,92	IPN 200	33,4	1,87	1,188	1,448	0,439	403,5	14,4%
	24	193,26	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	49,2%
	25	284,76	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	72,5%
	26	331,02	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	84,3%
	27	338,4	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	86,2%
	28	337,91	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	86,1%
	29	307,95	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	78,4%
	30	235,51	compression	1,86	IPN 200	33,4	1,87	1,151	1,396	0,458	420,3	56,0%
	31	114,87	compression	2,74	IPN 200	33,4	1,87	1,696	2,305	0,259	237,6	48,3%
Bottom chord	32	210,84	compression	1,92	IPN 200	33,4	1,87	1,188	1,448	0,439	403,5	52,3%
	33	82,56	compression	1,96	IPN 200	33,4	1,87	1,213	1,484	0,427	392,7	21,0%
	34	45,67	tension	1,96	IPN 200	33,4	1,87					
	35	135,83	tension	1,96	IPN 200	33,4	1,87					
	36	180,11	tension	1,96	IPN 200	33,4	1,87					
	37	157,41	tension	1,96	IPN 200	33,4	1,87					
	38	85,84	tension	1,96	IPN 200	33,4	1,87					
	39	31,27	compression	1,86	IPN 200	33,4	1,87	1,151	1,396	0,458	420,3	7,4%
	40	204,96	compression	2,74	IPN 200	33,4	1,87	1,696	2,305	0,259	237,6	86,3%

Bending moment and axial force

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 53,03 kNm

  - Design bending resistance

$$N_{Ed} = 64{,}66\ kN \quad 2.34.$$

$$N_{pl,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{33{,}4 * 27{,}5}{1} = 918{,}5\ kN \quad 2.35.$$

$$M_{pl,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{248{,}0 * 27{,}5}{1 * 100} = 68{,}2\ kNm \quad 2.36.$$

$$M_{N,Rd} = M_{pl,Rd} * \left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] = 68{,}2 * \ [1 - \left(\frac{64{,}66}{918{,}5}\right)^2 = 67{,}9\ kN \quad 2.37.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{N,Rd}} < 1 \quad 2.38.$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{64{,}66}{67{,}9} = 0{,}781 < 1 - cross - section\ used\ in\ 78{,}1\ \% \quad 2.39.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.2.4.

Table 2.2.4 Calculations of Ultimate Limit Stress on bending moment and axial force.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mpl,Rd	NEd/Npl,Rd	M N,Rd	MEd/MNRd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]		[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	IPN 200	33,4	248,0	68,2	0,07	67,9	78,1%
	4	51,07	compression	0,91	IPN 200	33,4	248,0	68,2	0,07	67,9	75,3%
	6	-4,79	tension	2,16	IPN 100	10,6	39,8	10,9	0,44	8,8	54,4%
	7	6,45	compression	0,91	IPN 100	10,6	39,8	10,9	0,28	10,1	64,1%
	8	0,24	tension	2,19	IPN 80	7,57	22,8	6,3	0,66	3,6	6,8%
	9	-2,67	tension	0,91	IPN 80	7,57	22,8	6,3	0,26	5,9	45,6%
	10	1,04	tension	2,19	IPN 80	7,57	22,8	6,3	0,46	4,9	21,0%
	11	2,12	compression	0,91	IPN 80	7,57	22,8	6,3	0,19	6,0	35,1%
	12	0,32	tension	2,19	IPN 80	7,57	22,8	6,3	0,22	6,0	5,4%
	13	-1,22	compression	0,91	IPN 80	7,57	22,8	6,3	0,10	6,2	19,6%
	14	0,33	tension	2,19	IPN 80	7,57	22,8	6,3	0,02	6,3	5,3%
	15	-0,3	compression	0,91	IPN 80	7,57	22,8	6,3	0,08	6,2	4,8%
	16	0,52	tension	2,13	IPN 80	7,57	22,8	6,3	0,14	6,1	8,5%
	17	1,55	compression	0,91	IPN 80	7,57	22,8	6,3	0,16	6,1	25,3%
	18	0,92	tension	2,13	IPN 80	7,57	22,8	6,3	0,35	5,5	16,8%
	19	-1,99	compression	0,91	IPN 80	7,57	22,8	6,3	0,24	5,9	33,7%
	20	1,04	tension	2,04	IPN 80	7,57	22,8	6,3	0,59	4,1	25,6%
	21	3,73	compression	0,91	IPN 80	7,57	22,8	6,3	0,36	5,5	68,3%
	22	-3,83	tension	2,85	IPN 100	10,6	39,8	10,9	0,59	7,2	53,5%
Top chord	23	-2,63	compression	1,92	IPN 200	33,4	532,0	146,3	0,06	145,7	1,8%
	24	7,82	compression	1,96	IPN 200	33,4	532,0	146,3	0,21	139,8	5,6%
	25	8,15	compression	1,96	IPN 200	33,4	532,0	146,3	0,31	132,2	6,2%
	26	11,35	compression	1,96	IPN 200	33,4	532,0	146,3	0,36	127,3	8,9%
	27	11,89	compression	1,96	IPN 200	33,4	532,0	146,3	0,37	126,4	9,4%
	28	12,17	compression	1,96	IPN 200	33,4	532,0	146,3	0,37	126,5	9,6%
	29	9,31	compression	1,96	IPN 200	33,4	532,0	146,3	0,34	129,9	7,2%
	30	7,62	compression	1,86	IPN 200	33,4	532,0	146,3	0,26	136,7	5,6%
	31	-6,36	compression	2,74	IPN 200	33,4	532,0	146,3	0,13	144,0	4,4%
Bottom chord	32	-45,88	compression	1,92	IPN 200	33,4	358,0	98,5	0,23	93,3	49,2%
	33	3,31	compression	1,96	IPN 200	33,4	358,0	98,5	0,09	97,7	3,4%
	34	5,46	tension	1,96	IPN 200	33,4	358,0	98,5	0,05	98,2	5,6%
	35	6,67	tension	1,96	IPN 200	33,4	358,0	98,5	0,15	96,3	6,9%
	36	6,9	tension	1,96	IPN 200	33,4	358,0	98,5	0,20	94,7	7,3%
	37	7,01	tension	1,96	IPN 200	33,4	358,0	98,5	0,17	95,6	7,3%
	38	5,8	tension	1,96	IPN 200	33,4	358,0	98,5	0,09	97,6	5,9%
	39	7,12	compression	1,86	IPN 200	33,4	358,0	98,5	0,03	98,3	7,2%
	40	-36,96	compression	2,74	IPN 200	33,4	358,0	98,5	0,22	93,5	39,5%

2.3 CALCULATIONS OF A STEEL TRUSS WITH CHANGED STRUCTURE TOPOLOGY USING IPN CROSS-SECTIONS.

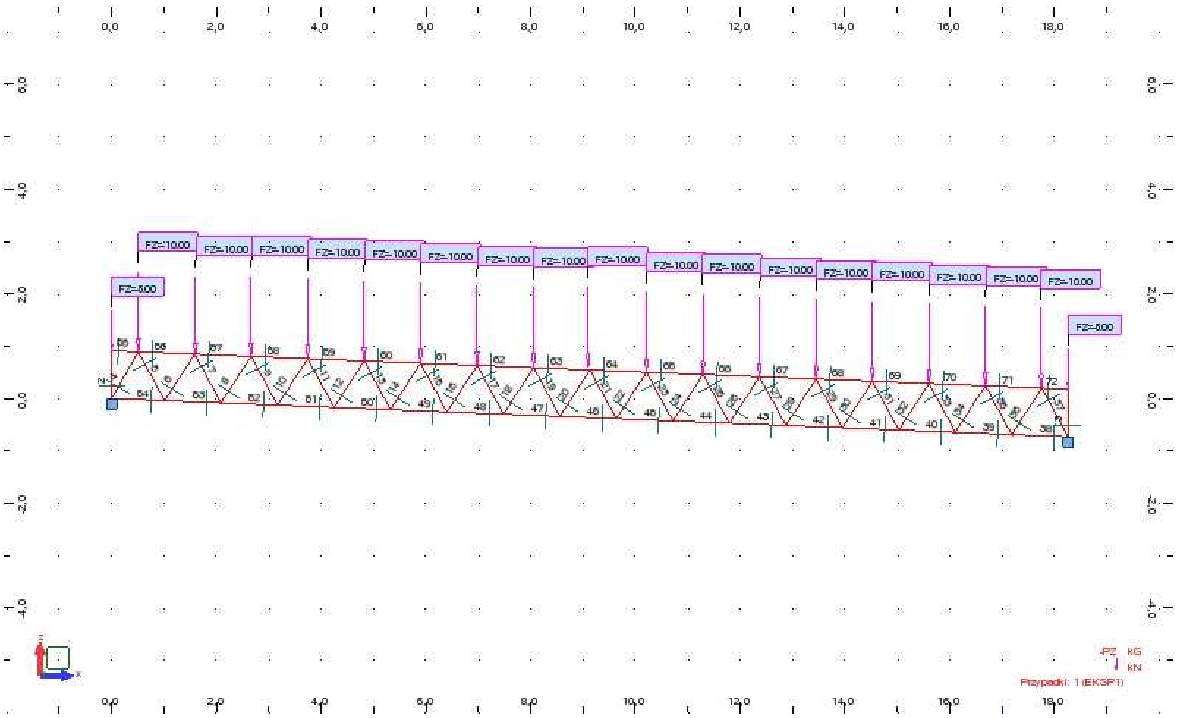


Figure 2.3.1 Truss with changed shape and IPN cross-sections.

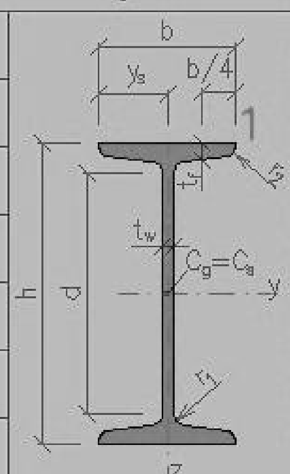
IPN 140			
Geometry		Section properties	
$h = 14$ cm		Axis y	Axis z
$b = 6.6$ cm		$I_y = 572.0\ cm^4$	$I_z = 35.10\ cm^4$
$t_f = 0.86$ cm		$W_{y1} = 81.80\ cm^3$	$W_{z1} = 10.60\ cm^3$
$t_w = 0.57$ cm		$W_{y,pl} = 95.20\ cm^3$	$W_{z,pl} = 18.40\ cm^3$
$r_1 = 0.57$ cm		$i_y = 5.6$ cm	$i_z = 1.39$ cm
$r_2 = 0.34$ cm		$S_y = 47.60\ cm^3$	$S_z = 9.200\ cm^3$
$y_s = 3.3$ cm		Warping and buckling	
$d = 10.91$ cm	$G = 14.3\ kg.m^{-1}$	$I_w = 1460\ cm^6$	$I_t = 4.330\ cm^4$
$A_L = 0.5\ m^2.m^{-1}$	$A = 18.2\ cm^2$	$i_w = 1.55$ cm	$i_{pc} = 5.77$ cm

Figure 2.3.2 Top chord cross-section properties.

Compression - tension without considering the effect of buckling

- Capacity of bar 64
  Maximum compression force N_{Ed} = 334,10 kN

  - Design compression resistance

$$N_{c,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{22{,}8 * 27{,}5}{1} = 627{,}0kN \qquad 2.40.$$

  - Ultimate Limit Stress for compression

$$\frac{N_{Ed}}{N_{c,Rd}} < 1 \qquad 2.41.$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{334{,}10}{627{,}0} = 0{,}533 < 1 - cross - section\ used\ in\ 53{,}3\ \% \qquad 2.42.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.3.1.

Table 2.3.1 Calculations of Ultimate Limit Stress on compression and tension.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	Nt,Rd	Nc,Rd	NEd/Nt,Rd NEd/Nc,Rd
		kN		[m]		[cm^2]	[kN]	[kN]	[kN]
Diagonals	2	-10,39	tension	0,91	IPN 120	14,2	390,5		2,7%
	3	-11,83	tension	0,91	IPN 120	14,2	390,5		3,0%
	4	69,61	compression	1,03	IPN 120	14,2		390,5	17,8%
	5	-52,24	tension	1,06	IPN 80	7,57	208,2		25,1%
	6	76,3	compression	1,06	IPN 80	7,57		208,2	36,7%
	7	-71,73	tension	1,06	IPN 80	7,57	208,2		34,5%
	8	70,7	compression	1,06	IPN 80	7,57		208,2	34,0%
	9	-58,55	tension	1,06	IPN 80	7,57	208,2		28,1%
	10	60,02	compression	1,06	IPN 80	7,57		208,2	28,8%
	11	-47,02	tension	1,06	IPN 80	7,57	208,2		22,6%
	12	48,28	compression	1,06	IPN 80	7,57		208,2	23,2%
	13	-35,4	tension	1,06	IPN 80	7,57	208,2		17,0%
	14	36,68	compression	1,06	IPN 80	7,57		208,2	17,6%
	15	-23,79	tension	1,06	IPN 80	7,57	208,2		11,4%
	16	25,07	compression	1,06	IPN 80	7,57		208,2	12,0%
	17	-12,15	tension	1,06	IPN 80	7,57	208,2		5,8%
	18	13,45	compression	1,06	IPN 80	7,57		208,2	6,5%
	19	-0,64	tension	1,06	IPN 80	7,57	208,2		0,3%
	20	1,83	compression	1,06	IPN 80	7,57		208,2	0,9%
	21	-0,15	tension	1,06	IPN 80	7,57	208,2		0,1%
	22	1,36	compression	1,06	IPN 80	7,57		208,2	0,7%
	23	11,53	compression	1,06	IPN 80	7,57		208,2	5,5%
	24	-10,22	tension	1,06	IPN 80	7,57	208,2		4,9%
	25	23,15	compression	1,06	IPN 80	7,57		208,2	11,1%
	26	-21,85	tension	1,06	IPN 80	7,57	208,2		10,5%
	27	34,77	compression	1,06	IPN 80	7,57		208,2	16,7%
	28	-33,47	tension	1,06	IPN 80	7,57	208,2		16,1%
	29	46,37	compression	1,06	IPN 80	7,57		208,2	22,3%
	30	-45,08	tension	1,06	IPN 80	7,57	208,2		21,7%
	31	58,1	compression	1,06	IPN 80	7,57		208,2	27,9%
	32	-56,62	tension	1,06	IPN 80	7,57	208,2		27,2%
	33	68,91	compression	1,06	IPN 80	7,57		208,2	33,1%
	34	-69,73	tension	1,06	IPN 80	7,57	208,2		33,5%
	35	85,55	compression	1,06	IPN 80	7,57		208,2	41,1%
	36	-63,5	tension	1,06	IPN 80	7,57	208,2		30,5%
	37	82,47	compression	1,06	IPN 120	14,2		390,5	21,1%

Top chord	38	212,55	compression	1,08	IPN 140	18,2		500,5	42,5%
	39	129,9	compression	1,08	IPN 140	18,2		500,5	26,0%
	40	58,28	compression	1,08	IPN 140	18,2		500,5	11,6%
	41	-1,67	tension	1,08	IPN 140	18,2	500,5		0,3%
	42	-49,37	tension	1,08	IPN 140	18,2	500,5		9,9%
	43	-84,95	tension	1,08	IPN 140	18,2	500,5		17,0%
	44	-108,41	tension	1,08	IPN 140	18,2	500,5		21,7%
	45	-119,73	tension	1,08	IPN 140	18,2	500,5		23,9%
	46	-119,07	tension	1,08	IPN 140	18,2	500,5		23,8%
	47	-117,73	tension	1,08	IPN 140	18,2	500,5		23,5%
	48	-104,42	tension	1,08	IPN 140	18,2	500,5		20,9%
	49	-78,96	tension	1,08	IPN 140	18,2	500,5		15,8%
	50	-41,37	tension	1,08	IPN 140	18,2	500,5		8,3%
	51	8,33	compression	1,08	IPN 140	18,2		500,5	1,7%
	52	70,28	compression	1,08	IPN 140	18,2		500,5	14,0%
	53	143,76	compression	1,08	IPN 140	18,2		500,5	28,7%
	54	215,88	compression	1,01	IPN 140	18,2		500,5	43,1%
Bottom chord	55	-19,32	tension	0,51	IPN 160	22,8	627,0		3,1%
	56	27,3	compression	1,08	IPN 160	22,8		627,0	4,4%
	57	105,52	compression	1,08	IPN 160	22,8		627,0	16,8%
	58	173,35	compression	1,08	IPN 160	22,8		627,0	27,6%
	59	229,58	compression	1,08	IPN 160	22,8		627,0	36,6%
	60	273,64	compression	1,08	IPN 160	22,8		627,0	43,6%
	61	305,57	compression	1,08	IPN 160	22,8		627,0	48,7%
	62	325,37	compression	1,08	IPN 160	22,8		627,0	51,9%
	63	333,09	compression	1,08	IPN 160	22,8		627,0	53,1%
	64	334,10	compression	1,08	IPN 160	22,8		627,0	53,3%
	65	329,2	compression	1,08	IPN 160	22,8		627,0	52,5%
	66	312,22	compression	1,08	IPN 160	22,8		627,0	49,8%
	67	283,11	compression	1,08	IPN 160	22,8		627,0	45,2%
	68	241,87	compression	1,08	IPN 160	22,8		627,0	38,6%
	69	188,47	compression	1,08	IPN 160	22,8		627,0	30,1%
	70	123,4	compression	1,08	IPN 160	22,8		627,0	19,7%
	71	41,85	compression	1,08	IPN 160	22,8		627,0	6,7%
	72	-20,88	tension	0,50	IPN 160	22,8	627,0		3,3%

Bending moment

- Capacity of bar 3
  Maximum bending moment M_{Ed} = 14,07 kNm

  - Design bending resistance

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{63,6 * 27,5}{1 * 100} = 17,5\ kNm \quad 2.43.$$

  - Ultimate Limit Stress for bending

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{63,6 * 27,5}{1 * 100} = 17,5\ kNm \quad 2.44.$$

$$\frac{M_{Ed}}{M_{c,Rd}} < 1 \quad 2.45.$$

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{14,07}{17,5} = 0,804 < 1 - cross - section\ used\ in\ 80,4\ \% \quad 2.46.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.3.2.

Table 2.3.2 Calculations of Ultimate Limit Stress on bending moment.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mc,Rd	MEd/Mc,Rd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]	[%]
Diagonals	2	-13,73	tension	0,91	IPN 120	14,2	63,6	17,5	78,5%
	3	14,07	tension	0,91	IPN 120	14,2	63,6	17,5	80,4%
	4	-12,79	compression	1,03	IPN 120	14,2	63,6	17,5	73,1%
	5	-2,34	tension	1,06	IPN 80	7,57	22,8	6,3	37,3%
	6	2,55	compression	1,06	IPN 80	7,57	22,8	6,3	40,7%
	7	-0,52	tension	1,06	IPN 80	7,57	22,8	6,3	8,3%
	8	-1,01	compression	1,06	IPN 80	7,57	22,8	6,3	16,1%
	9	0,17	tension	1,06	IPN 80	7,57	22,8	6,3	2,7%
	10	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	18,5%
	11	0,42	tension	1,06	IPN 80	7,57	22,8	6,3	6,7%
	12	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	18,5%
	13	0,59	tension	1,06	IPN 80	7,57	22,8	6,3	9,4%
	14	1,15	compression	1,06	IPN 80	7,57	22,8	6,3	18,3%
	15	0,74	tension	1,06	IPN 80	7,57	22,8	6,3	11,8%
	16	1,12	compression	1,06	IPN 80	7,57	22,8	6,3	17,9%
	17	1,06	tension	1,06	IPN 80	7,57	22,8	6,3	16,9%
	18	-0,22	compression	1,06	IPN 80	7,57	22,8	6,3	3,5%
	19	0,96	tension	1,06	IPN 80	7,57	22,8	6,3	15,3%
	20	1,03	compression	1,06	IPN 80	7,57	22,8	6,3	16,4%
	21	1,02	tension	1,06	IPN 80	7,57	22,8	6,3	16,3%
	22	0,98	compression	1,06	IPN 80	7,57	22,8	6,3	15,6%
	23	1,06	compression	1,06	IPN 80	7,57	22,8	6,3	16,9%
	24	0,89	tension	1,06	IPN 80	7,57	22,8	6,3	14,2%
	25	1,12	compression	1,06	IPN 80	7,57	22,8	6,3	17,9%
	26	0,77	tension	1,06	IPN 80	7,57	22,8	6,3	12,3%
	27	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	18,5%
	28	0,63	tension	1,06	IPN 80	7,57	22,8	6,3	10,0%
	29	1,18	compression	1,06	IPN 80	7,57	22,8	6,3	18,8%
	30	0,46	tension	1,06	IPN 80	7,57	22,8	6,3	7,3%
	31	1,18	compression	1,06	IPN 80	7,57	22,8	6,3	18,8%
	32	0,23	tension	1,06	IPN 80	7,57	22,8	6,3	3,7%
	33	1,01	compression	1,06	IPN 80	7,57	22,8	6,3	16,1%
	34	-0,45	tension	1,06	IPN 80	7,57	22,8	6,3	7,2%
	35	2,57	compression	1,06	IPN 80	7,57	22,8	6,3	41,0%
	36	-2,35	tension	1,06	IPN 80	7,57	22,8	6,3	37,5%
	37	-12,98	compression	1,06	IPN 120	14,2	63,6	17,5	74,2%

Top chord	38	-14,24	compression	1,08	IPN 140	18,2	95,2	26,2	54,4%
	39	0,7	compression	1,08	IPN 140	18,2	95,2	26,2	2,7%
	40	0,87	compression	1,08	IPN 140	18,2	95,2	26,2	3,3%
	41	0,91	tension	1,08	IPN 140	18,2	95,2	26,2	3,5%
	42	0,98	tension	1,08	IPN 140	18,2	95,2	26,2	3,7%
	43	0,99	tension	1,08	IPN 140	18,2	95,2	26,2	3,8%
	44	0,97	tension	1,08	IPN 140	18,2	95,2	26,2	3,7%
	45	0,88	tension	1,08	IPN 140	18,2	95,2	26,2	3,4%
	46	0,82	tension	1,08	IPN 140	18,2	95,2	26,2	3,1%
	47	0,89	tension	1,08	IPN 140	18,2	95,2	26,2	3,4%
	48	0,97	tension	1,08	IPN 140	18,2	95,2	26,2	3,7%
	49	0,99	tension	1,08	IPN 140	18,2	95,2	26,2	3,8%
	50	0,96	tension	1,08	IPN 140	18,2	95,2	26,2	3,7%
	51	0,89	compression	1,08	IPN 140	18,2	95,2	26,2	3,4%
	52	0,85	compression	1,08	IPN 140	18,2	95,2	26,2	3,2%
	53	0,7	compression	1,08	IPN 140	18,2	95,2	26,2	2,7%
	54	-14,56	compression	1,01	IPN 140	18,2	95,2	26,2	55,6%
Bottom chord	55	4,43	tension	0,51	IPN 160	22,8	136,0	37,4	11,8%
	56	-0,27	compression	1,08	IPN 160	22,8	136,0	37,4	0,7%
	57	-1,01	compression	1,08	IPN 160	22,8	136,0	37,4	2,7%
	58	0,82	compression	1,08	IPN 160	22,8	136,0	37,4	2,2%
	59	0,94	compression	1,08	IPN 160	22,8	136,0	37,4	2,5%
	60	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	2,6%
	61	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	2,6%
	62	0,95	compression	1,08	IPN 160	22,8	136,0	37,4	2,5%
	63	0,85	compression	1,08	IPN 160	22,8	136,0	37,4	2,3%
	64	0,87	compression	1,08	IPN 160	22,8	136,0	37,4	2,3%
	65	0,94	compression	1,08	IPN 160	22,8	136,0	37,4	2,5%
	66	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	2,6%
	67	0,99	compression	1,08	IPN 160	22,8	136,0	37,4	2,6%
	68	0,96	compression	1,08	IPN 160	22,8	136,0	37,4	2,6%
	69	0,85	compression	1,08	IPN 160	22,8	136,0	37,4	2,3%
	70	-0,89	compression	1,08	IPN 160	22,8	136,0	37,4	2,4%
	71	-0,39	compression	1,08	IPN 160	22,8	136,0	37,4	1,0%
	72	4,36	tension	0,50	IPN 160	22,8	136,0	37,4	11,7%

Buckling

- Capacity of bar 64
  Maximum compression force N_{Ed} = 334,10 kN

-Buckling curve

$For\ every\ channel\ section \rightarrow \boldsymbol{buckling\ curve}$ „c"

- imperfection factor α

For buckling curve„c" imperfection parameter equals $\alpha = 0{,}49$

- Buckling length

$$L_{cr} = \mu * L = 1 * 1{,}08 = 1{,}08\ m \tag{2.47.}$$

- Slenderness $\bar{\lambda}$

$$\lambda_1 = 93.9 * \varepsilon = 93.9 * 0{,}92 = 86{,}39 \tag{2.48.}$$

$$\bar{\lambda} = \frac{L_{c,r}}{i_z} * \frac{1}{\lambda_1} = \frac{1{,}08 * 100}{1{,}55} * \frac{1}{86{,}93} = 0{,}807 \tag{2.49.}$$

- Reduction factor χ

$$\phi = 0{,}5 * \left[1 + \alpha * \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0{,}5 * [1 + 0{,}49 * (0{,}807 - 0{,}2) + 0{,}807^2] = 0{,}974 \tag{2.50.}$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0{,}974 + \sqrt{0{,}974^2 - 0{,}807^2}} = 0{,}658 \tag{2.51.}$$

- Design buckling resistance

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} = \frac{0{,}658 * 22{,}8 * 27{,}5}{1} = 412{,}6\ kN \tag{2.52.}$$

- Ultimate Limit Stress for Buckling

$$\frac{N_{Ed}}{N_{b,Rd}} < 1 \tag{2.53.}$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{334{,}10}{412{,}6} = 0{,}810 < 1 - cross - section\ used\ in\ 81{,}0\ \% \tag{2.54.}$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.3.3.

Table 2.3.3 Calculations of Ultimate Limit Stress on buckling.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	i	Normalized slenderness $\bar{\lambda}$	Parameter ϕ	Reduction factor χ	$N_{b,RdNb,Rd}$	$N_{Ed}/N_{b,RdNEd}/N_{b,Rd}$
		kN		[m]		[cm^2]	[cm]					
Diagonals	2	-10,39	tension	0,91	IPN 120	14,2	1,23					
	3	-11,83	tension	0,91	IPN 120	14,2	1,23					
	4	69,61	compression	1,03	IPN 120	14,2	1,23	0,969	1,158	0,558	217,9	31,9%
	5	-52,24	tension	1,06	IPN 80	7,57	0,911					
	6	76,3	compression	1,06	IPN 100	10,6	1,07	1,147	1,389	0,460	134,1	56,9%
	7	-71,73	tension	1,06	IPN 80	7,57	0,911					
	8	70,7	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	91,9%
	9	-58,55	tension	1,06	IPN 80	7,57	0,911					
	10	60,02	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	78,0%
	11	-47,02	tension	1,06	IPN 80	7,57	0,911					
	12	48,28	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	62,7%
	13	-35,4	tension	1,06	IPN 80	7,57	0,911					
	14	36,68	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	47,7%
	15	-23,79	tension	1,06	IPN 80	7,57	0,911					
	16	25,07	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	32,6%
	17	-12,15	tension	1,06	IPN 80	7,57	0,911					
	18	13,45	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	17,5%
	19	-0,64	tension	1,06	IPN 80	7,57	0,911					
	20	1,83	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	2,4%
	21	-0,15	tension	1,06	IPN 80	7,57	0,911					
	22	1,36	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	1,8%
	23	11,53	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	15,0%
	24	-10,22	tension	1,06	IPN 80	7,57	0,911					
	25	23,15	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	30,1%
	26	-21,85	tension	1,06	IPN 80	7,57	0,911					
	27	34,77	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	45,2%
	28	-33,47	tension	1,06	IPN 80	7,57	0,911					
	29	46,37	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	60,3%
	30	-45,08	tension	1,06	IPN 80	7,57	0,911					
	31	58,1	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	75,5%
	32	-56,62	tension	1,06	IPN 80	7,57	0,911					
	33	68,91	compression	1,06	IPN 80	7,57	0,911	1,347	1,688	0,370	76,9	89,6%
	34	-69,73	tension	1,06	IPN 80	7,57	0,911					
	35	85,55	compression	1,06	IPN 100	10,6	1,07	1,147	1,389	0,460	134,1	63,8%
	36	-63,5	tension	1,06	IPN 80	7,57	0,911					
	37	82,47	compression	1,06	IPN 120	14,2	1,23	0,998	1,193	0,541	211,4	39,0%

Top chord	38	212,55	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	70,8%
	39	129,9	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	43,2%
	40	58,28	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	19,4%
	41	-1,67	tension	1,08	IPN 140	18,2	1,39					
	42	-49,37	tension	1,08	IPN 140	18,2	1,39					
	43	-84,95	tension	1,08	IPN 140	18,2	1,39					
	44	-108,41	tension	1,08	IPN 140	18,2	1,39					
	45	-119,73	tension	1,08	IPN 140	18,2	1,39					
	46	-119,07	tension	1,08	IPN 140	18,2	1,39					
	47	-117,73	tension	1,08	IPN 140	18,2	1,39					
	48	-104,42	tension	1,08	IPN 140	18,2	1,39					
	49	-78,96	tension	1,08	IPN 140	18,2	1,39					
	50	-41,37	tension	1,08	IPN 140	18,2	1,39					
	51	8,33	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	2,8%
	52	70,28	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	23,4%
	53	143,76	compression	1,08	IPN 140	18,2	1,39	0,899	1,076	0,600	300,4	47,9%
	54	215,88	compression	1,01	IPN 140	18,2	1,39	0,841	1,011	0,636	318,5	67,8%
Bottom chord	55	-19,32	tension	0,51	IPN 160	22,8	1,55					
	56	27,3	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	6,6%
	57	105,52	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	25,6%
	58	173,35	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	42,0%
	59	229,58	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	55,6%
	60	273,64	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	66,3%
	61	305,57	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	74,1%
	62	325,37	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	78,9%
	63	333,09	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	80,7%
	64	334,1	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	81,0%
	65	329,2	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	79,8%
	66	312,22	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	75,7%
	67	283,11	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	68,6%
	68	241,87	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	58,6%
	69	188,47	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	45,7%
	70	123,4	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	29,9%
	71	41,85	compression	1,08	IPN 160	22,8	1,55	0,807	0,974	0,658	412,6	10,1%
	72	-20,88	tension	0,50	IPN 160	22,8	1,55					

Bending moment and axial force

- Capacity of bar 6
  Maximum bending moment M_{Ed} = 2,55 kNm

  - Design bending resistance

$$N_{Ed} = 76,3\ kN \qquad 2.55.$$

$$N_{pl,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{7,57 * 27,5}{1} = 208,18\ kN \qquad 2.56.$$

$$M_{pl,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{22,8 * 27,5}{1 * 100} = 6,3\ kNm \qquad 2.57.$$

$$M_{N,Rd} = M_{pl,Rd} * \left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] = 6,3 * \ [1 - \left(\frac{76,3}{208,18}\right)^2 = 5,4\ kN \qquad 2.58.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{N,Rd}} < 1 \qquad 2.59.$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{2,55}{5,4} = 0,470 < 1 - cross - section\ used\ in\ 47,0\ \% \qquad 2.60.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.3.4.

Table 2.3.4 Calculations of Ultimate Limit Stress on bending moment and axial force.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mpl,Rd	NEd/Npl,Rd	M N,Rd	MEd/MNRd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]		[kNm]	[%]
Diagonals	2	-13,73	tension	0,91	IPN 120	14,2	63,6	17,5	0,03	17,5	78,6%
	3	14,07	tension	0,91	IPN 120	14,2	63,6	17,5	0,03	17,5	80,5%
	4	-12,79	compression	1,03	IPN 120	14,2	63,6	17,5	0,18	16,9	75,5%
	5	-2,34	tension	1,06	IPN 80	7,57	22,8	6,3	0,25	5,9	39,8%
	6	2,55	compression	1,06	IPN 80	7,57	22,8	6,3	0,37	5,4	47,0%
	7	-0,52	tension	1,06	IPN 80	7,57	22,8	6,3	0,34	5,5	9,4%
	8	-1,01	compression	1,06	IPN 80	7,57	22,8	6,3	0,34	5,5	18,2%
	9	0,17	tension	1,06	IPN 80	7,57	22,8	6,3	0,28	5,8	2,9%
	10	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	0,29	5,7	20,2%
	11	0,42	tension	1,06	IPN 80	7,57	22,8	6,3	0,23	6,0	7,1%
	12	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	0,23	5,9	19,6%
	13	0,59	tension	1,06	IPN 80	7,57	22,8	6,3	0,17	6,1	9,7%
	14	1,15	compression	1,06	IPN 80	7,57	22,8	6,3	0,18	6,1	18,9%
	15	0,74	tension	1,06	IPN 80	7,57	22,8	6,3	0,11	6,2	12,0%
	16	1,12	compression	1,06	IPN 80	7,57	22,8	6,3	0,12	6,2	18,1%
	17	1,06	tension	1,06	IPN 80	7,57	22,8	6,3	0,06	6,2	17,0%
	18	-0,22	compression	1,06	IPN 80	7,57	22,8	6,3	0,06	6,2	3,5%
	19	0,96	tension	1,06	IPN 80	7,57	22,8	6,3	0,00	6,3	15,3%
	20	1,03	compression	1,06	IPN 80	7,57	22,8	6,3	0,01	6,3	16,4%
	21	1,02	tension	1,06	IPN 80	7,57	22,8	6,3	0,00	6,3	16,3%
	22	0,98	compression	1,06	IPN 80	7,57	22,8	6,3	0,01	6,3	15,6%
	23	1,06	compression	1,06	IPN 80	7,57	22,8	6,3	0,06	6,3	17,0%
	24	0,89	tension	1,06	IPN 80	7,57	22,8	6,3	0,05	6,3	14,2%
	25	1,12	compression	1,06	IPN 80	7,57	22,8	6,3	0,11	6,2	18,1%
	26	0,77	tension	1,06	IPN 80	7,57	22,8	6,3	0,10	6,2	12,4%
	27	1,16	compression	1,06	IPN 80	7,57	22,8	6,3	0,17	6,1	19,0%
	28	0,63	tension	1,06	IPN 80	7,57	22,8	6,3	0,16	6,1	10,3%
	29	1,18	compression	1,06	IPN 80	7,57	22,8	6,3	0,22	6,0	19,8%
	30	0,46	tension	1,06	IPN 80	7,57	22,8	6,3	0,22	6,0	7,7%
	31	1,18	compression	1,06	IPN 80	7,57	22,8	6,3	0,28	5,8	20,4%
	32	0,23	tension	1,06	IPN 80	7,57	22,8	6,3	0,27	5,8	4,0%
	33	1,01	compression	1,06	IPN 80	7,57	22,8	6,3	0,33	5,6	18,1%
	34	-0,45	tension	1,06	IPN 80	7,57	22,8	6,3	0,33	5,6	8,1%
	35	2,57	compression	1,06	IPN 80	7,57	22,8	6,3	0,41	5,2	49,3%
	36	-2,35	tension	1,06	IPN 80	7,57	22,8	6,3	0,31	5,7	41,3%
	37	-12,98	compression	1,06	IPN 120	14,2	63,6	17,5	0,21	16,7	77,7%

Top chord	38	-14,24	compression	1,08	IPN 140	18,2	95,2	26,2	0,42	21,5	66,4%
	39	0,7	compression	1,08	IPN 140	18,2	95,2	26,2	0,26	24,4	2,9%
	40	0,87	compression	1,08	IPN 140	18,2	95,2	26,2	0,12	25,8	3,4%
	41	0,91	tension	1,08	IPN 140	18,2	95,2	26,2	0,00	26,2	3,5%
	42	0,98	tension	1,08	IPN 140	18,2	95,2	26,2	0,10	25,9	3,8%
	43	0,99	tension	1,08	IPN 140	18,2	95,2	26,2	0,17	25,4	3,9%
	44	0,97	tension	1,08	IPN 140	18,2	95,2	26,2	0,22	25,0	3,9%
	45	0,88	tension	1,08	IPN 140	18,2	95,2	26,2	0,24	24,7	3,6%
	46	0,82	tension	1,08	IPN 140	18,2	95,2	26,2	0,24	24,7	3,3%
	47	0,89	tension	1,08	IPN 140	18,2	95,2	26,2	0,24	24,7	3,6%
	48	0,97	tension	1,08	IPN 140	18,2	95,2	26,2	0,21	25,0	3,9%
	49	0,99	tension	1,08	IPN 140	18,2	95,2	26,2	0,16	25,5	3,9%
	50	0,96	tension	1,08	IPN 140	18,2	95,2	26,2	0,08	26,0	3,7%
	51	0,89	compression	1,08	IPN 140	18,2	95,2	26,2	0,02	26,2	3,4%
	52	0,85	compression	1,08	IPN 140	18,2	95,2	26,2	0,14	25,7	3,3%
	53	0,7	compression	1,08	IPN 140	18,2	95,2	26,2	0,29	24,0	2,9%
	54	-14,56	compression	1,01	IPN 140	18,2	95,2	26,2	0,43	21,3	68,3%
Bottom chord	55	4,43	tension	0,51	IPN 160	22,8	136,0	37,4	0,03	37,4	11,9%
	56	-0,27	compression	1,08	IPN 160	22,8	136,0	37,4	0,04	37,3	0,7%
	57	-1,01	compression	1,08	IPN 160	22,8	136,0	37,4	0,17	36,3	2,8%
	58	0,82	compression	1,08	IPN 160	22,8	136,0	37,4	0,28	34,5	2,4%
	59	0,94	compression	1,08	IPN 160	22,8	136,0	37,4	0,37	32,4	2,9%
	60	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	0,44	30,3	3,2%
	61	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	0,49	28,5	3,4%
	62	0,95	compression	1,08	IPN 160	22,8	136,0	37,4	0,52	27,3	3,5%
	63	0,85	compression	1,08	IPN 160	22,8	136,0	37,4	0,53	26,8	3,2%
	64	0,87	compression	1,08	IPN 160	22,8	136,0	37,4	0,53	26,8	3,2%
	65	0,94	compression	1,08	IPN 160	22,8	136,0	37,4	0,53	27,1	3,5%
	66	0,98	compression	1,08	IPN 160	22,8	136,0	37,4	0,50	28,1	3,5%
	67	0,99	compression	1,08	IPN 160	22,8	136,0	37,4	0,45	29,8	3,3%
	68	0,96	compression	1,08	IPN 160	22,8	136,0	37,4	0,39	31,8	3,0%
	69	0,85	compression	1,08	IPN 160	22,8	136,0	37,4	0,30	34,0	2,5%
	70	-0,89	compression	1,08	IPN 160	22,8	136,0	37,4	0,20	36,0	2,5%
	71	-0,39	compression	1,08	IPN 160	22,8	136,0	37,4	0,07	37,2	1,0%
	72	4,36	tension	0,50	IPN 160	22,8	136,0	37,4	0,03	37,4	11,7%

2.4 CALCULATIONS OF A STEEL TRUSS WITH ORIGINAL STRUCTURE TOPOLOGY USING RHS CROSS-SECTIONS.

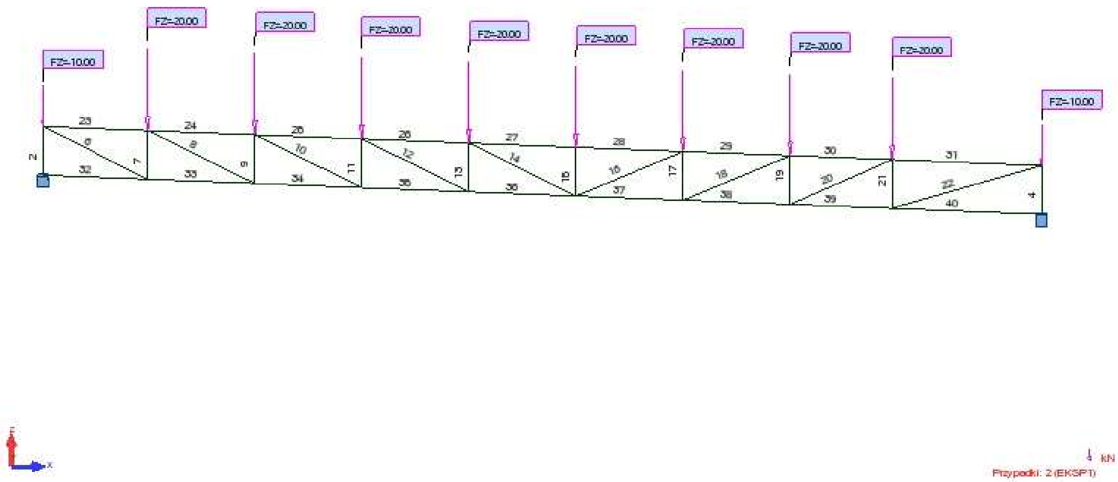
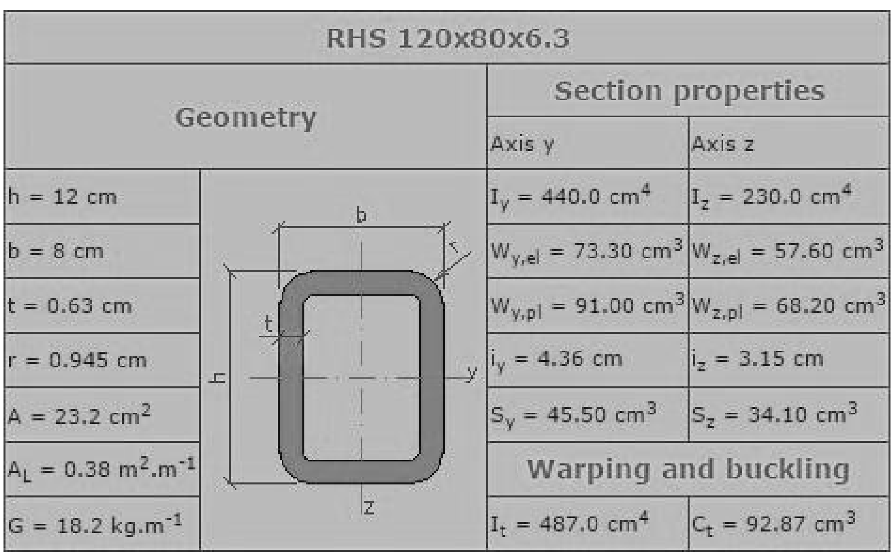


Figure 2.4.1 Truss with original shape and RHS cross-sections.



RHS 120x80x6.3			
Geometry		Section properties	
		Axis y	Axis z
h = 12 cm		I_y = 440.0 cm^4	I_z = 230.0 cm^4
b = 8 cm		$W_{y,el}$ = 73.30 cm^3	$W_{z,el}$ = 57.60 cm^3
t = 0.63 cm		$W_{y,pl}$ = 91.00 cm^3	$W_{z,pl}$ = 68.20 cm^3
r = 0.945 cm		i_y = 4.36 cm	i_z = 3.15 cm
A = 23.2 cm^2		S_y = 45.50 cm^3	S_z = 34.10 cm^3
A_L = 0.38 $m^2.m^{-1}$		Warping and buckling	
G = 18.2 $kg.m^{-1}$		I_t = 487.0 cm^4	C_t = 92.87 cm^3

Figure 2.4.2 Top chord cross-section properties.

Compression - tension without considering the effect of buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN

  - Design compression resistance

$$N_{c,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{23,2 * 27,5}{1} = 638,0kN \tag{2.61.}$$

  - Ultimate Limit Stress for compression

$$\frac{N_{Ed}}{N_{c,Rd}} < 1 \tag{2.62.}$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{338,40}{638,0} = 0,530 < 1 - cross - section\ used\ in\ 53,0\ \% \tag{2.63.}$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.4.1.

Table 2.4.1 Calculations of Ultimate Limit Stress on compression and tension.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	Nt,Rd	Nc,Rd	NEd/Nt,Rd NEd/Nc,Rd
		kN		[m]		[cm^2]	[kN]	[kN]	[kN]
Diagonals	2	64,66	compression	0,91	RHS 200x100x6,3	35,8		984,5	6,6%
	4	65,25	compression	0,91	RHS 200x100x6,3	35,8		984,5	6,6%
	6	129,02	tension	2,16	RHS 80x40x6,3	13,1	360,3		35,8%
	7	82,69	compression	0,91	RHS 80x40x6,3	13,1		360,3	23,0%
	8	137	tension	2,19	RHS 80x40x6,3	13,1	360,3		38,0%
	9	53,72	tension	0,91	RHS 80x40x6,3	13,1	360,3		14,9%
	10	95,52	tension	2,19	RHS 80x40x6,3	13,1	360,3		26,5%
	11	39,92	compression	0,91	RHS 80x40x6,3	13,1		360,3	11,1%
	12	46,59	tension	2,19	RHS 80x40x6,3	13,1	360,3		12,9%
	13	20,24	compression	0,91	RHS 80x40x6,3	13,1		360,3	5,6%
	14	5,19	tension	2,19	RHS 80x40x6,3	13,1	360,3		1,4%
	15	16,48	compression	0,91	RHS 80x40x6,3	13,1		360,3	4,6%
	16	28,92	tension	2,13	RHS 80x40x6,3	13,1	360,3		8,0%
	17	32,63	compression	0,91	RHS 80x40x6,3	13,1		360,3	9,1%
	18	73,9	tension	2,13	RHS 80x40x6,3	13,1	360,3		20,5%
	19	50,2	compression	0,91	RHS 80x40x6,3	13,1		360,3	13,9%
	20	123,65	tension	2,04	RHS 80x40x6,3	13,1	360,3		34,3%
	21	74,66	compression	0,91	RHS 80x40x6,3	13,1		360,3	20,7%
	22	171,47	tension	2,85	RHS 80x40x6,3	13,1	360,3		47,6%
Top chord	23	57,96	compression	1,92	RHS 120x80x6,3	23,2		638,0	9,1%
	24	193,26	compression	1,96	RHS 120x80x6,3	23,2		638,0	30,3%
	25	284,76	compression	1,96	RHS 120x80x6,3	23,2		638,0	44,6%
	26	331,02	compression	1,96	RHS 120x80x6,3	23,2		638,0	51,9%
	27	338,4	compression	1,96	RHS 120x80x6,3	23,2		638,0	53,0%
	28	337,91	compression	1,96	RHS 120x80x6,3	23,2		638,0	53,0%
	29	307,95	compression	1,96	RHS 120x80x6,3	23,2		638,0	48,3%
	30	235,51	compression	1,86	RHS 120x80x6,3	23,2		638,0	36,9%
	31	114,87	compression	2,74	RHS 120x80x6,3	23,2		638,0	18,0%
Bottom chord	32	210,84	compression	1,92	RHS 200x100x6,3	35,8		984,5	21,4%
	33	82,56	compression	1,96	RHS 200x100x6,3	35,8		984,5	8,4%
	34	45,67	tension	1,96	RHS 200x100x6,3	35,8	984,5		4,6%
	35	135,83	tension	1,96	RHS 200x100x6,3	35,8	984,5		13,8%
	36	180,11	tension	1,96	RHS 200x100x6,3	35,8	984,5		18,3%
	37	157,41	tension	1,96	RHS 200x100x6,3	35,8	984,5		16,0%
	38	85,84	tension	1,96	RHS 200x100x6,3	35,8	984,5		8,7%
	39	31,27	compression	1,86	RHS 200x100x6,3	35,8		984,5	3,2%
	40	204,96	compression	2,74	RHS 200x100x6,3	35,8		984,5	20,8%

Bending moment

- Capacity of bar 2

  Maximum bending moment M_{Ed} = 53,03 kNm

  - Design bending resistance

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{228 * 27{,}5}{1 * 100} = 62{,}7\ kNm \quad (2.64.)$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{c,Rd}} < 1 \quad (2.65.)$$

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{53{,}03}{62{,}7} = 0{,}846 < 1 - cross - section\ used\ in\ 84{,}6\ \% \quad (2.66.)$$

  Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.4.2.

Table 2.4.2 Calculations of Ultimate Limit Stress on bending moment.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mc,Rd	MEd/Mc,Rd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	RHS 200x100x6,3	35,8	228,0	62,7	84,6%
	4	51,07	compression	0,91	RHS 200x100x6,3	35,8	228,0	62,7	81,5%
	6	-4,79	tension	2,16	RHS 80x40x6,3	13,1	31,1	8,6	56,0%
	7	6,45	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	75,4%
	8	0,24	tension	2,19	RHS 80x40x6,3	13,1	31,1	8,6	2,8%
	9	-2,67	tension	0,91	RHS 80x40x6,3	13,1	31,1	8,6	31,2%
	10	1,04	tension	2,19	RHS 80x40x6,3	13,1	31,1	8,6	12,2%
	11	2,12	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	24,8%
	12	0,32	tension	2,19	RHS 80x40x6,3	13,1	31,1	8,6	3,7%
	13	-1,22	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	14,3%
	14	0,33	tension	2,19	RHS 80x40x6,3	13,1	31,1	8,6	3,9%
	15	-0,3	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	3,5%
	16	0,52	tension	2,13	RHS 80x40x6,3	13,1	31,1	8,6	6,1%
	17	1,55	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	18,1%
	18	0,92	tension	2,13	RHS 80x40x6,3	13,1	31,1	8,6	10,8%
	19	-1,99	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	23,3%
	20	1,04	tension	2,04	RHS 80x40x6,3	13,1	31,1	8,6	12,2%
	21	3,73	compression	0,91	RHS 80x40x6,3	13,1	31,1	8,6	43,6%
	22	-3,83	tension	2,85	RHS 80x40x6,3	13,1	31,1	8,6	44,8%
Top chord	23	-2,63	compression	1,92	RHS 120x80x6,3	23,2	91,0	25,0	10,5%
	24	7,82	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	31,2%
	25	8,15	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	32,6%
	26	11,35	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	45,4%
	27	11,89	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	47,5%
	28	12,17	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	48,6%
	29	9,31	compression	1,96	RHS 120x80x6,3	23,2	91,0	25,0	37,2%
	30	7,62	compression	1,86	RHS 120x80x6,3	23,2	91,0	25,0	30,4%
	31	-6,36	compression	2,74	RHS 120x80x6,3	23,2	91,0	25,0	25,4%
Bottom chord	32	-45,88	compression	1,92	RHS 200x100x6,3	35,8	228,0	62,7	73,2%
	33	3,31	compression	1,96	RHS 200x100x6,3	35,8	228,0	62,7	5,3%
	34	5,46	tension	1,96	RHS 200x100x6,3	35,8	228,0	62,7	8,7%
	35	6,67	tension	1,96	RHS 200x100x6,3	35,8	228,0	62,7	10,6%
	36	6,9	tension	1,96	RHS 200x100x6,3	35,8	228,0	62,7	11,0%
	37	7,01	tension	1,96	RHS 200x100x6,3	35,8	228,0	62,7	11,2%
	38	5,8	tension	1,96	RHS 200x100x6,3	35,8	228,0	62,7	9,3%
	39	7,12	compression	1,86	RHS 200x100x6,3	35,8	228,0	62,7	11,4%
	40	-36,96	compression	2,74	RHS 200x100x6,3	35,8	228,0	62,7	58,9%

Buckling

- Capacity of bar 27
  Maximum compression force N_{Ed} = 338,40 kN
  -Buckling curve

$For\ every\ cha \qquad section \rightarrow \boldsymbol{buckling\ curve}$ „c"

- imperfection factor α

For buckling curve„c" imperfection parameter equals $\alpha = 0{,}49$

- Buckling length

$$L_{cr} = \mu * L = 1 * 1{,}96 = 1{,}96\ m \qquad 2.67.$$

- Slenderness $\bar{\lambda}$

$$\lambda_1 = 93.9 * \varepsilon = 93.9 * 0{,}92 = 86{,}39 \qquad 2.68.$$

$$\bar{\lambda} = \frac{L_{c,r}}{i_z} * \frac{1}{\lambda_1} = \frac{1{,}96 * 100}{3{,}15} * \frac{1}{86{,}93} = 0{,}720 \qquad 2.69.$$

- Reduction factor χ

$$\phi = 0{,}5 * \left[1 + \alpha * \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0{,}5 * [1 + 0{,}49 * (0{,}720 - 0{,}2) + 0{,}720^2] = 0{,}887 \qquad 2.70.$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0{,}887 + \sqrt{0{,}887^2 - 0{,}720^2}} = 0{,}712 \qquad 2.71.$$

- Design buckling resistance

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} = \frac{0{,}712 * 23{,}2 * 27{,}5}{1} = 454{,}3\ kN \qquad 2.72.$$

- Ultimate Limit Stress for Buckling

$$\frac{N_{Ed}}{N_{b,Rd}} < 1 \qquad 2.73.$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{338{,}4}{454{,}3} = 0{,}745 < 1 - cross - section\ used\ in\ 74{,}5\ \% \qquad 2.74.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.4.3.

Table 2.4.3 Calculations of Ultimate Limit Stress on buckling.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	i	Normalized slenderness $\bar{\lambda}$	Parameter Φ	Reduction factor χ	$N_{b,RdNb,Rd}$	$N_{Ed}/N_{b,RdNEd}$
		kN		[m]		[cm^2]	[cm]					
Diagonals	2	64,66	compression	0,91	RHS 200x100x6,3	35,8	4,14	0,254	0,546	0,972	957,3	6,8%
	4	65,25	compression	0,91	RHS 200x100x6,3	35,8	4,14	0,254	0,546	0,972	957,3	6,8%
	6	129,02	tension	2,16	RHS 80x40x6,3	13,1	1,49					
	7	82,69	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	31,9%
	8	137	tension	2,19	RHS 80x40x6,3	13,1	1,49					
	9	53,72	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	20,7%
	10	95,52	tension	2,19	RHS 80x40x6,3	13,1	1,49					
	11	39,92	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	15,4%
	12	46,59	tension	2,19	RHS 80x40x6,3	13,1	1,49					
	13	20,24	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	7,8%
	14	5,19	tension	2,19	RHS 80x40x6,3	13,1	1,49					
	15	16,48	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	6,4%
	16	28,92	tension	2,13	RHS 80x40x6,3	13,1	1,49					
	17	32,63	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	12,6%
	18	73,9	tension	2,13	RHS 80x40x6,3	13,1	1,49					
	19	50,2	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	19,3%
	20	123,65	tension	2,04	RHS 80x40x6,3	13,1	1,49					
	21	74,66	compression	0,91	RHS 80x40x6,3	13,1	1,49	0,707	0,874	0,720	259,5	28,8%
	22	171,47	tension	2,85	RHS 80x40x6,3	13,1	1,49					
Top chord	23	57,96	compression	1,92	RHS 120x80x6,3	23,2	3,15	0,706	0,873	0,721	460,2	12,6%
	24	193,26	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	42,5%
	25	284,76	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	62,7%
	26	331,02	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	72,9%
	27	338,4	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	74,5%
	28	337,91	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	74,4%
	29	307,95	compression	1,96	RHS 120x80x6,3	23,2	3,15	0,720	0,887	0,712	454,3	67,8%
	30	235,51	compression	1,86	RHS 120x80x6,3	23,2	3,15	0,684	0,852	0,735	468,9	50,2%
	31	114,87	compression	2,74	RHS 120x80x6,3	23,2	3,15	1,007	1,205	0,536	341,9	33,6%
Bottom chord	32	210,84	compression	1,92	RHS 200x100x6,3	35,8	4,14	0,537	0,727	0,822	809,4	26,0%
	33	82,56	compression	1,96	RHS 200x100x6,3	35,8	4,14	0,548	0,735	0,816	803,1	10,3%
	34	45,67	tension	1,96	RHS 200x100x6,3	35,8	4,14					
	35	135,83	tension	1,96	RHS 200x100x6,3	35,8	4,14					
	36	180,11	tension	1,96	RHS 200x100x6,3	35,8	4,14					
	37	157,41	tension	1,96	RHS 200x100x6,3	35,8	4,14					
	38	85,84	tension	1,96	RHS 200x100x6,3	35,8	4,14					
	39	31,27	compression	1,86	RHS 200x100x6,3	35,8	4,14	0,520	0,714	0,832	818,8	3,8%
	40	204,96	compression	2,74	RHS 200x100x6,3	35,8	4,14	0,766	0,932	0,683	672,8	30,5%

Bending moment and axial force

- Capacity of bar 27
  Maximum bending moment M_{Ed} = 11,89 kNm

  - Design bending resistance

$$N_{Ed} = 338{,}4\ kN \quad 2.75.$$

$$N_{pl,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{23{,}2 * 27{,}5}{1} = 638\ kN \quad 2.76.$$

$$M_{pl,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{91{,}0 * 27{,}5}{1 * 100} = 25\ kNm \quad 2.77.$$

$$M_{N,Rd} = M_{pl,Rd} * \left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] = 25 * \ [1 - \left(\frac{338{,}4}{638}\right)^2] = 18\ kN \quad 2.78.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{N,Rd}} < 1 \quad 2.79.$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{11{,}89}{18} = 0{,}661 < 1 - cross - section\ used\ in\ 66{,}1\ \% \quad 2.80.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.4.4.

Table 2.4.4 Calculations of Ultimate Limit Stress on bending moment and axial force.

	Number	MEd	Compression / Tension	Length	Type of profile		Area of cross-section	Wpl	Mpl,Rd	NEd/Npl,Rd	M N,Rd	MEd/MNRd
		[kNm]		[m]			[cm^2]	[cm3]	[kNm]		[kNm]	[%]
Diagonals	2	-53,03	compression	0,91	RHS	200x100x6,3	35,8	228,0	62,7	0,07	62,4	84,9%
	4	51,07	compression	0,91	RHS	200x100x6,3	35,8	228,0	62,7	0,07	62,4	81,8%
	6	-4,79	tension	2,16	RHS	80x40x6,3	13,1	31,1	8,6	0,36	7,5	64,2%
	7	6,45	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,23	8,1	79,6%
	8	0,24	tension	2,19	RHS	80x40x6,3	13,1	31,1	8,6	0,38	7,3	3,3%
	9	-2,67	tension	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,15	8,4	31,9%
	10	1,04	tension	2,19	RHS	80x40x6,3	13,1	31,1	8,6	0,27	8,0	13,1%
	11	2,12	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,11	8,4	25,1%
	12	0,32	tension	2,19	RHS	80x40x6,3	13,1	31,1	8,6	0,13	8,4	3,8%
	13	-1,22	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,06	8,5	14,3%
	14	0,33	tension	2,19	RHS	80x40x6,3	13,1	31,1	8,6	0,01	8,6	3,9%
	15	-0,3	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,05	8,5	3,5%
	16	0,52	tension	2,13	RHS	80x40x6,3	13,1	31,1	8,6	0,08	8,5	6,1%
	17	1,55	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,09	8,5	18,3%
	18	0,92	tension	2,13	RHS	80x40x6,3	13,1	31,1	8,6	0,21	8,2	11,2%
	19	-1,99	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,14	8,4	23,7%
	20	1,04	tension	2,04	RHS	80x40x6,3	13,1	31,1	8,6	0,34	7,5	13,8%
	21	3,73	compression	0,91	RHS	80x40x6,3	13,1	31,1	8,6	0,21	8,2	45,6%
	22	-3,83	tension	2,85	RHS	80x40x6,3	13,1	31,1	8,6	0,48	6,6	57,9%
Top chord	23	-2,63	compression	1,92	RHS	120x80x6,3	23,2	91,0	25,0	0,09	24,8	10,6%
	24	7,82	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,30	22,7	34,4%
	25	8,15	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,45	20,0	40,7%
	26	11,35	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,52	18,3	62,1%
	27	11,89	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,53	18,0	66,1%
	28	12,17	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,53	18,0	67,6%
	29	9,31	compression	1,96	RHS	120x80x6,3	23,2	91,0	25,0	0,48	19,2	48,5%
	30	7,62	compression	1,86	RHS	120x80x6,3	23,2	91,0	25,0	0,37	21,6	35,3%
	31	-6,36	compression	2,74	RHS	120x80x6,3	23,2	91,0	25,0	0,18	24,2	26,3%
Bottom chord	32	-45,88	compression	1,92	RHS	200x100x6,3	35,8	228,0	62,7	0,21	59,8	76,7%
	33	3,31	compression	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,08	62,3	5,3%
	34	5,46	tension	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,05	62,6	8,7%
	35	6,67	tension	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,14	61,5	10,8%
	36	6,9	tension	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,18	60,6	11,4%
	37	7,01	tension	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,16	61,1	11,5%
	38	5,8	tension	1,96	RHS	200x100x6,3	35,8	228,0	62,7	0,09	62,2	9,3%
	39	7,12	compression	1,86	RHS	200x100x6,3	35,8	228,0	62,7	0,03	62,6	11,4%
	40	-36,96	compression	2,74	RHS	200x100x6,3	35,8	228,0	62,7	0,21	60,0	61,6%

2.5 CALCULATIONS OF A STEEL TRUSS WITH CHANGED STRUCTURE TOPOLOGY USING IPN CROSS-SECTIONS.

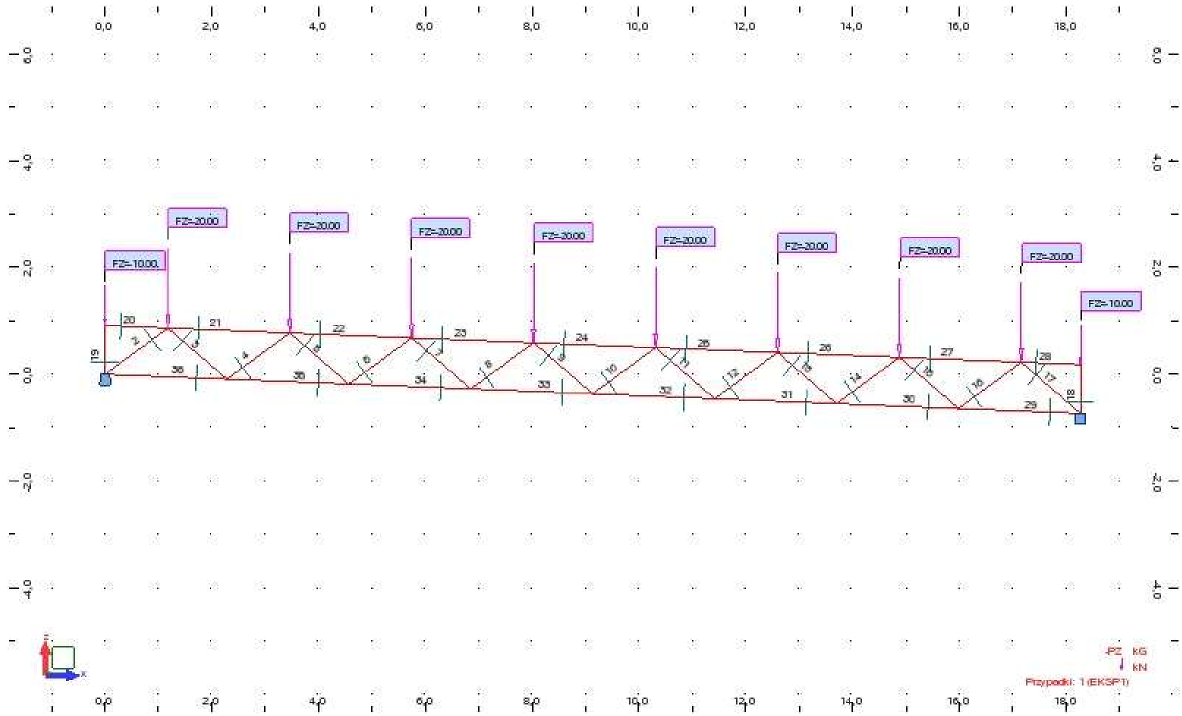


Figure 2.5.1 Truss with changes shape and IPN cross-sections.

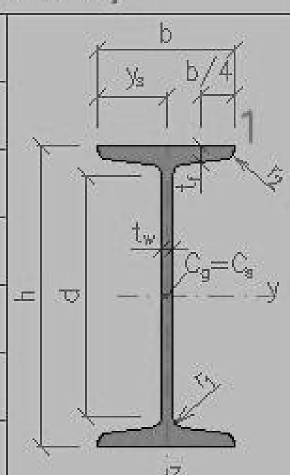
IPN 220			
Geometry		Section properties	
h = 22 cm		Axis y	Axis z
b = 9.8 cm		I_y = 3050 cm^4	I_z = 162.0 cm^4
t_f = 1.22 cm		W_{y1} = 278.0 cm^3	W_{z1} = 33.10 cm^3
t_w = 0.81 cm		$W_{y,pl}$ = 322.0 cm^3	$W_{z,pl}$ = 54.60 cm^3
r_1 = 0.81 cm		i_y = 8.79 cm	i_z = 2.03 cm
r_2 = 0.49 cm		S_y = 161.0 cm^3	S_z = 27.30 cm^3
y_s = 4.9 cm		Warping and buckling	
d = 17.58 cm	G = 31 $kg.m^{-1}$	I_w = 1.69E+4 cm^6	I_t = 18.70 cm^4
A_L = 0.77 $m^2.m^{-1}$	A = 39.5 cm^2	i_w = 2.29 cm	i_{pc} = 9.02 cm

Figure 2.5.2 Top chord cross-section properties.

Compression - tension without considering the effect of buckling

- Capacity of bar 24

  Maximum compression force N_{Ed} = 312,66 kN

  - Design compression resistance

$$N_{c,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{39,5 * 27,5}{1} = 1086,3\ kN \quad 2.81.$$

  - Ultimate Limit Stress for compression

$$\frac{N_{Ed}}{N_{c,Rd}} < 1 \quad 2.82.$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{312,66}{1086,3} = 0,288 < 1 - cross - section\ used\ in\ 28,8\ \% \quad 2.83.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.5.1.

Table 2.5.1 Calculations of Ultimate Limit Stress on compression and tension.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	Nt,Rd	Nc,Rd	NEd/Nt,Rd NEd/Nc,Rd
		kN		[m]		[cm^2]	[kN]	[kN]	[kN]
Diagonals	2	104,99	compression	1,46	IPN 180	27,9		767,3	13,7%
	3	-82,99	tension	1,46	IPN 100	10,6	291,5		28,5%
	4	110,72	compression	1,46	IPN 120	14,2		390,5	28,4%
	5	-63,23	tension	1,46	IPN 100	10,6	291,5		21,7%
	6	70,88	compression	1,46	IPN 100	10,6		291,5	24,3%
	7	-29,15	tension	1,46	IPN 100	10,6	291,5		10,0%
	8	37,77	compression	1,46	IPN 100	10,6		291,5	13,0%
	9	4,92	compression	1,46	IPN 100	10,6		291,5	1,7%
	10	4,04	compression	1,46	IPN 100	10,6		291,5	1,4%
	11	38,69	compression	1,46	IPN 100	10,6		291,5	13,3%
	12	-29,95	tension	1,46	IPN 100	10,6	291,5		10,3%
	13	71,86	compression	1,46	IPN 100	10,6		291,5	24,7%
	14	-63,97	tension	1,46	IPN 100	10,6	291,5		21,9%
	15	111,72	compression	1,46	IPN 120	14,2		390,5	28,6%
	16	-83,85	tension	1,46	IPN 120	14,2	390,5		21,5%
	17	107,93	compression	1,46	IPN 180	27,9		767,3	14,1%
	18	-11,35	tension	0,91	IPN 180	27,9	767,3		1,5%
	19	-5,57	tension	0,91	IPN 180	27,9	767,3		0,7%
Top chord	20	-61,47	tension	1,18	IPN 220	39,5	1086,3		5,7%
	21	68,58	compression	2,28	IPN 220	39,5		1086,3	6,3%
	22	206,76	compression	2,28	IPN 220	39,5		1086,3	19,0%
	23	286,01	compression	2,28	IPN 220	39,5		1086,3	26,3%
	24	312,66	compression	2,28	IPN 220	39,5		1086,3	28,8%
	25	286,29	compression	2,28	IPN 220	39,5		1086,3	26,4%
	26	207,31	compression	2,28	IPN 220	39,5		1086,3	19,1%
	27	69,45	compression	2,28	IPN 220	39,5		1086,3	6,4%
	28	-62,12	tension	1,11	IPN 220	39,5	1086,3		5,7%
Bottom chord	29	186,9	compression	2,29	IPN 180	27,9		767,3	24,4%
	30	28,24	compression	2,28	IPN 180	27,9		767,3	3,7%
	31	-77,79	tension	2,28	IPN 180	27,9	767,3		10,1%
	32	-131,61	tension	2,28	IPN 180	27,9	767,3		17,2%
	33	-132,32	tension	2,29	IPN 180	27,9	767,3		17,2%
	34	-79,93	tension	2,28	IPN 180	27,9	767,3		10,4%
	35	24,67	compression	2,28	IPN 180	27,9		767,3	3,2%
	36	181,81	compression	2,28	IPN 180	27,9		767,3	23,7%

Bending moment

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 34,46 kNm

  - Design bending resistance

$$M_{c,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{187 * 27,5}{1 * 100} = 51,4\ kNm \qquad 2.84.$$

  - Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{c,Rd}} < 1 \qquad 2.85.$$

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{34,46}{51,4} = 0,670 < 1 - cross - section\ used\ in\ 67,0\ \% \qquad 2.86.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.5.2.

Table 2.5.2 Calculations of Ultimate Limit Stress on bending moment.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mc,Rd	MEd/Mc,Rd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]	[%]
Diagonals	2	-34,46	compression	1,46	IPN 180	27,9	187,0	51,4	67,0%
	3	-3,08	tension	1,46	IPN 100	10,6	39,8	10,9	28,1%
	4	6,11	compression	1,46	IPN 120	14,2	63,6	17,5	34,9%
	5	4,16	tension	1,46	IPN 100	10,6	39,8	10,9	38,0%
	6	4,77	compression	1,46	IPN 100	10,6	39,8	10,9	43,6%
	7	4,91	tension	1,46	IPN 100	10,6	39,8	10,9	44,9%
	8	5,57	compression	1,46	IPN 100	10,6	39,8	10,9	50,9%
	9	5,61	compression	1,46	IPN 100	10,6	39,8	10,9	51,3%
	10	5,61	compression	1,46	IPN 100	10,6	39,8	10,9	51,3%
	11	5,6	compression	1,46	IPN 100	10,6	39,8	10,9	51,2%
	12	4,93	tension	1,46	IPN 100	10,6	39,8	10,9	45,0%
	13	4,82	compression	1,46	IPN 100	10,6	39,8	10,9	44,0%
	14	4,2	tension	1,46	IPN 100	10,6	39,8	10,9	38,4%
	15	6,16	compression	1,46	IPN 120	14,2	39,8	17,5	35,2%
	16	-3	tension	1,46	IPN 120	14,2	63,6	17,5	17,2%
	17	-34,09	compression	1,46	IPN 180	27,9	187,0	51,4	66,3%
	18	45,85	tension	0,91	IPN 180	27,9	187,0	51,4	89,2%
	19	-46,36	tension	0,91	IPN 180	27,9	187,0	51,4	90,2%
Top chord	20	-11,23	tension	1,18	IPN 220	39,5	322,0	88,6	12,7%
	21	1,65	compression	2,28	IPN 220	39,5	322,0	88,6	1,9%
	22	3,52	compression	2,28	IPN 220	39,5	322,0	88,6	4,0%
	23	3,89	compression	2,28	IPN 220	39,5	322,0	88,6	4,4%
	24	3,61	compression	2,28	IPN 220	39,5	322,0	88,6	4,1%
	25	3,9	compression	2,28	IPN 220	39,5	322,0	88,6	4,4%
	26	3,52	compression	2,28	IPN 220	39,5	322,0	88,6	4,0%
	27	1,63	compression	2,28	IPN 220	39,5	322,0	88,6	1,8%
	28	-11,09	tension	1,11	IPN 220	39,5	322,0	88,6	12,5%
Bottom chord	29	-26,32	compression	2,29	IPN 180	27,9	187,0	51,4	51,2%
	30	2,06	compression	2,28	IPN 180	27,9	187,0	51,4	4,0%
	31	3,8	tension	2,28	IPN 180	27,9	187,0	51,4	7,4%
	32	3,87	tension	2,28	IPN 180	27,9	187,0	51,4	7,5%
	33	3,86	tension	2,29	IPN 180	27,9	187,0	51,4	7,5%
	34	3,8	tension	2,28	IPN 180	27,9	187,0	51,4	7,4%
	35	2,07	compression	2,28	IPN 180	27,9	187,0	51,4	4,0%
	36	-26,44	compression	2,28	IPN 180	27,9	187,0	51,4	51,4%

Buckling

- Capacity of bar 29
  Maximum compression force N_{Ed} = 186,9 kN

-Buckling curve

$For\ every\ channel\ section \rightarrow \boldsymbol{buckling\ curve}$ „c"

- imperfection factor α

For buckling curve„c" imperfection parameter equals $\alpha = 0{,}49$

- Buckling length

$$L_{cr} = \mu * L = 1 * 2{,}29 = 2{,}29\ m \qquad 2.87.$$

- Slenderness $\bar{\lambda}$

$$\lambda_1 = 93.9 * \varepsilon = 93.9 * 0{,}92 = 86{,}39 \qquad 2.88.$$

$$\bar{\lambda} = \frac{L_{c,r}}{i_z} * \frac{1}{\lambda_1} = \frac{2{,}29 * 100}{1{,}71} * \frac{1}{86{,}93} = 1{,}55 \qquad 2.89.$$

- Reduction factor χ

$$\phi = 0{,}5 * \left[1 + \alpha * \left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0{,}5 * [1 + 0{,}49 * (1{,}55 - 0{,}2) + 1{,}55^2] = 2{,}032 \qquad 2.90.$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{2{,}032 + \sqrt{2{,}032^2 - 1{,}55^2}} = 0{,}299 \qquad 2.91.$$

- Design buckling resistance

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} = \frac{0{,}299 * 27{,}9 * 27{,}5}{1} = 229{,}3\ kN \qquad 2.92.$$

- Ultimate Limit Stress for Buckling

$$\frac{N_{Ed}}{N_{b,Rd}} < 1 \qquad 2.93.$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{186{,}9}{229{,}3} = 0{,}815 < 1 - cross - section\ used\ in\ 81{,}5\ \% \qquad 2.94.$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.5.3.

Table 2.5.3 Calculations of Ultimate Limit Stress on buckling.

	Number	NEd	Compression / Tension	Length	Type of profile	Area of cross-section	i	Normalized slenderness $\bar{\lambda}$	Parameter ϕ	Reduction factor χ	$N_{b,RdNb,Rd}$	$N_{Ed}/N_{b,RdNEd}/N_{b,Rd}$
		kN		[m]		[cm^2]	[cm]					
Diagonals	2	104,99	compression	1,46	IPN 180	27,9	1,71	0,988	1,182	0,547	419,5	25,0%
	3	-82,99	tension	1,46	IPN 100	10,6	1,07					
	4	110,72	compression	1,46	IPN 120	14,2	1,23	1,374	1,732	0,359	140,2	79,0%
	5	-63,23	tension	1,46	IPN 100	10,6	1,07					
	6	70,88	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	83,8%
	7	-29,15	tension	1,46	IPN 100	10,6	1,07					
	8	37,77	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	44,7%
	9	4,92	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	5,8%
	10	4,04	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	4,8%
	11	38,69	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	45,7%
	12	-29,95	tension	1,46	IPN 100	10,6	1,07					
	13	71,86	compression	1,46	IPN 100	10,6	1,07	1,579	2,085	0,290	84,6	85,0%
	14	-63,97	tension	1,46	IPN 100	10,6	1,07					
	15	111,72	compression	1,46	IPN 120	14,2	1,23	1,374	1,732	0,359	140,2	79,7%
	16	-83,85	tension	1,46	IPN 120	14,2	1,23					
	17	107,93	compression	1,46	IPN 180	27,9	1,71	0,988	1,182	0,547	419,5	25,7%
	18	-11,35	tension	0,91	IPN 180	27,9	1,71					
	19	-5,57	tension	0,91	IPN 180	27,9	1,71					
Top chord	20	-61,47	tension	1,18	IPN 220	39,5	2,03					
	21	68,58	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	16,2%
	22	206,76	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	49,0%
	23	286,01	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	67,7%
	24	312,66	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	74,0%
	25	286,29	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	67,8%
	26	207,31	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	49,1%
	27	69,45	compression	2,28	IPN 220	39,5	2,03	1,300	1,615	0,389	422,3	16,4%
	28	-62,12	tension	1,11	IPN 220	39,5	2,03					
Bottom chord	29	186,9	compression	2,29	IPN 180	27,9	1,71	1,550	2,032	0,299	229,3	81,5%
	30	28,24	compression	2,28	IPN 180	27,9	1,71	1,543	2,020	0,301	230,8	12,2%
	31	-77,79	tension	2,28	IPN 180	27,9	1,71					
	32	-131,61	tension	2,28	IPN 180	27,9	1,71					
	33	-132,32	tension	2,29	IPN 180	27,9	1,71					
	34	-79,93	tension	2,28	IPN 180	27,9	1,71					
	35	24,67	compression	2,28	IPN 180	27,9	1,71	1,543	2,020	0,301	230,8	10,7%
	36	181,81	compression	2,28	IPN 180	27,9	1,71	1,543	2,020	0,301	230,8	78,8%

Bending moment and axial force

- Capacity of bar 2
  Maximum bending moment M_{Ed} = 34,46 kNm

  - Design bending resistance

$$N_{Ed} = 104{,}99\ kN \tag{2.95.}$$

$$N_{pl,Rd} = \frac{A * f_y}{\gamma_{M1}} = \frac{27{,}9 * 27{,}5}{1} = 767{,}25\ kN \tag{2.96.}$$

$$M_{pl,Rd} = \frac{W_{pl} * f_y}{\gamma_{M1}} = \frac{187{,}0 * 27{,}5}{1 * 100} = 51{,}4\ kNm \tag{2.97.}$$

$$M_{N,Rd} = M_{pl,Rd} * \left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] = 51{,}4 * \ [1 - \left(\frac{104{,}99}{767{,}25}\right)^2] = 50{,}5\ kN \tag{2.98.}$$

- Ultimate Limit Stress for bending

$$\frac{M_{Ed}}{M_{N,Rd}} < 1 \tag{2.99.}$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{34{,}46}{50{,}5} = 0{,}683 < 1 - cross - section\ used\ in\ 68{,}3\ \% \tag{2.100.}$$

Calculations of all elements (diagonals, top chord, bottom chord) are presented in Table 2.5.4.

Table 2.5.4 Calculations of Ultimate Limit Stress on bending moment and axial force.

	Number	MEd	Compression / Tension	Length	Type of profile	Area of cross-section	Wpl	Mpl,Rd	NEd/Npl,Rd	M N,Rd	MEd/MNRd
		[kNm]		[m]		[cm^2]	[cm3]	[kNm]		[kNm]	[%]
Diagonals	2	-34,46	compression	1,46	IPN 180	27,9	187,0	51,4	0,14	50,5	68,3%
	3	-3,08	tension	1,46	IPN 100	10,6	39,8	10,9	0,28	10,1	30,6%
	4	6,11	compression	1,46	IPN 120	14,2	63,6	17,5	0,28	16,1	38,0%
	5	4,16	tension	1,46	IPN 100	10,6	39,8	10,9	0,22	10,4	39,9%
	6	4,77	compression	1,46	IPN 100	10,6	39,8	10,9	0,24	10,3	46,3%
	7	4,91	tension	1,46	IPN 100	10,6	39,8	10,9	0,10	10,8	45,3%
	8	5,57	compression	1,46	IPN 100	10,6	39,8	10,9	0,13	10,8	51,8%
	9	5,61	compression	1,46	IPN 100	10,6	39,8	10,9	0,02	10,9	51,3%
	10	5,61	compression	1,46	IPN 100	10,6	39,8	10,9	0,01	10,9	51,3%
	11	5,6	compression	1,46	IPN 100	10,6	39,8	10,9	0,13	10,8	52,1%
	12	4,93	tension	1,46	IPN 100	10,6	39,8	10,9	0,10	10,8	45,5%
	13	4,82	compression	1,46	IPN 100	10,6	39,8	10,9	0,25	10,3	46,9%
	14	4,2	tension	1,46	IPN 100	10,6	39,8	10,9	0,22	10,4	40,3%
	15	6,16	compression	1,46	IPN 120	14,2	39,8	17,5	0,29	16,1	38,3%
	16	-3	tension	1,46	IPN 120	14,2	63,6	17,5	0,21	16,7	18,0%
	17	-34,09	compression	1,46	IPN 180	27,9	187,0	51,4	0,14	50,4	67,6%
	18	45,85	tension	0,91	IPN 180	27,9	187,0	51,4	0,01	51,4	89,2%
	19	-46,36	tension	0,91	IPN 180	27,9	187,0	51,4	0,01	51,4	90,2%
Top chord	20	-11,23	tension	1,18	IPN 220	39,5	322,0	88,6	0,06	88,3	12,7%
	21	1,65	compression	2,28	IPN 220	39,5	322,0	88,6	0,06	88,2	1,9%
	22	3,52	compression	2,28	IPN 220	39,5	322,0	88,6	0,19	85,3	4,1%
	23	3,89	compression	2,28	IPN 220	39,5	322,0	88,6	0,26	82,4	4,7%
	24	3,61	compression	2,28	IPN 220	39,5	322,0	88,6	0,29	81,2	4,4%
	25	3,9	compression	2,28	IPN 220	39,5	322,0	88,6	0,26	82,4	4,7%
	26	3,52	compression	2,28	IPN 220	39,5	322,0	88,6	0,19	85,3	4,1%
	27	1,63	compression	2,28	IPN 220	39,5	322,0	88,6	0,06	88,2	1,8%
	28	-11,09	tension	1,11	IPN 220	39,5	322,0	88,6	0,06	88,3	12,6%
Bottom chord	29	-26,32	compression	2,29	IPN 180	27,9	187,0	51,4	0,24	48,4	54,4%
	30	2,06	compression	2,28	IPN 180	27,9	187,0	51,4	0,04	51,4	4,0%
	31	3,8	tension	2,28	IPN 180	27,9	187,0	51,4	0,10	50,9	7,5%
	32	3,87	tension	2,28	IPN 180	27,9	187,0	51,4	0,17	49,9	7,8%
	33	3,86	tension	2,29	IPN 180	27,9	187,0	51,4	0,17	49,9	7,7%
	34	3,8	tension	2,28	IPN 180	27,9	187,0	51,4	0,10	50,9	7,5%
	35	2,07	compression	2,28	IPN 180	27,9	187,0	51,4	0,03	51,4	4,0%
	36	-26,44	compression	2,28	IPN 180	27,9	187,0	51,4	0,24	48,5	54,5%

3 FINAL CONSIDERATIONS

3.1 CONCLUSIONS

All the presented steel truss solutions were compared in terms of price execution. The cost comparison took into account two factors: the price of steel and the cost of covering the presented trusses with fire-resistant paint.

The cost of coating the steel in fire retardant paint may represented a significant increase on the total cost of steel structures. Therefore, in this project it was important to use profiles that have the largest cross-sectional area as possible with the lateral surface to be painted.

Lateral surface has to be known to calculate price of fire-resistant paint needed to cover a truss. System STEELGUARD 585 was used. This paint consists three layers: undercoat, fire-resistant layer, topcoat. Purchase cost of them is 6,50, 9,90 and 10,80 €/L, respectively. Theoretical efficiency equals 0,10, 1,00 and 0,15 L/m^2, respectively. Total cost of fire-resistant paint equals 12,20 euros per square meter of lateral surface. Calculations are presented in Table 3.1.1.

Table 3.1.1 Calculations of price per square meter of fire-resistant paint.

	Layers			**Total price €/m²**
	Undercoat	Main	Topcoat	
Price €/L	6,5	9,9	10,8	
Efficiency L/m²	0,10	1,00	0,15	
Price €/m²	0,7	9,9	1,6	**12,2**

Below tables with index of steel and prices of steel trusses are presented. To estimate cost two factors were taken into account: steel price and fire-resistant paint.

Table 3.1.2 Index of steel and price for steel truss based on Continente Bom Dia construction project.

Cross section	Length [m]	Painting area [m2/m]	Quantity	Mass of 1m [kg]	Price per ton [€]	Steel cost [€]	Painting cost [€]
UPN 100	0,91	0,37	7	10,6	360	24,31	28,67
	2,19	0,37	2	10,6	360	16,71	19,71
UPN 120	0,91	0,43	1	13,3	360	4,36	4,76
	2,13	0,43	1	13,3	360	10,20	11,14
UPN 140	2,19	0,49	1	16,0	340	11,91	13,05
	2,13	0,49	1	16,0	340	11,59	12,70
UPN 160	2,19	0,54	1	18,9	340	14,07	14,38
	2,04	0,54	1	18,9	340	13,11	13,40
UPN 180	2,16	0,60	1	22,0	340	16,16	15,76
UPN 220	2,85	0,72	1	29,4	340	28,49	24,96
UPN 240	0,91	0,78	2	33,2	325	19,64	17,27
UPN 240	18,28	0,78	1	33,2	325	197,24	173,43
UPN 280	18,28	0,89	1	41,9	325	248,93	197,89
					Sum [€]	**616,71**	**547,13**
					Total [€]	**1163,84**	

Table 3.1.3 Index of steel and price of steel truss with original structure and IPN cross-sections.

Cross section	Length [m]	Painting area [m2/m]	Quantity	Mass of 1m [kg]	Price per ton [€]	Steel cost [€]	Painting cost [€]
IPN 80	2,16	0,3	1	5,94	360	4,62	7,88
	2,19	0,3	4	5,94	360	18,73	31,97
	0,91	0,3	7	5,94	360	13,62	23,24
	2,13	0,3	2	5,94	360	9,11	15,55
	2,04	0,3	1	5,94	360	4,36	7,44
	2,85	0,3	1	5,94	360	6,09	10,40
IPN 100	0,91	0,37	1	8,34	360	2,73	4,10
IPN 200	0,91	0,71	2	26,2	340	16,21	15,72
IPN 200	18,28	0,71	2	26,2	340	325,68	315,74
					Sum [€]	**401,16**	**432,03**
					Total [€]	**833,19**	

Table 3.1.4 Index of steel and price of steel truss with changed structure and IPN cross-sections.

Cross section	Length [m]	Painting area [m2/m]	Quantity	Mass of 1m [kg]	Price per ton [€]	Price [€]	Painting cost [€]
IPN 80	1,06	0,3	31	5,94	360	70,27	119,91
	1	0,3	1	5,94	360	2,14	3,65
IPN 120	0,91	0,44	2	11,1	360	7,27	9,74
	1,06	0,44	1	11,1	360	4,24	5,67
	1,03	0,44	1	11,1	360	4,12	5,51
IPN 140	18,28	0,5	2	14,3	340	177,75	222,35
IPN 160	18,28	0,57	2	17,9	340	222,50	253,48
					Sum [€]	**488,29**	**620,32**
					Total [€]	**1108,61**	

Table 3.1.5 Index of steel and price of steel truss with original structure and RHS cross-sections.

Cross section	Length [m]	Painting area [m2/m]	Quantity	Mass of 1m [kg]	Price per ton [€]	Price [€]	Painting cost [€]
RHS 80x40x6,3	0,91	0,22	8	10,3	440	32,99	19,48
RHS 120x80x6,3	18,28	0,38	1	18,2	410	136,41	84,49
RHS 200x100x6,3	18,28	0,58	1	28,1	410	210,60	128,96
	0,91	0,58	2	28,1	410	20,97	12,84
					Sum [€]	**400,97**	**245,78**
					Total [€]	**646,75**	

Table 3.1.6 Index of steel and price of steel truss with changed structure and IPN cross-sections.

Cross section	Length [m]	Painting area [m2/m]	Quantity	Mass of 1m [kg]	Price per ton [€]	Price [€]	Painting cost [€]
IPN 100	1,46	0,37	11	8,34	360	48,22	72,28
IPN 120	1,46	0,44	3	11,1	360	17,50	23,44
IPN 180	0,91	0,64	2	21,9	340	13,55	14,17
	1,46	0,64	2	21,9	340	21,74	22,73
IPN 180	18,28	0,64	1	21,9	340	136,11	142,30
IPN 220	18,28	0,77	1	31	340	192,67	171,21
					Sum [€]	**429,80**	**446,14**
					Total [€]	**875,93**	

Taking into account only these two factors, the most cost effective solution is to use cross-sections RHS.

All of the solutions presented were cheaper than the structure on which the project was based – used in supermarket Continente Bom Dia. These conclusions are valid not considering the effects of the wind load. If that load was considered, most probably the conclusion would change when comparing with the original solution. The conclusions and comparison for solutions 2 to 5 seem to be acceptable though.

One must keep in mind that the cost of the steel structure does not stop only on those two factors. The cost of installation, transportation, and the connections can significantly affect the final price. In designing new solutions only those two factors were mentioned.

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