Metal Structures

Design Project I

Steel truss

PROJECT OBJECTIVE'S

Reminder of rules for combination of loads from Introduction to Contruction Designing;
Calculation of element under bi-axial bending; resistance and deflection;
Calculation of element uder axial compression; resistance and stability;
Analysis of equivalent loads from imperfection and instability;
Calculation of selected types of joints in steel structure: truss nodes, truss splice joints;
resistances of joints and introduction to analysis stiffness of joints;

Topic: restoration of old masonry building.

Photo: pixabay.com

New roof will be supported by complex of steel trusses.

Photo: liaeng.com

The building is > 200 years old. It was built on the ell or arshin scale. Because of this, now the dimensions in meters are not round.

Example of real structure: Wawel Royal Castle, Krakow

Photo: Konserwacja Wawelu w świetle doktryn Konserwatorskich, P. Stępień
Ochrona Zabytków 62/1 (244), 83-100 2009

From 1846 (when Krakow was occupied by Austria), Wawel was a military garrison. In the years 1905-1911, an action was carried out to buy castle from the military authorities. Buildings were devastated and needed renovation.

Photo: wawel.krakow.pl

In many places, instead of heavy wooden trusses supporting roof, light steel trusses were used (~1910).

Rys: Rekonstrukcja i kreacja w odnowie zamku na Wawelu, P. Stępień, Ochrona Zabytków 2007 / 2 / 27-50

Rys: buildercorp.pl

Topic:

Design of steel roof truss over masonry building:

B..

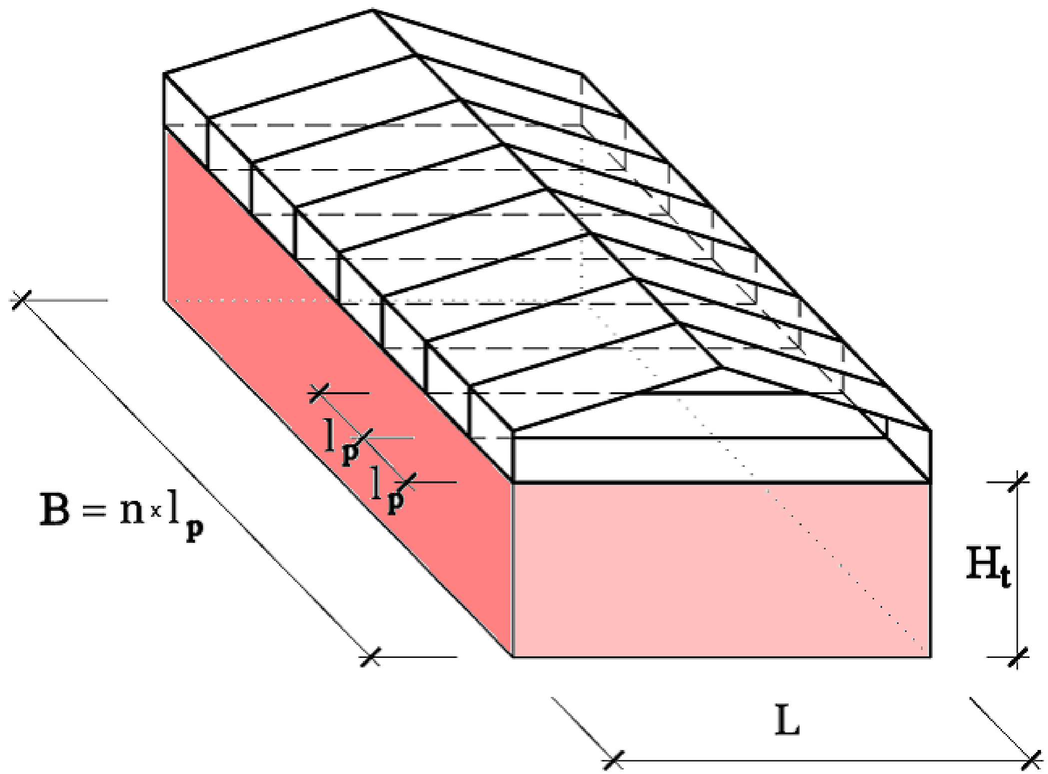
L..

H_t..

Roofing > ....

Location..

Steel..



$l_p = 6,0$

Photo: Author

Roofing, first layer: sandwich panels; thermal insulation, protection from rain, wind and snow

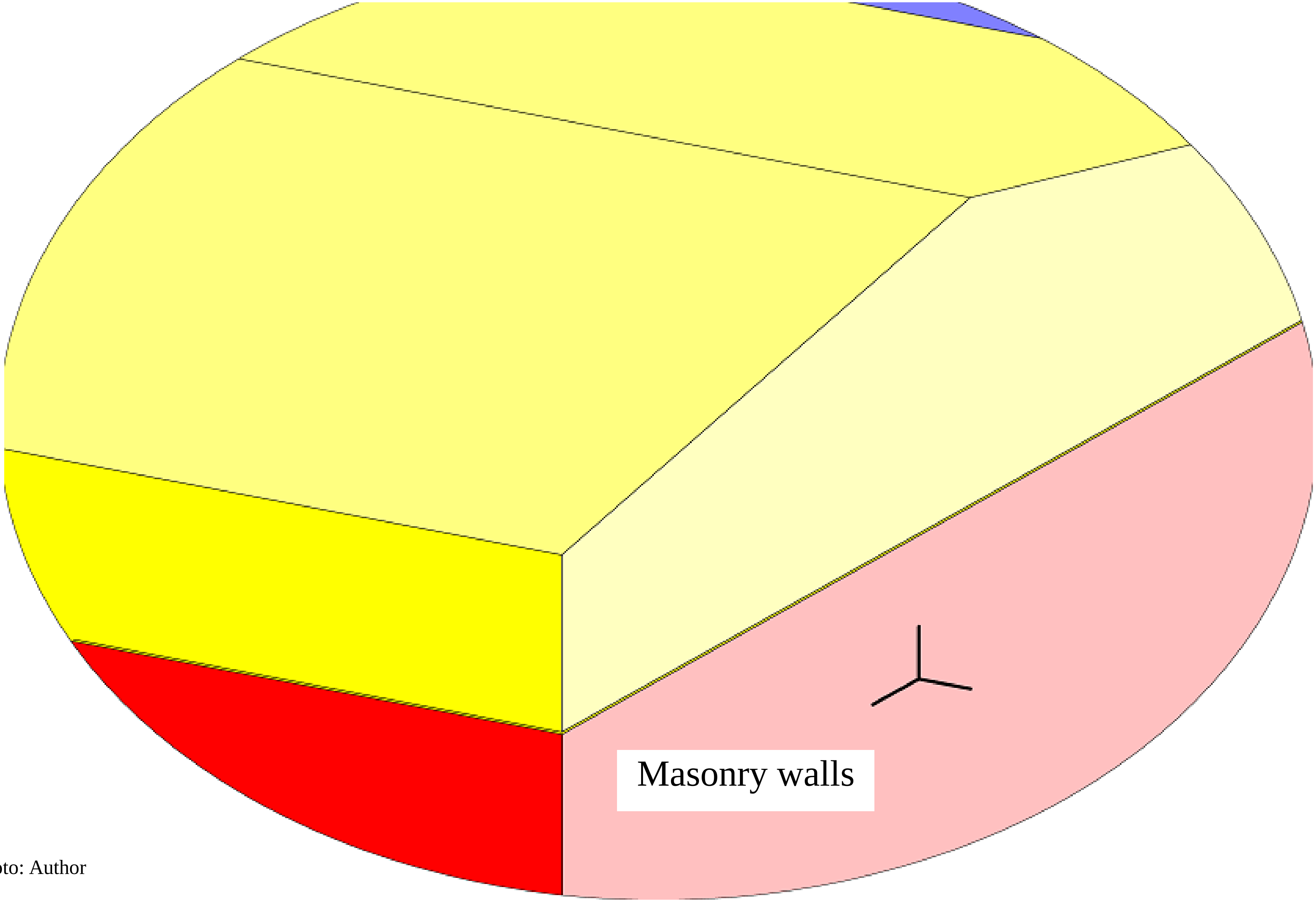
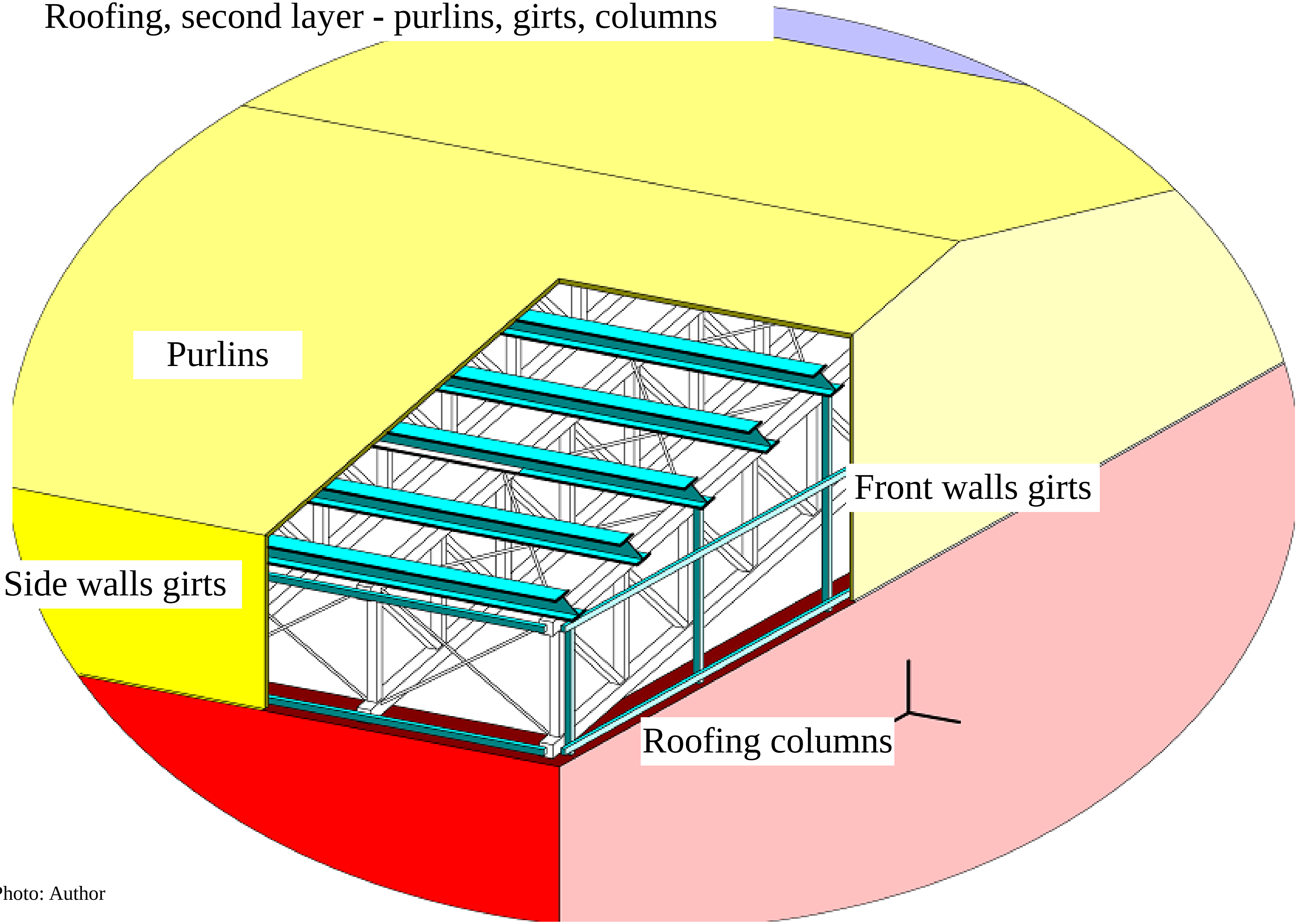


Photo: Author

Roofing, second layer - purlins, girts, columns



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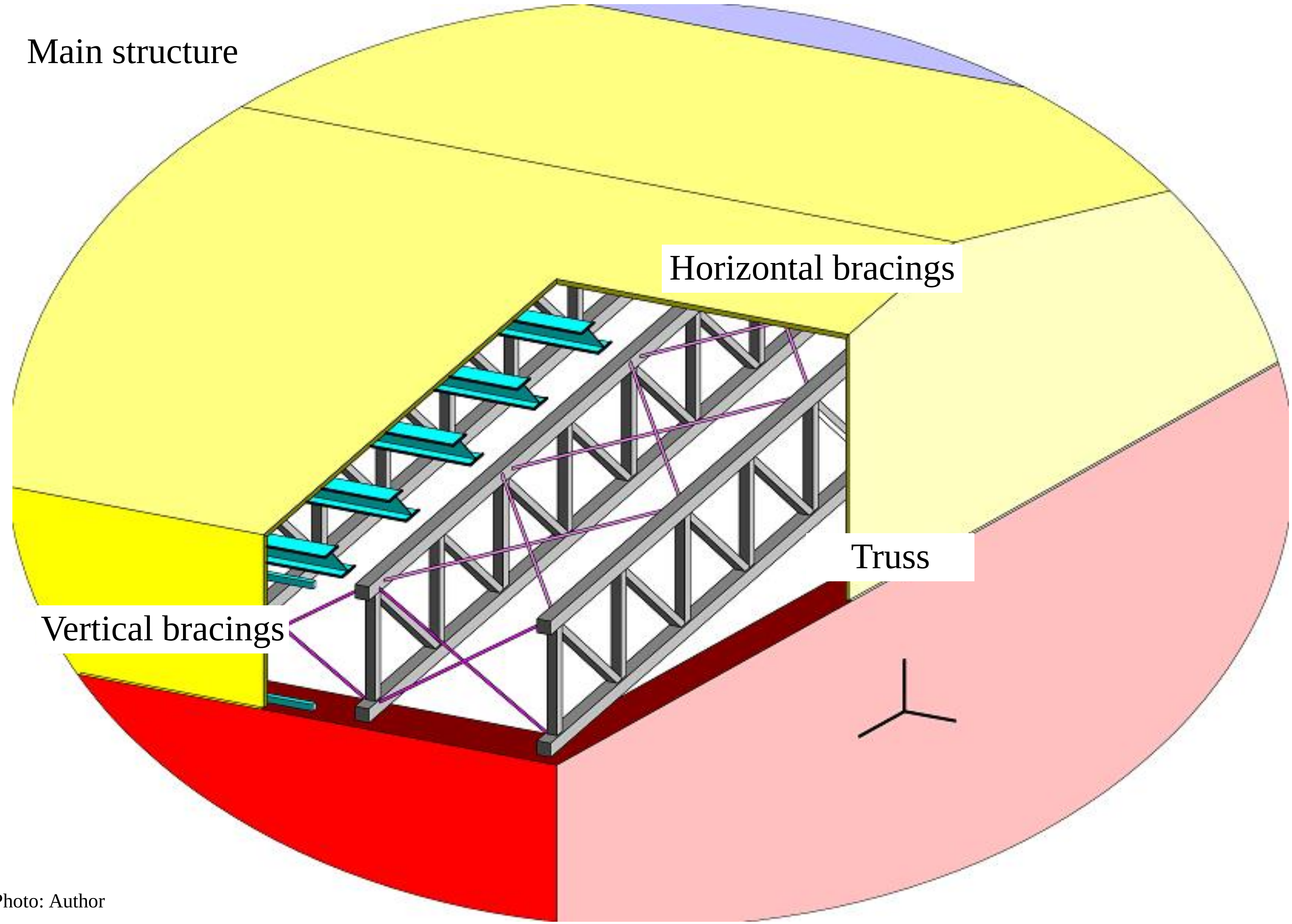


Photo: Author

Definition

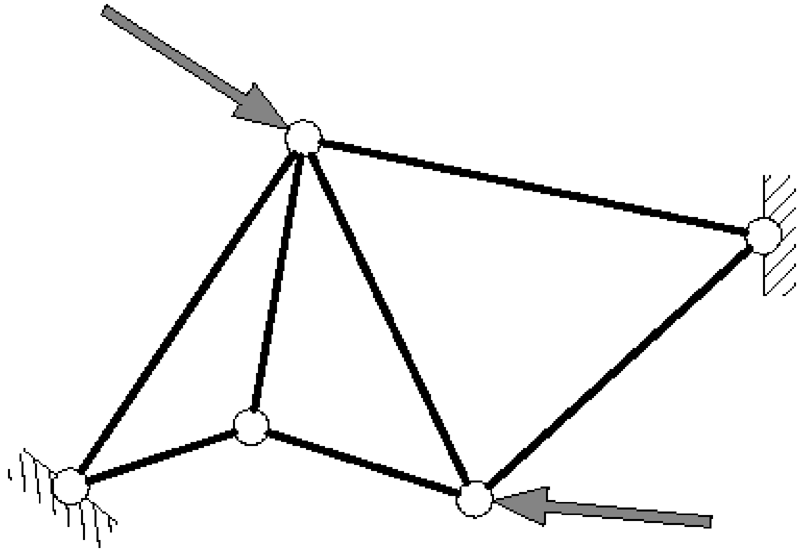


Photo: Author

There are axial forces only

Truss – theory (idealization):

- Straight bars only;
- Forces in joints only;
- Hinged joints;

Schwedler-Żurawski formula for straight bar:

$$d\,M(x) / dx = Q(x)$$
$$d\,Q(x) / dx = q(x)$$

Forces in joints only → no loads along bar ($q(x) = 0$):

$$q(x) = 0 \rightarrow Q(x) = const = C \rightarrow M(x) = C\,x + A$$

Hinges:

$$M(0) = 0 \rightarrow A = 0 \quad ; \quad M(L) = 0 \rightarrow C = 0$$

$$M(x) = 0 \quad ; \quad Q(x) = 0$$

Algorithm

Calculation of each metal structure can be divided into few groups of problem:

- Initial assumptions about geometry of structure (initial drawing);
- Analysis of loads and actions;
- Calculation of elements (resistance, stability, deflection);
- Calculation of connections and joints between elements (stiffness, resistance);
- Final drawings and documentatnion;

Your range of project:

- Initial drawing
- Loads
- Roofing
- Purlins
- Girts & columns
- Truss bars
- Bracings

- Supports for purlins
- Supports for columns
- Joints truss - bracing
- Joints between truss bars
- Joints between transport members
- Support for truss

- Drawings and list of materials

Initial assumptions about geometry:

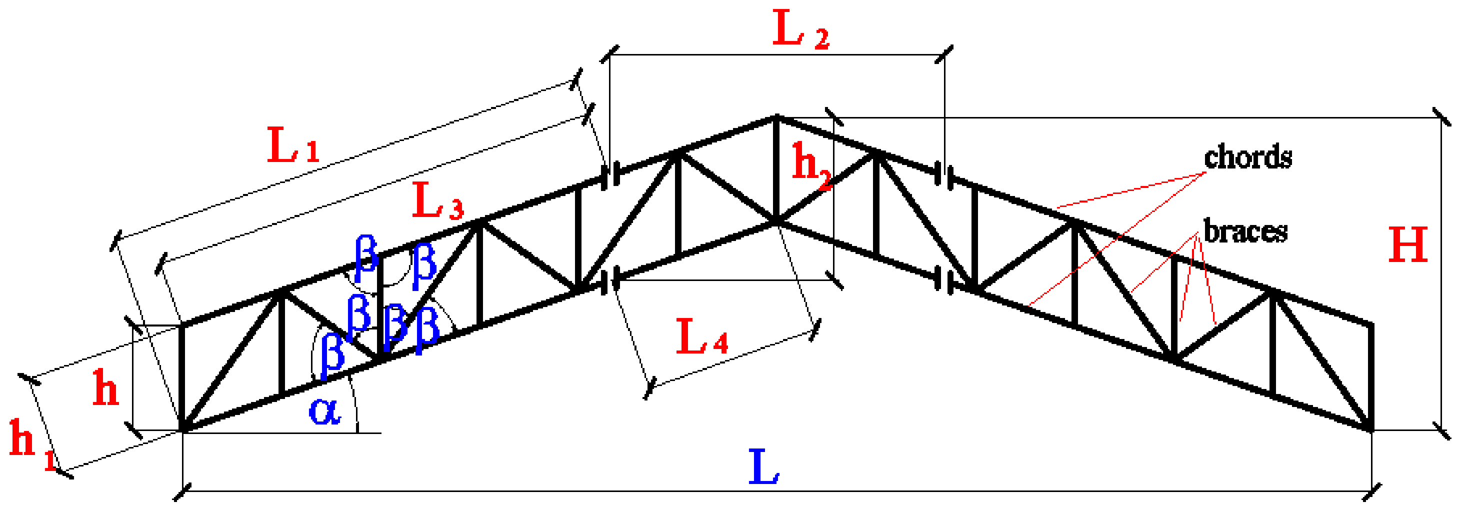


Photo: Author

$h = L\ (1/10 \sim 1/15)$

$H = L\ (1/5 \sim 1/10)$

$\alpha \geq 5^{o}$

$30^{o} \geq \beta \geq 60^{o}$ or $\beta \approx 90^{o}$

$\max\ (h_1; h_2) \leq 3{,}20$ m

$\max\ (L_1; L_2; L_3; L_4) \leq 12{,}00$ m (road transport)

Initial drawing:

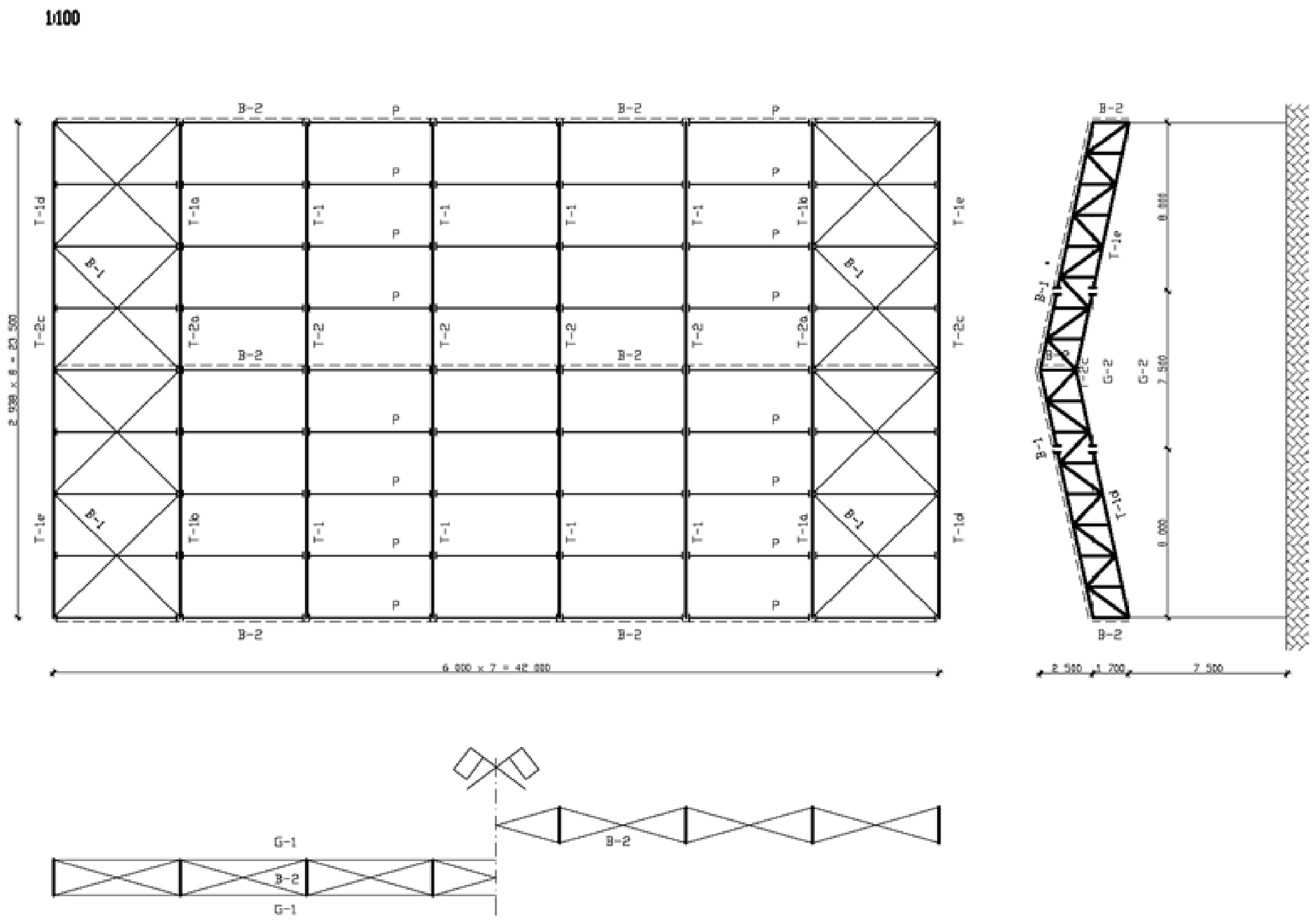
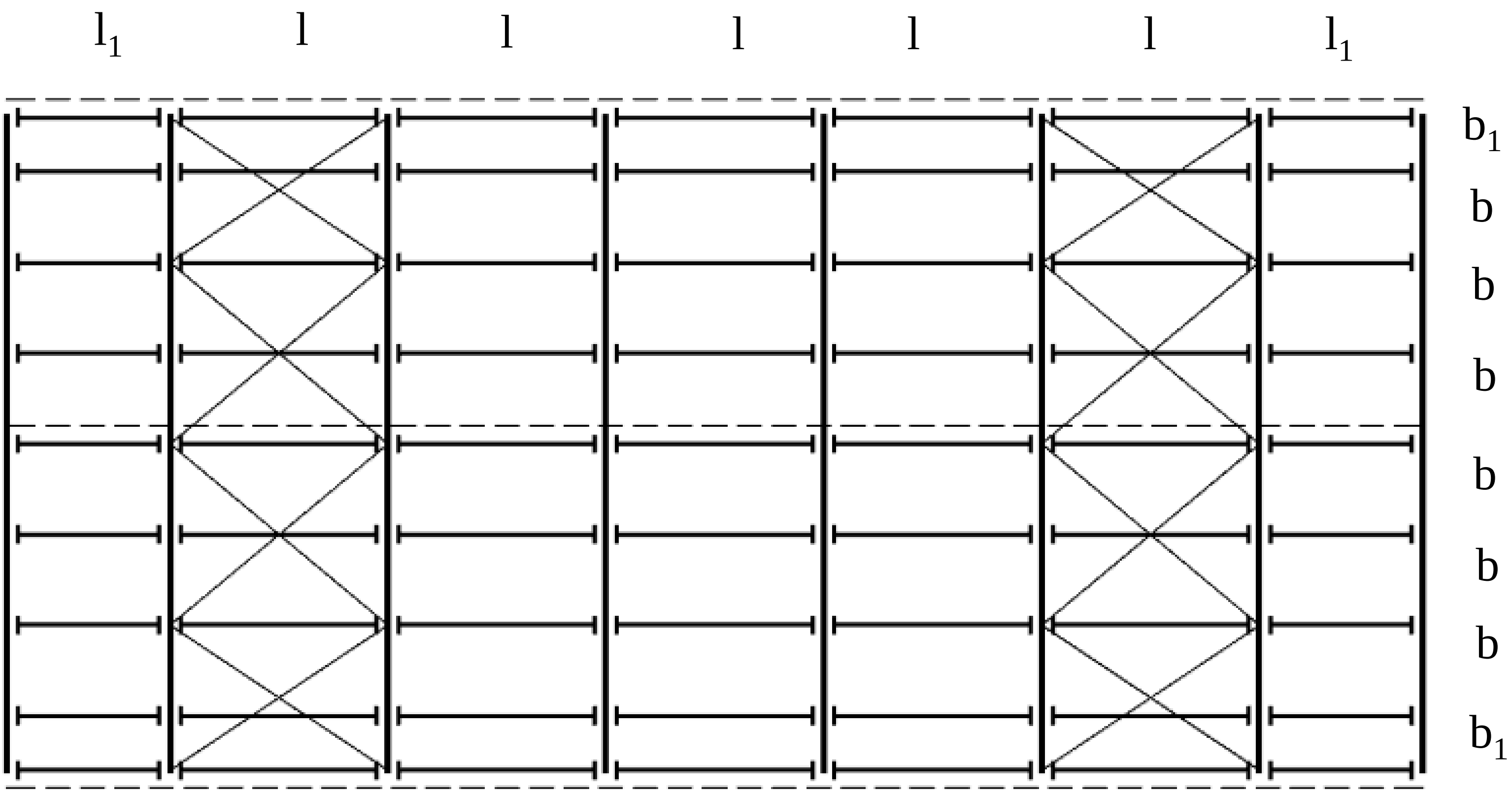


Photo: Author

Sometimes we can't divide our structures into constant distances between truss and purlins.



$l = 6{,}00$ m

$l_1 = 3{,}00 \sim 6{,}00$ m

$b = 2{,}00 \sim 2{,}50$ m

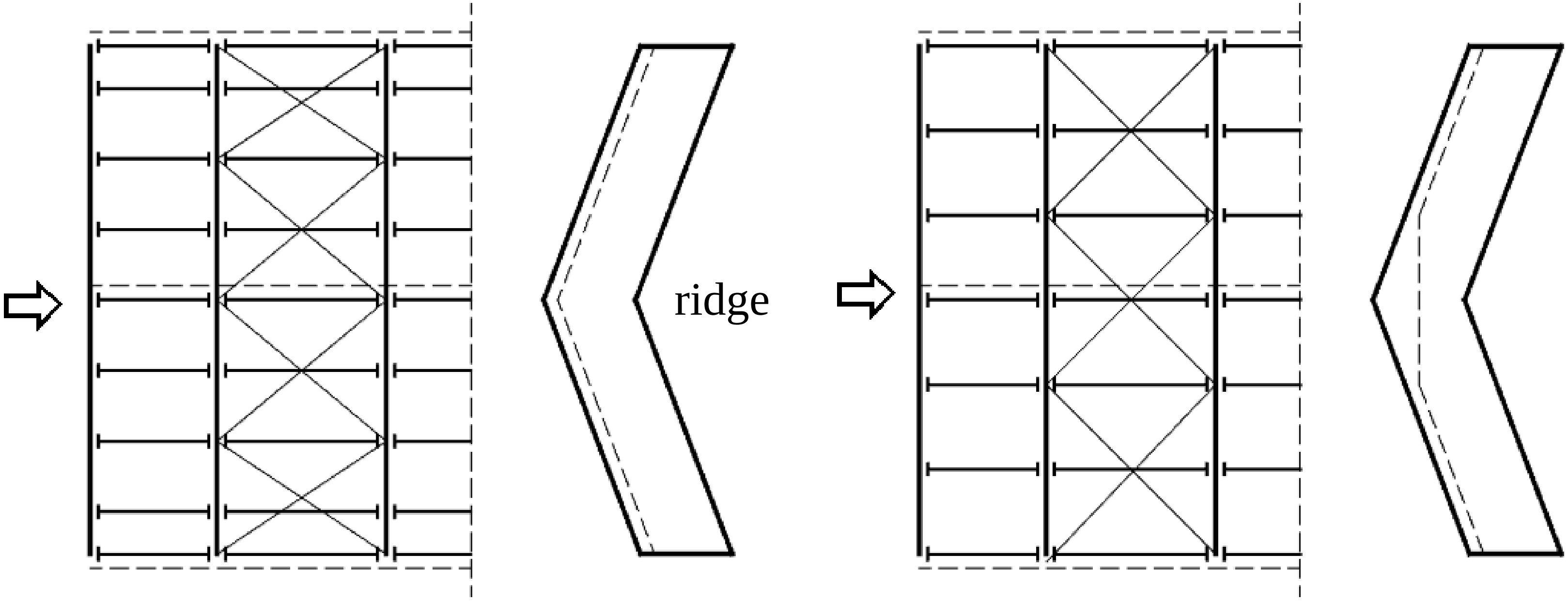
$b_1 = 1{,}50 \sim 2{,}00$ m

Photo: Author

Additional information about distances between purlins

Recommended solution: ridge purlins cooperate with horizontal bracings

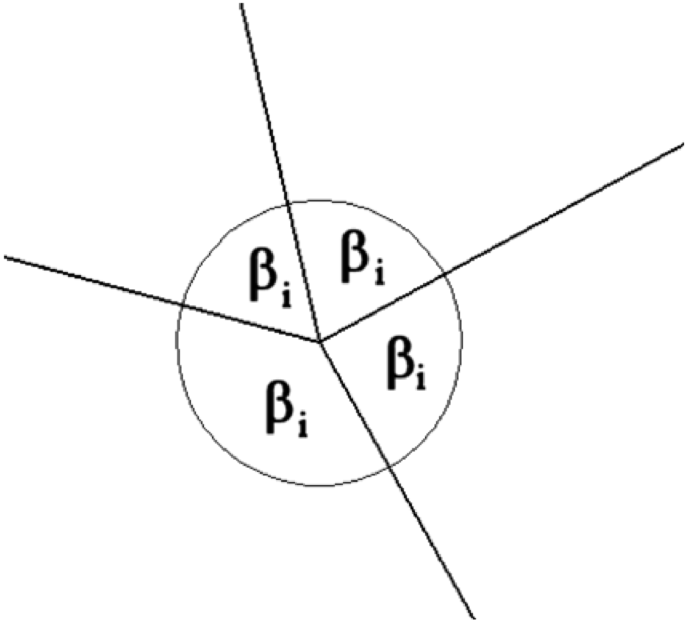
Photo: Author



Not recommended solution: ridge purlins not cooperate with horizontal bracings

All angles between axes of elements (truss bars and bracing bars) must be bigger than 30°

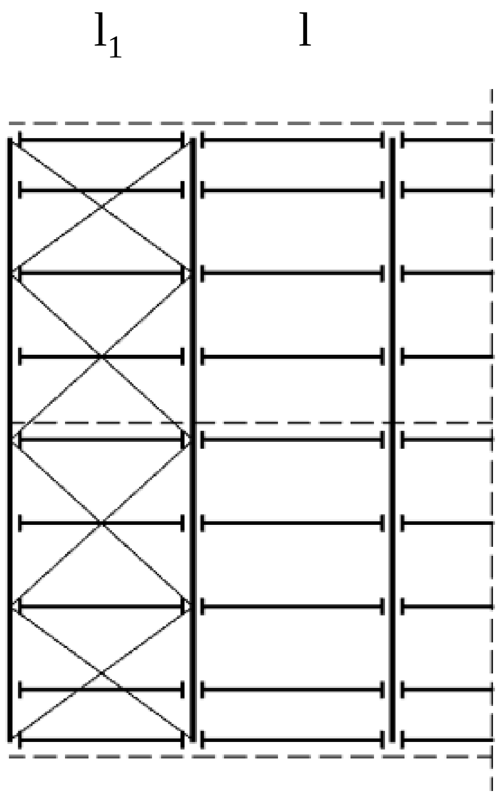
(EN 1090-2)



$\beta_i \geq 30^o$

Photo: Author

Position of horizontal bracings



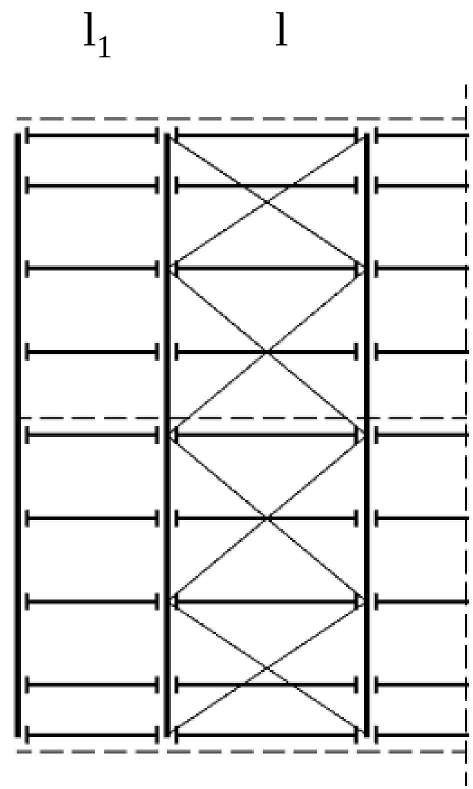


Photo: Author

Small difference between l and l_1: bracings in first and last bands

Big difference between l and l_1: bracings in second and penultimate bands

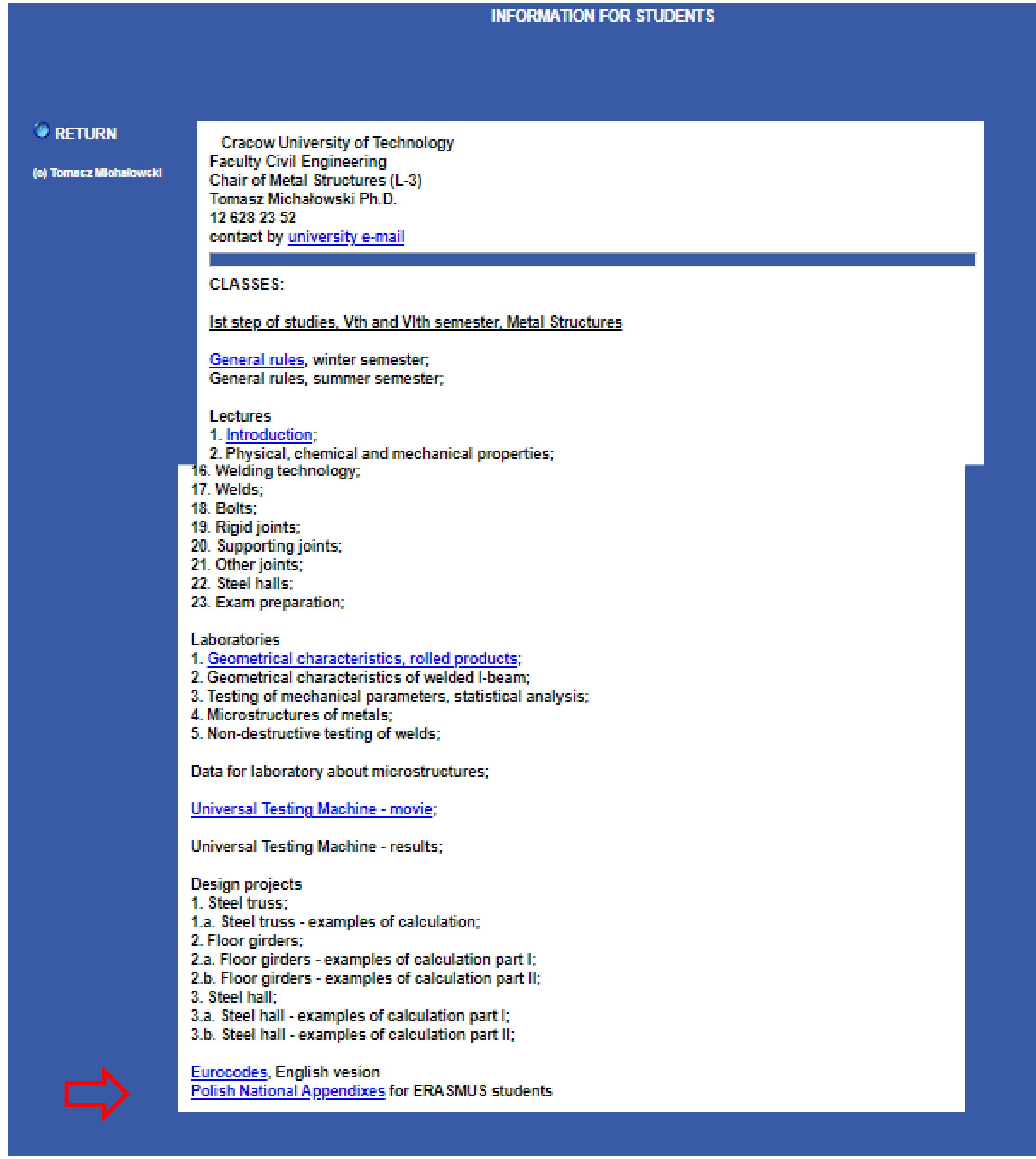
Loads

- Dead weight of roofing g_r [kN / m^2]
- Dead weight of purlin g_p [kN / m]
- Dead weight of girts g_g [kN / m]
- Snow q_s [kN / m^2] (EN 1991-1-3)
- Wind q_w [kN / m^2] (EN 1991-1-4)
- Dead weight of truss g_t [kN / m^2]
- Imposed loads q_i [kN / m^2] (EN 1991-1-1)
- Thermal actions
- Exposed to fire
- Accidental actions
- Actions durin execution

Eurocodes

You can download standards from my website

Photo: Author


INFORMATION FOR STUDENTS

RETURN

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CLASSES:

Ist step of studies, Vth and VIth semester, Metal Structures

General rules, winter semester;
General rules, summer semester;

Lectures
1. Introduction;
2. Physical, chemical and mechanical properties;
16. Welding technology;
17. Welds;
18. Bolts;
19. Rigid joints;
20. Supporting joints;
21. Other joints;
22. Steel halls;
23. Exam preparation;

Laboratories
1. Geometrical characteristics, rolled products;
2. Geometrical characteristics of welded I-beam;
3. Testing of mechanical parameters, statistical analysis;
4. Microstructures of metals;
5. Non-destructive testing of welds;

Data for laboratory about microstructures;

Universal Testing Machine - movie;

Universal Testing Machine - results;

Design projects
1. Steel truss;
1.a. Steel truss - examples of calculation;
2. Floor girders;
2.a. Floor girders - examples of calculation part I;
2.b. Floor girders - examples of calculation part II;
3. Steel hall;
3.a. Steel hall - examples of calculation part I;
3.b. Steel hall - examples of calculation part II;

Eurocodes, English vesion
Polish National Appendixes for ERASMUS students

Roofing - loads

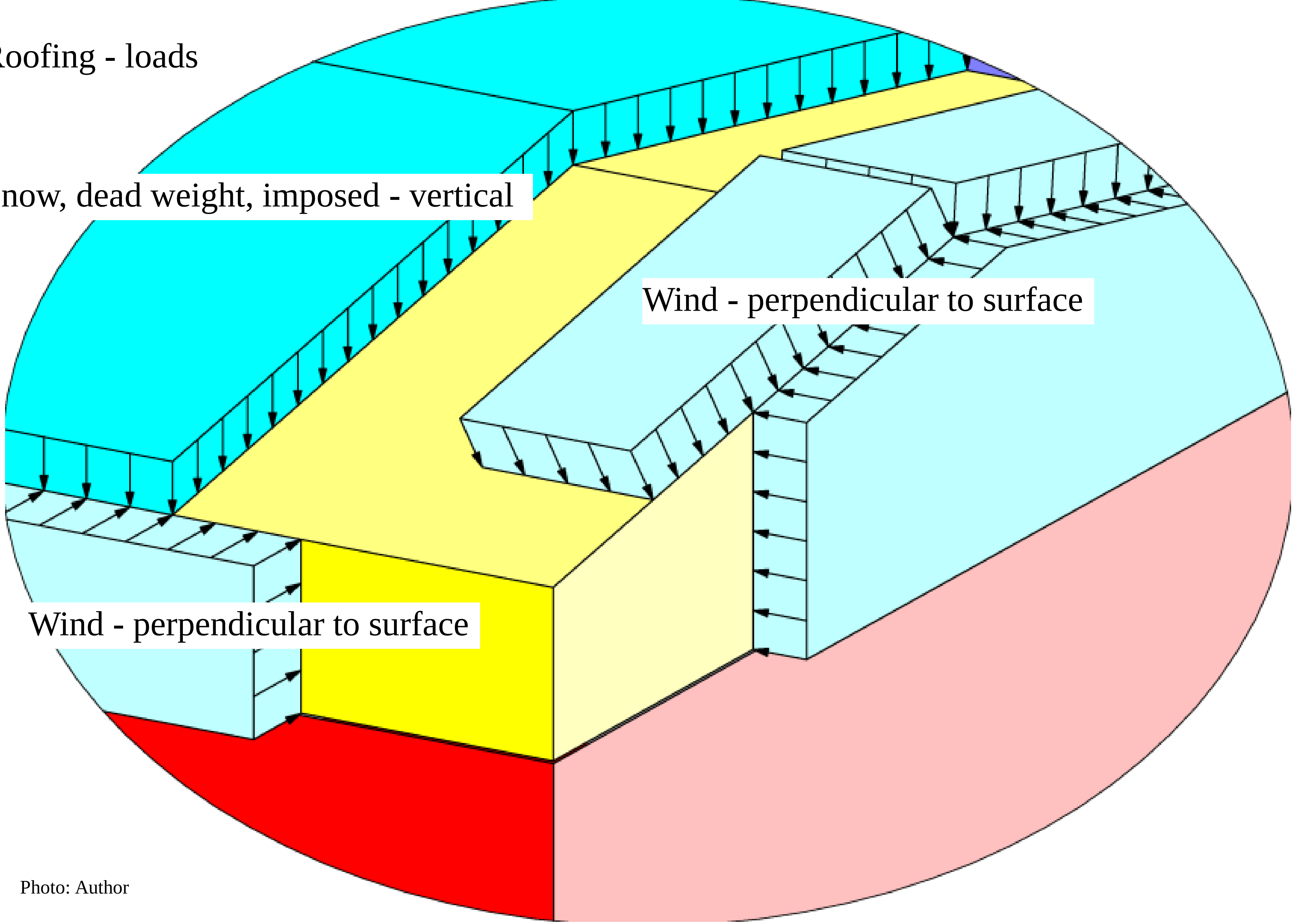
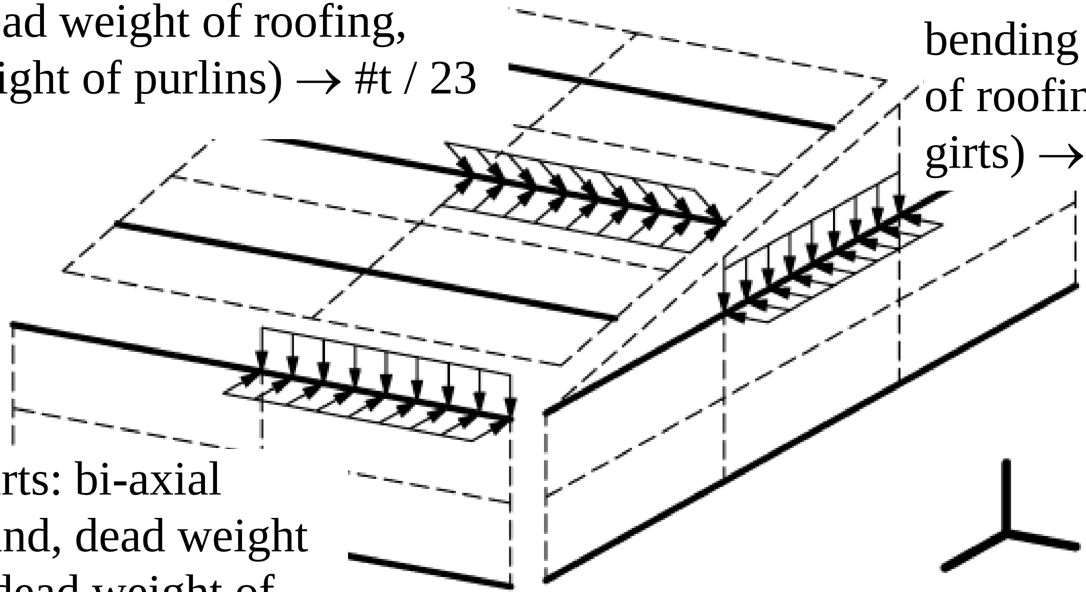


Photo: Author

Purlins: bi-axial bending (snow, wind, dead weight of roofing, dead weight of purlins) → #t / 23

Front wall girts: bi-axial bending (wind, dead weight of roofing, dead weight of girts) → #t / 24



Side wall girts: bi-axial bending (wind, dead weight of roofing, dead weight of girts) → #t / 23

Photo: Author

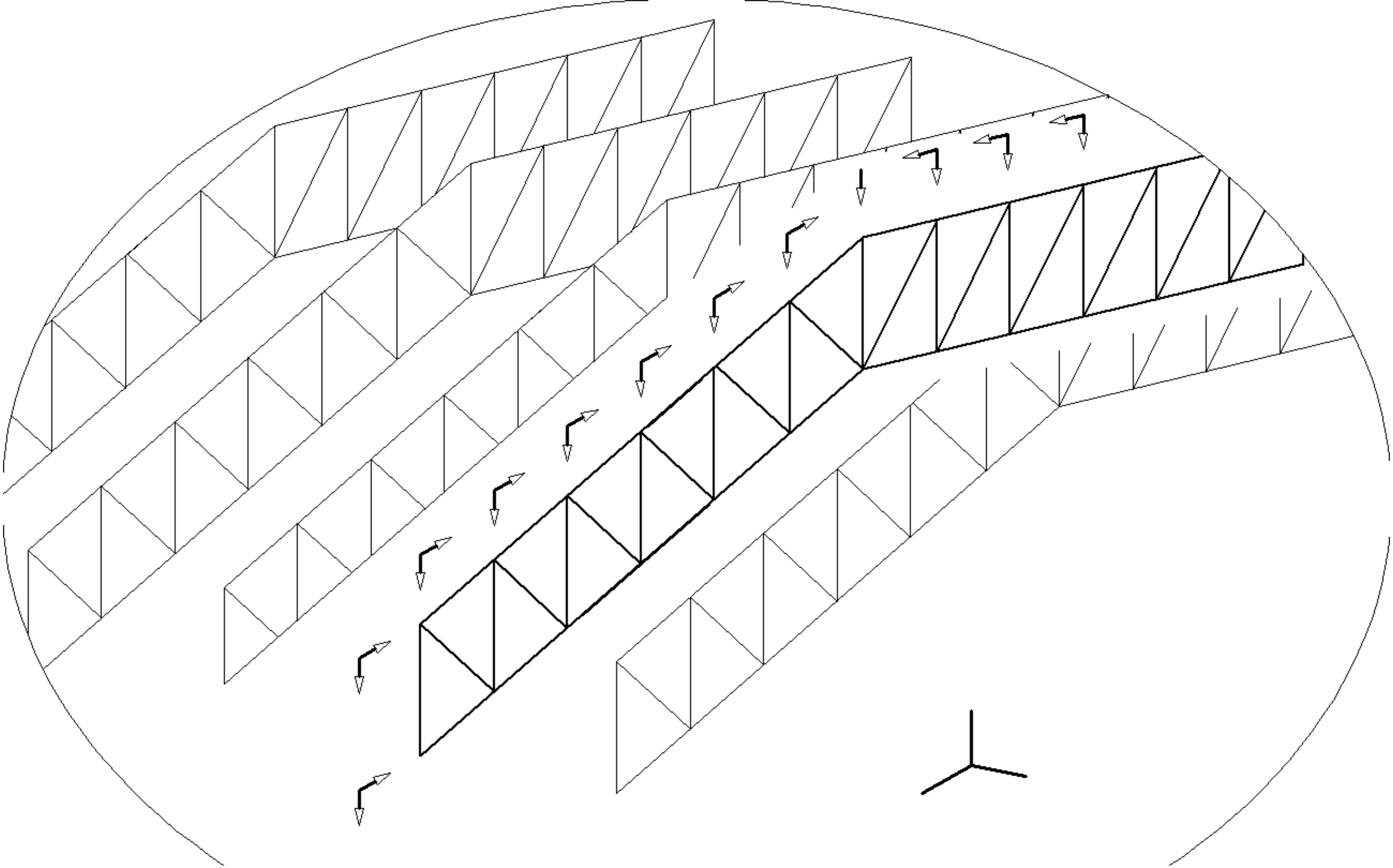


Photo: Author

Loads applicated to truss from roof slope and side walls: horizontal and vertical forces from purlins; horizontal and vertical forces from side wall girts.

Loads applicated from front wall:

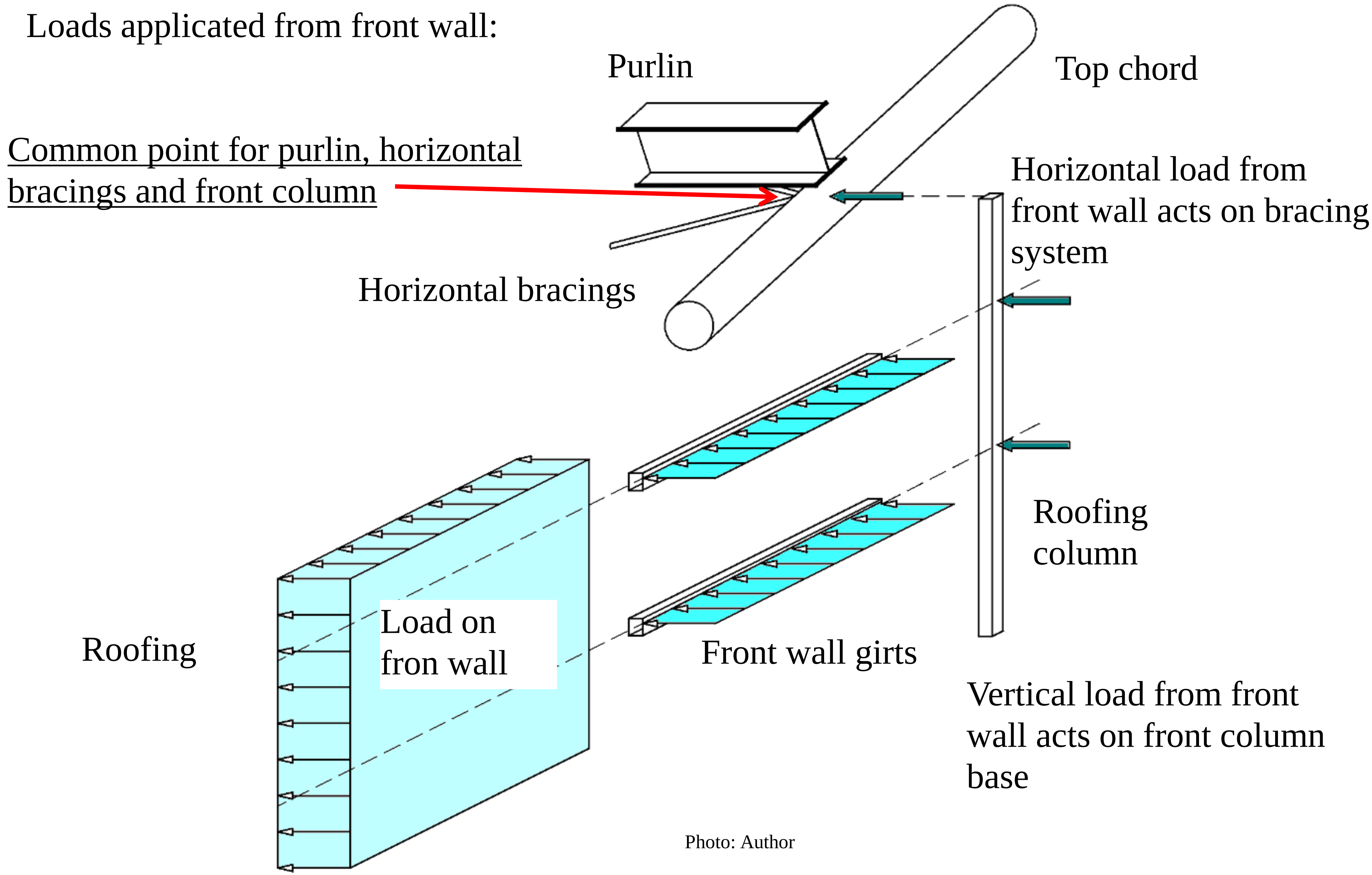


Photo: Author

Ultimately, loads will be applied to:

From part	Load	Goes through	Ultimately acts on	Notices
Roof slope	Horizonal	Purlins	Roof truss	→ #t / 46-58
	Vertical			
Side wall	Horizonal	Side wall girts		
	Vertical			
Front wall	Horizonal	Front wall girts and columns	Horizontal bracing	→ #t / 59-70
	Vertical		Front wall column base	Non obligatory in Your range of project

Roofing: sandwich panel; minimum thickness are defined in topic (thickness → dead-weight).

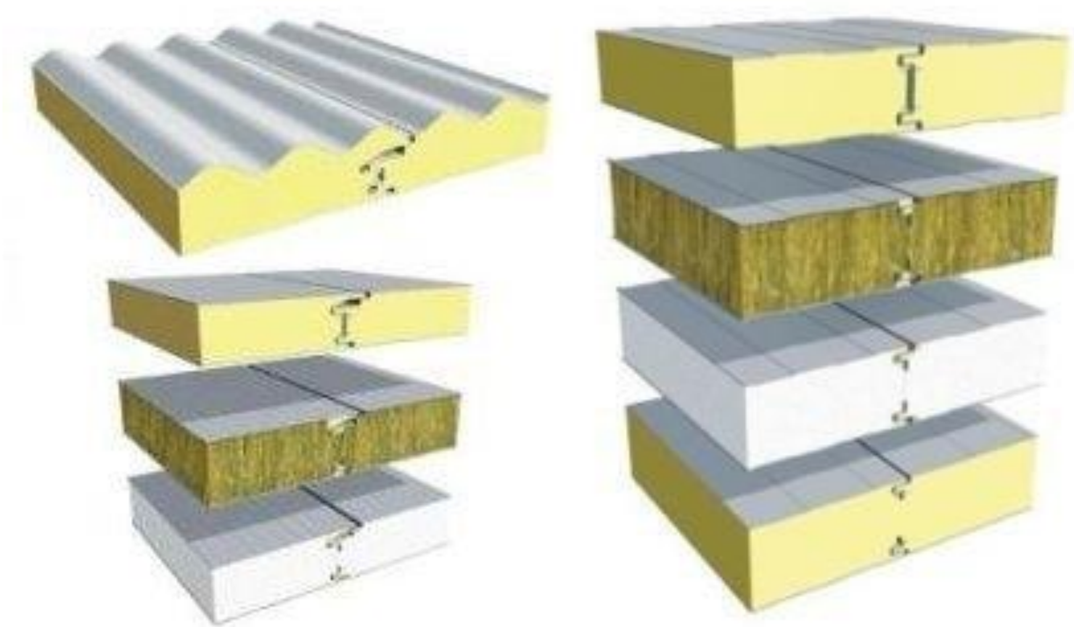


Photo: steelprofil.eu

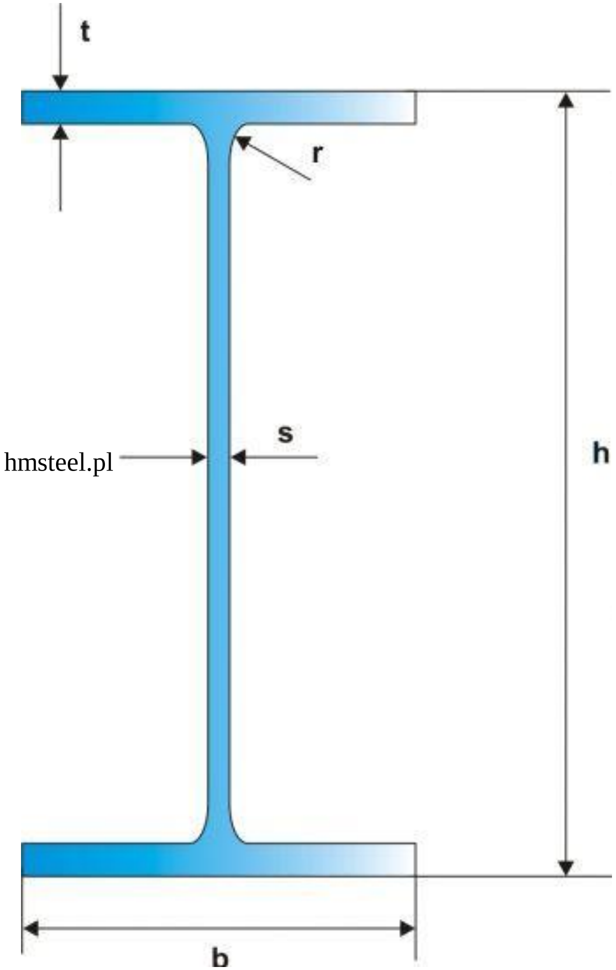


Photo: hmsteel.pl

Purlins - recomendations for height of cross-section and type of cross-section.

$h \approx l_p / 20 - l_p / 25$

IPE

(cross-section → dead-weight).

Housing columns - recomendations for height of cross-section and type of cross-section.

Photo: calgor.com.pl

$h \approx 1{,}5 \cdot$ housing girts

RHS

Housing girts - recomendations for height of cross-section and type of cross-section.

$h \approx l_p / 100$

C

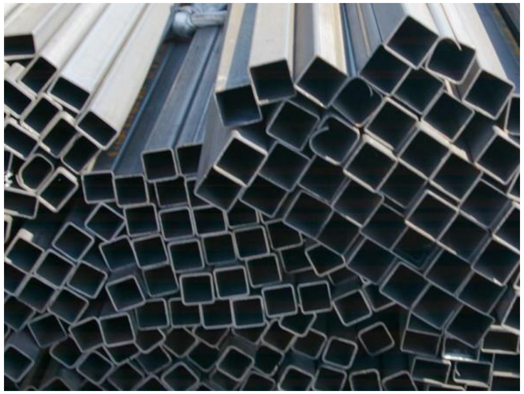


Photo: Author

Photo: wistal.pl

(cross-section → dead-weight).

Dead-weight of truss

I^{st} proposal (PN B 02001):

$$g_T = [\ 2 / a + 0{,}12\ (g + q)]\ L / 100$$

g_T (dead-weight of all trusses per area of roof), g (roofing + purlins), q (snow + wind) → [kN/m²], characteristic values

a (distance between trusses), L (truss span) → [m]

II^{nd} proposal:

$$g_{T1} = d_{steel}\ q_1\ L^3 / (2\ H\ f_y)$$

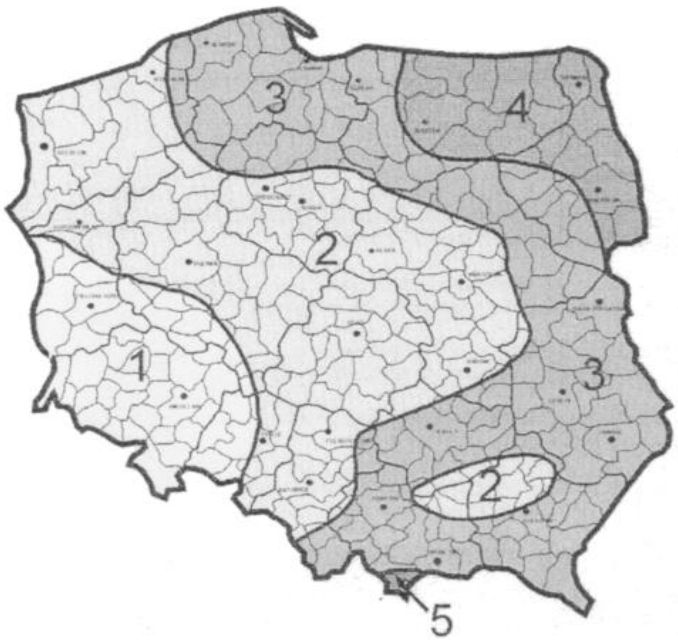
g_{T1} (dead-weight of one truss) → [kN], d_{steel} own weight of steel → [kN/m³], H – height of truss (vertical distance between top and bottom chord) → [m]

$$q_1 = a(g + q)$$

$$g_{T1} \approx a\ L\ g_T$$

EN 1991-1-3 Snow loads EN 1991-1-4 Wind actions

For both, we have map of Poland and information about value of load at any region.



EN 1991-1-3 fig. B.1

EN 1991-1-4 fig. NB.1

This is global location - load are different for differen part of Poland

Besides, local wind velocity or snow load can be different, in dependence on surroundings - wind acts in different way in narrow streets and on the open space.

Photo: visitcracovia.com

Photo: krakjw.wordpress.com

Because of this, local location are defined for different environmental conditions.

There are five terrain categories for wind and three for snow. Both types are defined independently: for snow (EN 1991-1-3 tab 5.1) and wind (EN 1991-1-4 tab 4.1). Rough comparison looks as follows:

Terrain

Wind - velocity decreases

Snow - load increases

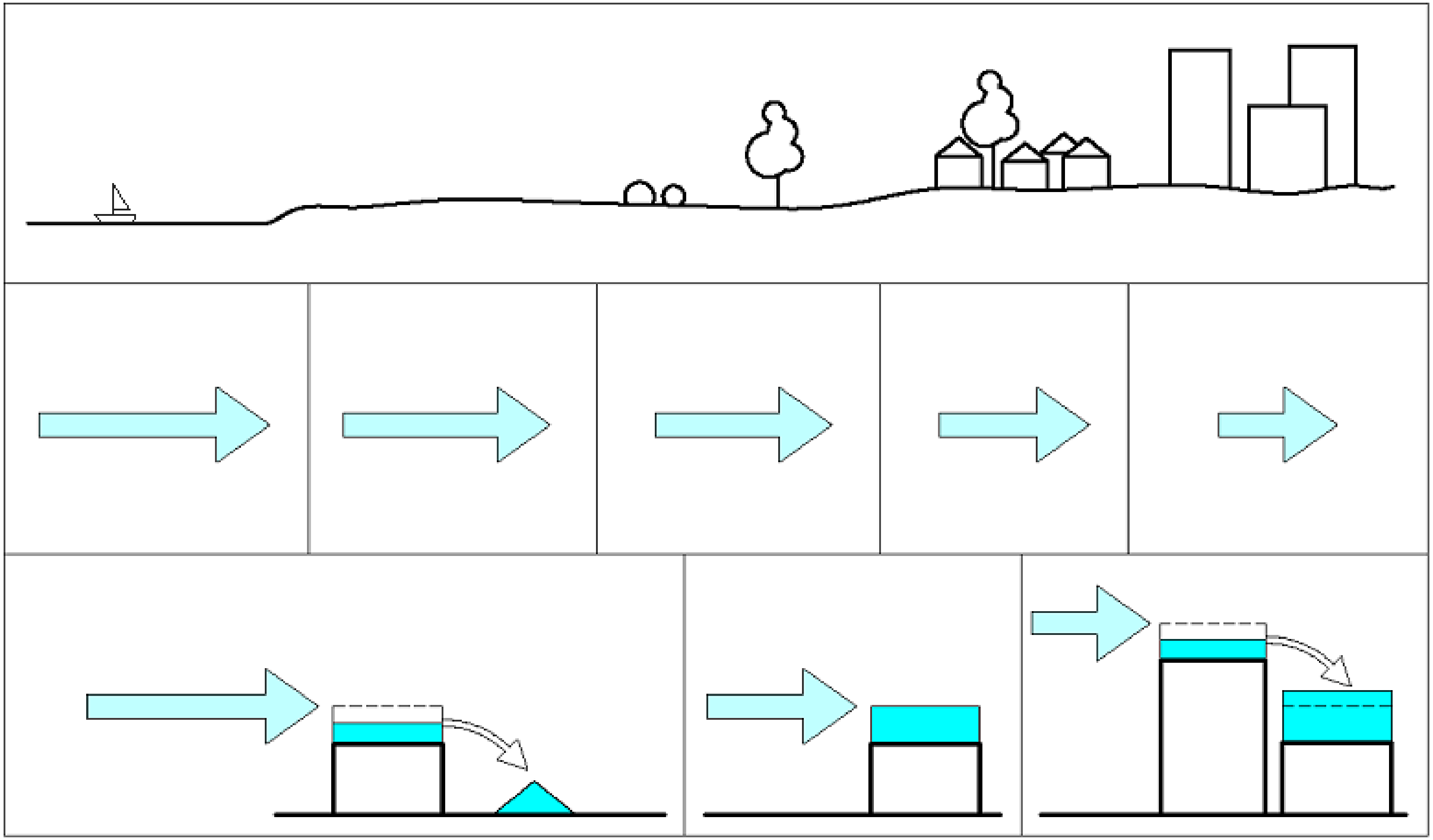


Photo: Author

Wind action acts on roof and walls. For this range of project, important is only actions on blue part of building (truss), not on red part (masonry). There is important, that for roof can be nonlinear wind action (wind action depends on height).

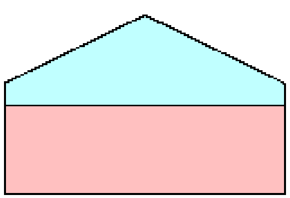
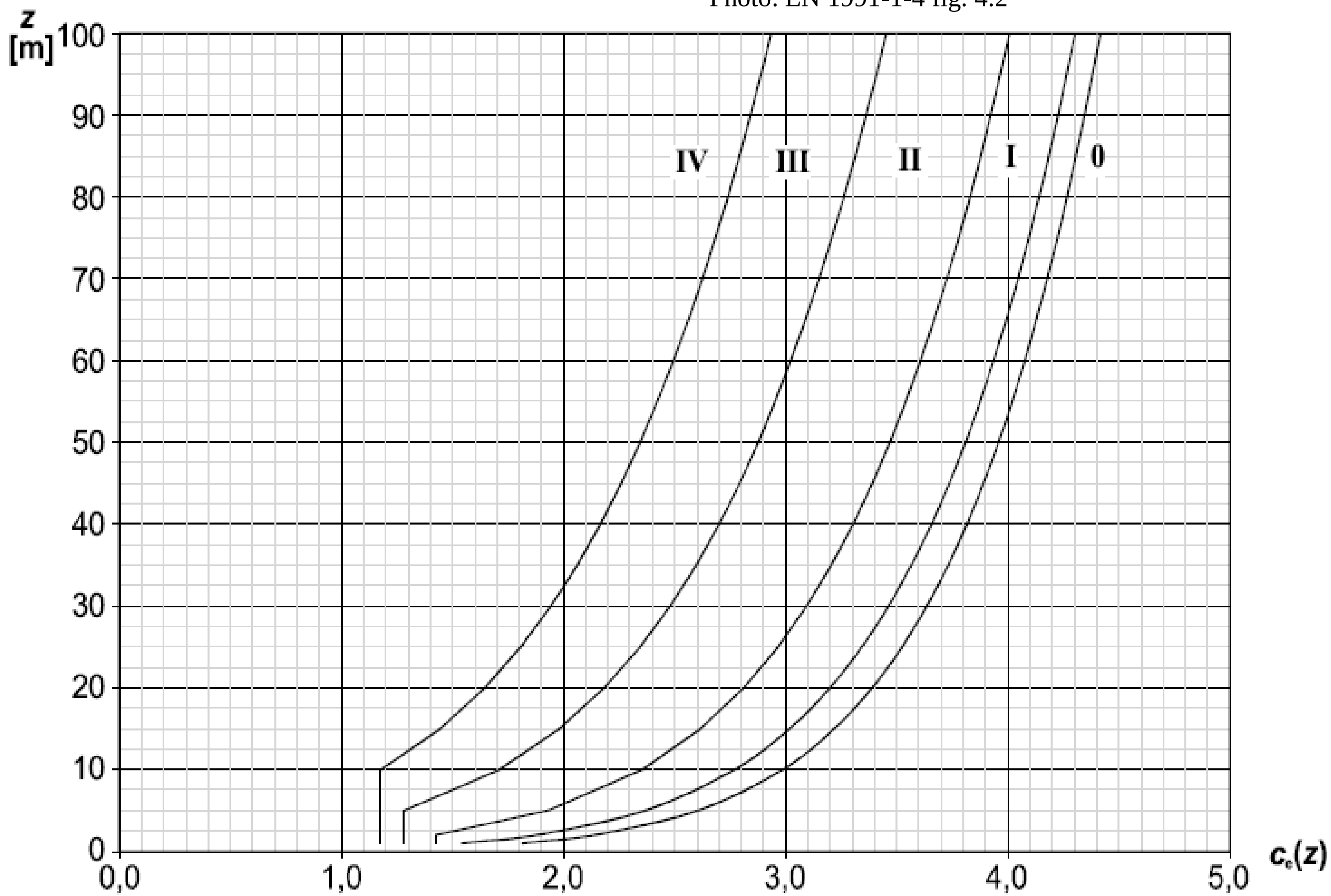


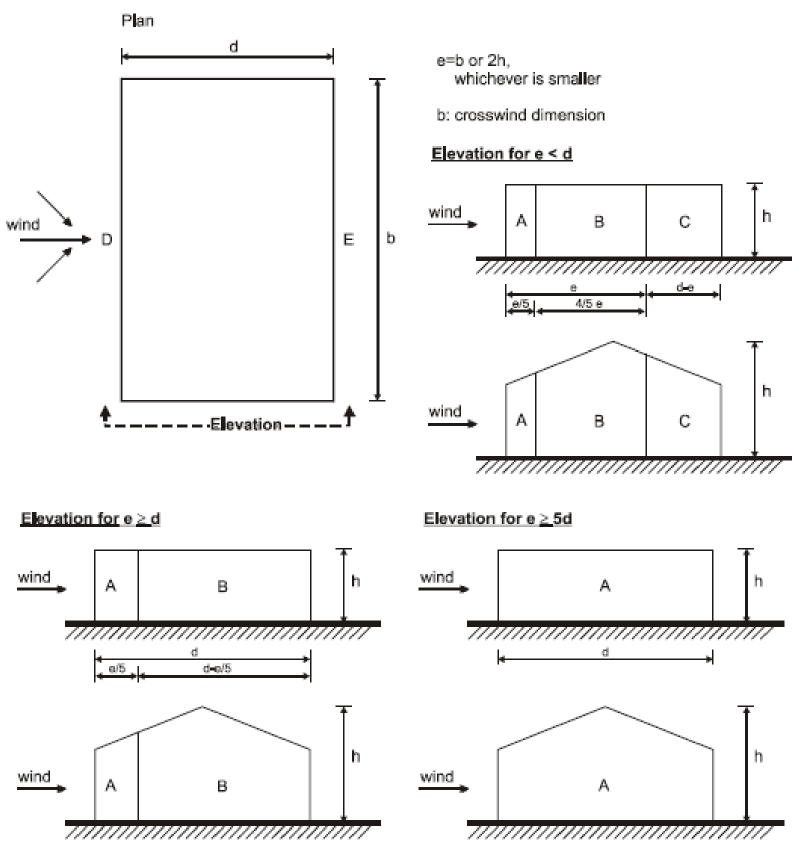
Photo: Author

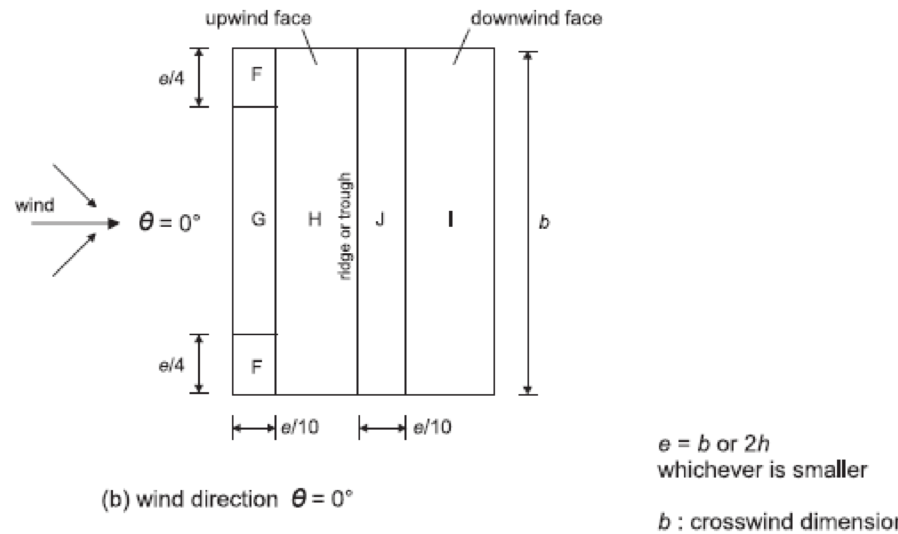
Photo: EN 1991-1-4 fig. 4.2



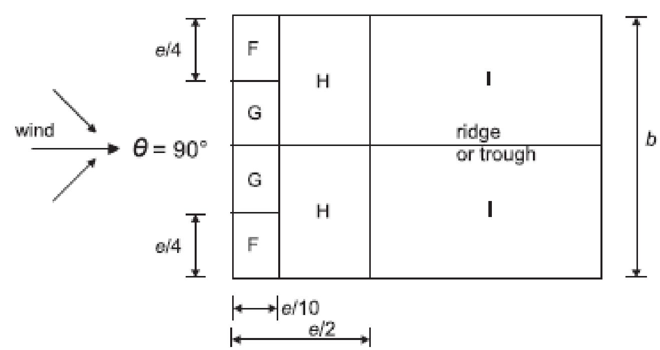
We must analyse wind parallel and perpendicular to longitudinal axis of building.

EN 1991-1-4 fig. 7.5, 7.8





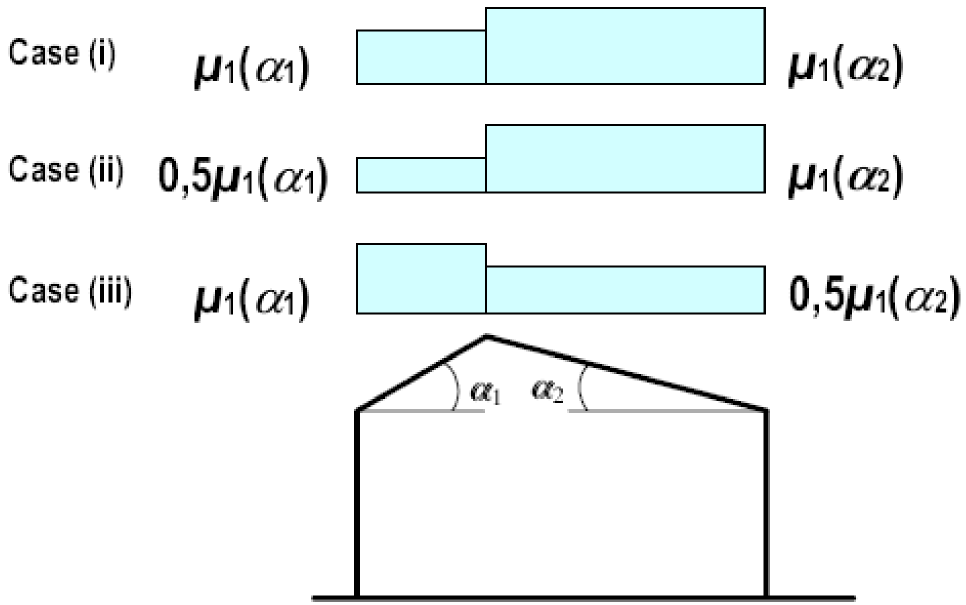
(b) wind direction θ = 0°



(c) wind direction θ = 90°

We must analyse symmetrical and antisymmetrical loads from snow.

EN 1991-1-3 fig. 5.3



Imposed load:

Roof not accesible except for normal maintenence and repair. Recommended value of loads according to EN 1991-1-1 tab. 6.10 $q_{i,\,k}$ = 0,4 [kN / m^2]

Maintenence and repair works can't be made in winter conditions. The snow load and imposed loads are mutually exclusive.

Photo: kattoliitto.fi

Combinations of loads for analysed structure (reminder from Introduction to Construction Design):

Case E_j	G		Q					
			Wind		**Snow** (Locations < 1000 m. above sea level)		**Imposed load** (roof)	
	γ_{Gi}	Ψ_i	γ_{Wi}	Ψ_i	γ_{Si}	Ψ_i	γ_{Ii}	Ψ_i
ULS								
1	1,35	1,00	1,50	1,00	1,50	0,50	1,50	0,00
2	1,35	1,00	1,50	0,60	1,50	1,00	1,50	0,00
3	1,35	1,00	1,50	0,60	1,50	0,00	1,50	1,00
4	1,00	1,00	1,50	1,00	1,50	0,00	1,50	0,00
SLS								
5	1,00	1,00	1,00	0,20	1,00	0,20	1,00	0,00
6	1,00	1,00	1,00	0,00	1,00	0,20	1,00	0,00
7	1,00	1,00	1,00	0,60	1,00	0,00	1,00	0,00

It will be enough to analyse green part

Case #1, 2, 3, 5, 6, 7: wind - pressure only

Case #4: wind - suction only

Elements

- Roofing panels
- Purlins
- Side wall girts
- Front wall girts
- Housing columns
- Truss members
- Horizontal bracings
- Vertical bracings

Roofing panels

Verification of roofing panles thickness based on the manufacturers' catalogs available online:

1 – distance between purlins (according to initial drawing);

2 – max loads could be applied to panels (dead weight + snow + wind pressure + imposed) for distance as above for ULS (nośność) ans SLS (sztywność);

1

2

Grubość rdzenia	Obc. ze względu na	Maksymalne obciążenia, daN/m² przy rozpiętości przęsła, m 2,1	2,4	2,7	3,0	3,3	3,6	3,9	4,2	4,5	4,8	5,1	5,4	5,7	6,0	6,3
50	nośność	139	107	84	68	57										
	sztywność	100	78	61	48	38										
75	nośność	211	162	128	103	86	72	61	53	46	40	36				
	sztywność	183	148	121	99	82	68	57	48	40	34	29				
100	nośność		283	223	181	149	126	107	93	80	71	63	56	50	45	41
	sztywność		199	166	141	120	102	88	76	66	57	50	44	39	34	30
125	nośność		355	281	227	188	158	134	116	101	89	78	70	63	57	51
	sztywność		265	224	193	166	144	125	109	96	85	75	66	58	52	46
15																
20																
25																

Photo: pruszynski.com.pl

1

2

Grupa kolorów	Warunki obciążenia		Obciążenie kN/m2 w zależności od rozpiętości 1,5	1,8	2,1	2,4	2,7	3,0	3,3	3,6	3,9	4,2	4,5	4,8	5,1	5,4	5,7	6,0	6,3	6,6	6,9	7,2
Grupa I kolory bardzo jasne	parcie	SGU	16,24	12,14	9,60	7,86	6,60	5,63	4,80	4,80	4,07	3,47	2,98	2,57	2,22	1,93	1,68	1,45	1,24	1,07	0,91	0,78
		SGN	7,35	6,38	5,55	4,83	4,28	3,83	3,47	3,47	3,17	2,90	2,67	2,42	2,19	2,00	1,82	1,65	1,52	1,38	1,26	1,17
	ssanie	SGU	16,58	12,48	9,94	8,21	6,94	5,98	5,08	5,08	4,35	3,75	3,26	2,84	2,50	2,21	1,96	1,75	1,57	1,41	1,28	1,16
		SGN	5,87	4,91	4,23	3,71	3,32	3,00	2,73	2,73	2,52	2,34	2,18	2,04	1,92	1,82	1,73	1,58	1,43	1,31	1,20	1,11
Grupa II kolory jasne	parcie	SGU	16,24	12,14	9,60	7,86	6,60	5,63	4,80	4,80	4,07	3,47	2,98	2,57	2,22	1,93	1,68	1,45	1,24	1,07	0,91	0,78
		SGN	7,35	6,38	5,55	4,83	4,28	3,83	3,47	3,47	3,17	2,90	2,67	2,42	2,19	2,00	1,82	1,65	1,52	1,38	1,26	1,17
	ssanie	SGU	16,58	12,48	9,94	8,21	6,94	5,98	5,08	5,08	4,35	3,75	3,26	2,84	2,50	2,21	1,96	1,75	1,57	1,41	1,28	1,16
		SGN	5,87	4,91	4,23	3,71	3,32	3,00	2,73	2,73	2,52	2,34	2,18	2,04	1,92	1,82	1,73	1,58	1,43	1,31	1,20	1,11
Grupa III kolory ciemne	parcie	SGU	16,24	12,14	9,60	7,86	6,60	5,63	4,80	4,80	4,07	3,47	2,98	2,57	2,22	1,93	1,68	1,45	1,24	1,07	0,91	0,78
		SGN	7,35	6,38	5,55	4,83	4,28	3,83	3,47	3,47	3,17	2,90	2,67	2,42	2,19	2,00	1,82	1,65	1,52	1,38	1,26	1,17
	ssanie	SGU	16,58	12,48	9,94	8,21	6,94	5,98	5,08	5,08	4,35	3,75	3,26	2,84	2,50	2,21	1,96	1,75	1,57	1,40	1,20	1,03
		SGN	5,87	4,91	4,23	3,71	3,32	3,00	2,73	2,73	2,52	2,34	2,18	2,04	1,92	1,82	1,73	1,58	1,43	1,31	1,20	1,11

Roofing acepted to the design must satisfys three requirements:

- Thickness must be non smaller than in topic;

- Max accepted load for analysed distance between purlins must be non smaller than loads in design project:
  - for ULS (SGN, nośność): cases 1, 2, 3, 4   #t / 37;
  - for SLS (SGU, sztywność): cases 5, 6, 7   #t / 37;

- Fire resistance must be non smaller than EI30 (E30 = fire integrity non smaller than 30 minutes; I30 = fire insulation non smaller than 30 minutes);

Roofing panel is Ist example of calculations in Example Part

Purlins

- Class of cross-section
- Shear resistance
- Bi-axial bending
- Deflections
- Axial force

Determination of the class of cross-section is always first step of calculation of steel members. Way of calculation will be presented on Lec #4. Resistance of cross-section depends on class of cross-section. More information is presented on Lab #1, Lab #2 and Lec #4.

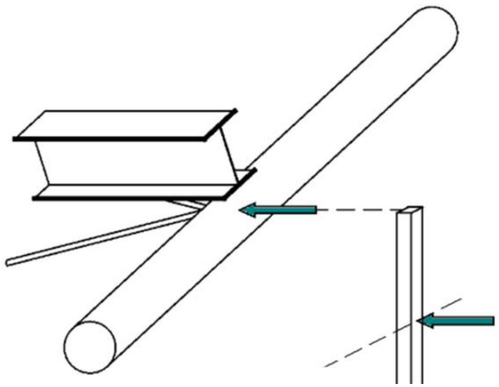


Photo: Author

Axial force occurs in purlins as a result of interaction between purlins and bracings (#t / 24). More information will be presented on Lecture #8 and #10.

If you use 3D computer full model of structure, you get immediatelly full information about cross-sectional forces in purlins (N_{Ed} , $M_{Ed, y}$, $M_{Ed, z}$).

Otherwise (2D), you must calculate purlins in two steps:

- for bi-axial bending;
- (after analysis of bracings) for bi-axial bending and axial force.

For this situations, effort in first step should be equal 0,8 ~ 0,9 to ensure „space" for additional effort from axial force.

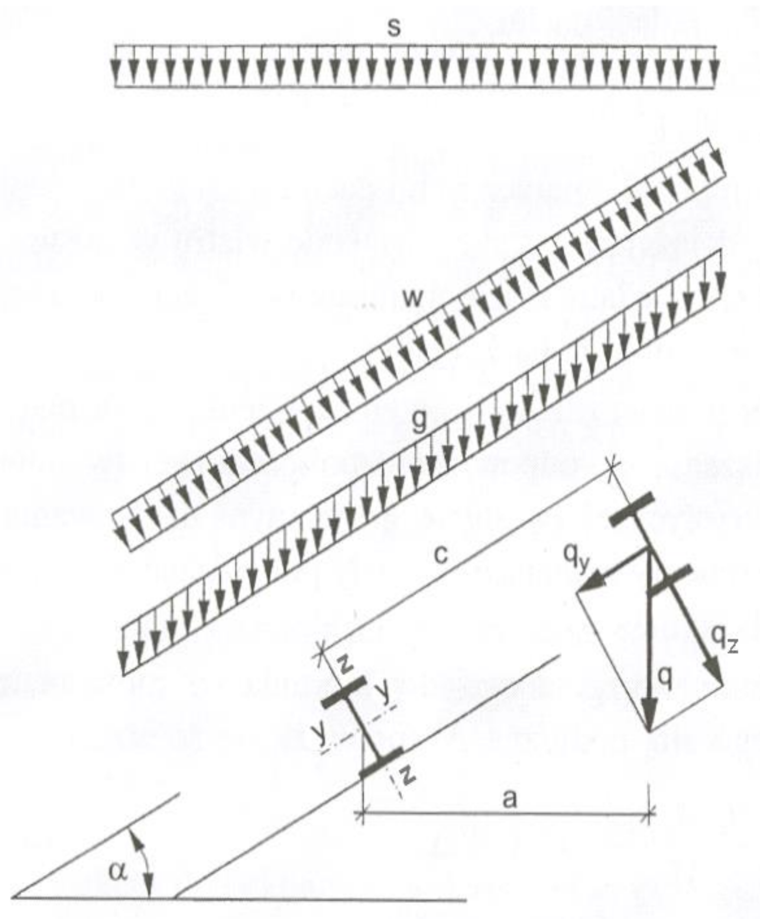


Photo: M. Łubiński, W. Żółtowski, Konstrukcje Metalowe t. II, Arkady, Warszawa 2004

Reminder from Introduction to Construction Design:

Three types of loads act on purlins:

- s - vertical related to the horizontal plane

([kN / m^2]; snow);

- g - vertical related to the plane of roof

([kN / m^2]; dead weight of roofing and imposed load);

- w - perpendicular to plane of roof

([kN / m^2]; wind).

These three types of loads must be recalculated to loads in main axes of inertia of purlin: q_y and q_z ([kN / m]). Dead weight of purlins ([kN / m]) acts vertically – must be recalculated by sin α and cos α to main axes. For one-span purlin:

$V_{Ey} = L\, q_y / 2$

$V_{Ez} = L\, q_z / 2$

$M_{Ey} = L^2\, q_z / 8$

$M_{Ez} = L^2\, q_y / 8$

There is bi-axial bending and bi-dierctional shear.

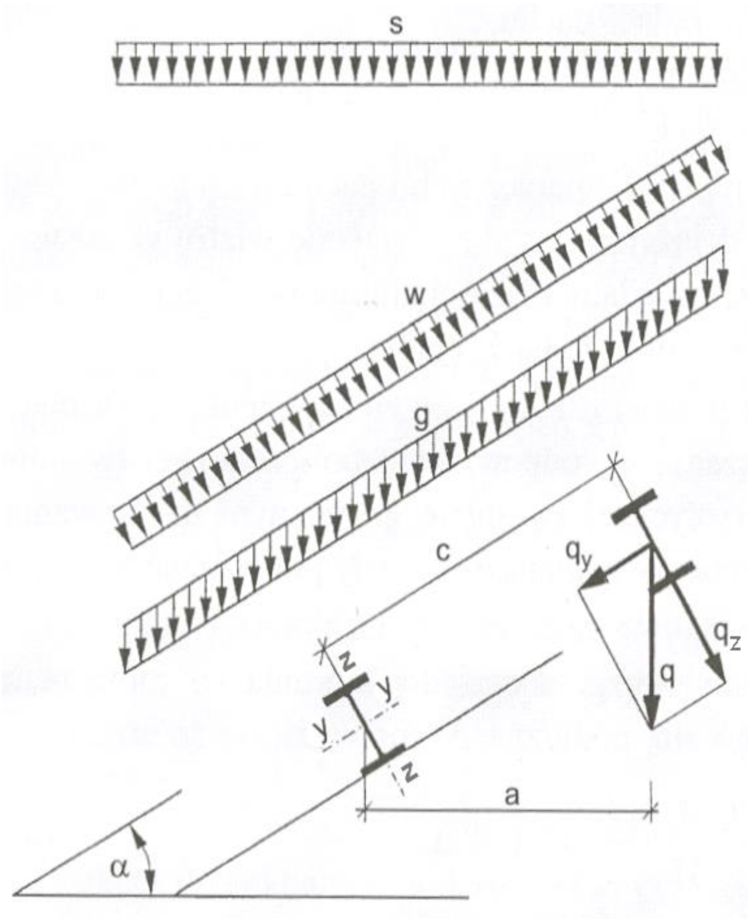


Photo: M. Łubiński, W. Żółtowski, Konstrukcje Metalowe t. II, Arkady, Warszawa 2004

Purlin is IInd example of calculations in Example Part

Housing girts (side wall / front wall)

- Class of cross-section
- Shear resistance
- Bi-axial bending
- Deflections

Calculation completely the same as in II^nd example of calculations in Example Part, but for other cross-section (C-section).

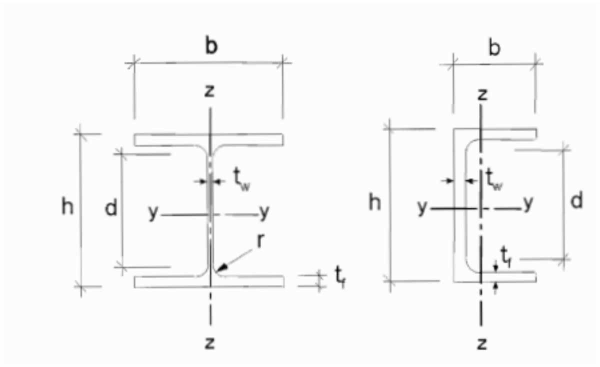


Photo: EN 1993-1-1 fig. 1.1

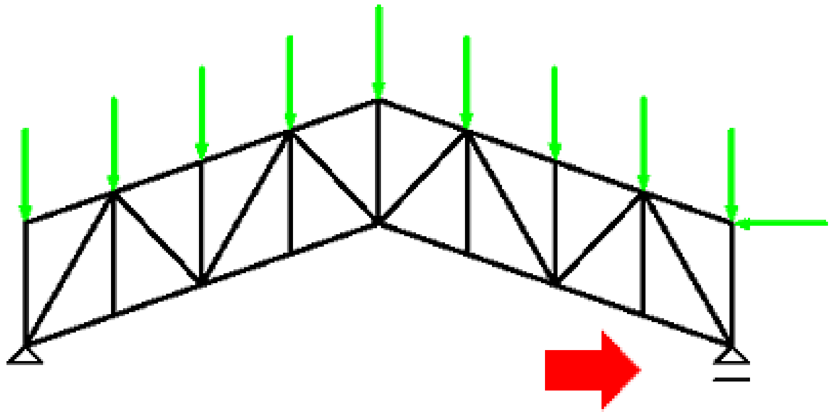
Housing columns

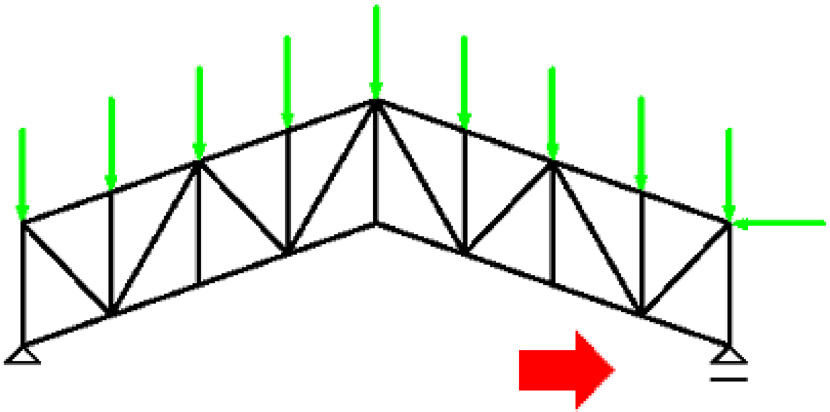
- Class of cross-section
- Shear resistance
- Bending with compressive axial force
- Flexural buckling under axial force
- Deflection

Truss bars

- Static calculation of forces in truss
- Class of cross-sections for truss members
- Resistance of truss members under tension
- Stability of truss members under compression
- Deflections

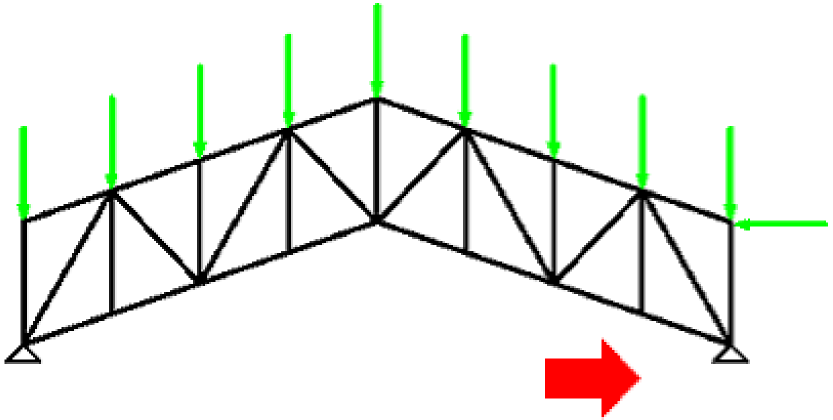
Static scheme of truss





These ↑ are closed to reality that these ↓

More information will be presented on Lec #9



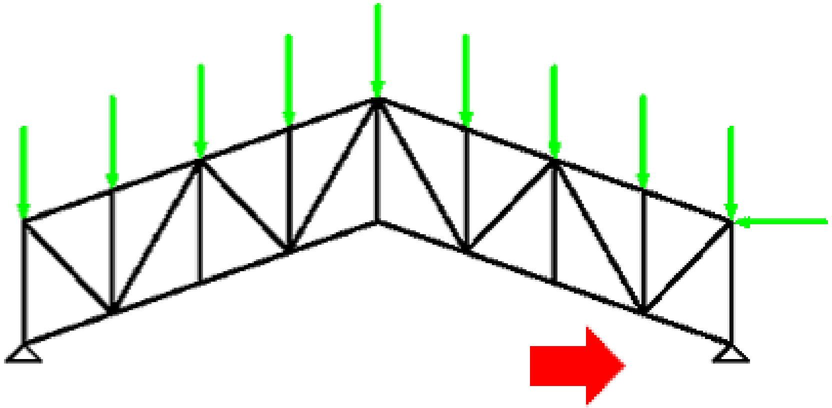
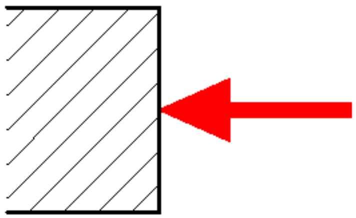


Photo: Author

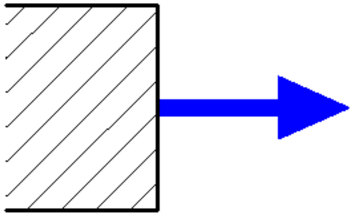
Positive and negative stress

According to Eurocodes:



$N_{Ed} > 0$
$\sigma > 0$

Photo: Author



$N_{Ed} < 0$
$\sigma < 0$

There is possible, that for diferent computer programmes these signs can be adopted by the opposite way. It's very important especially for buckling under axial force (buckling ↔ compressive force).

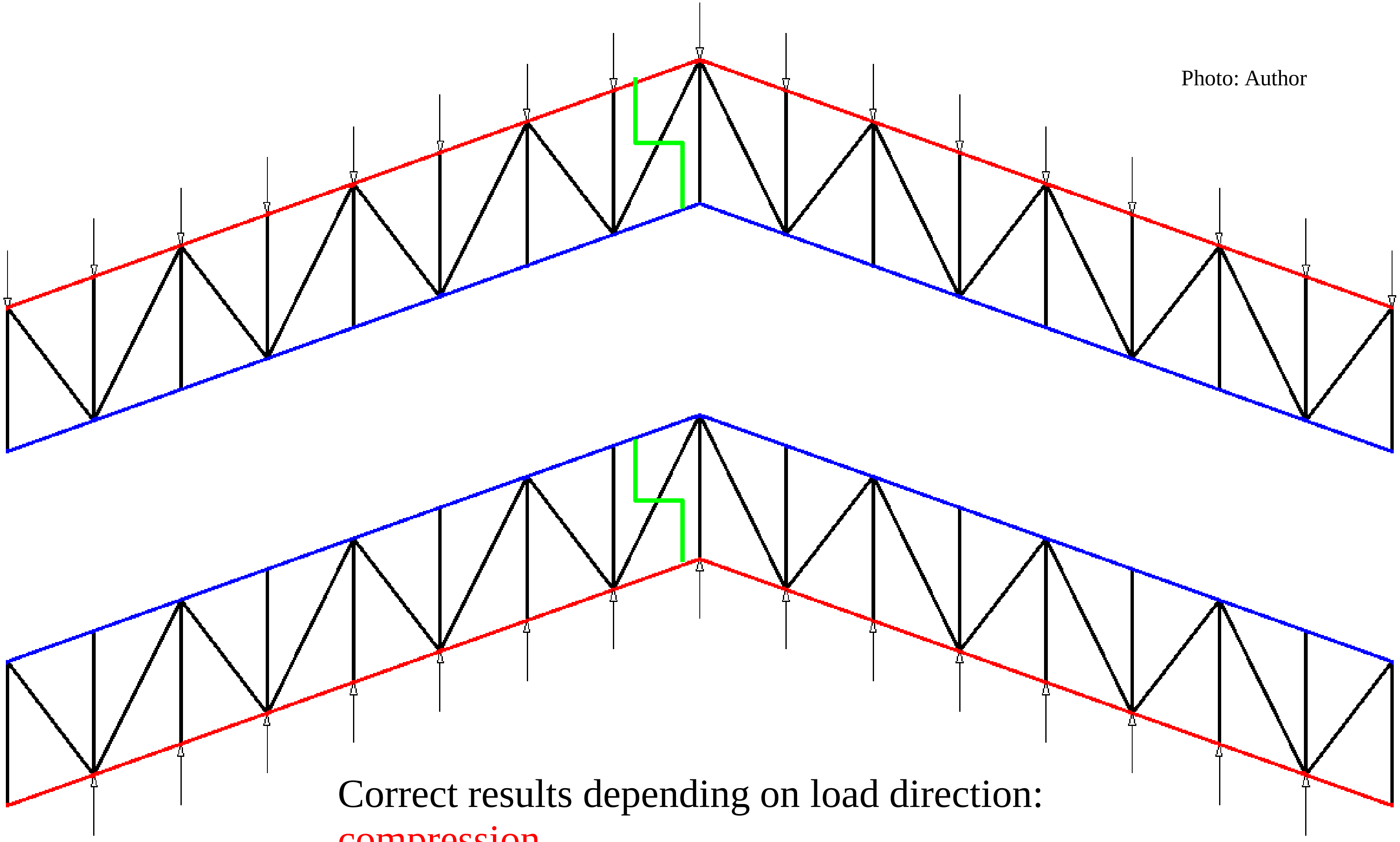


Photo: Author

Correct results depending on load direction:
compression
tension

Additionally:

|top tension| ≈ |bottom compression|

|top compression| ≈ |bottom tension|

Results from static calculation must be presented in table (envelope of axial forces):

# bar	$N_{Ed, min}$ [kN]	$N_{Ed, max}$ [kN]
1	-257,234	89,332
2	-264,875	92,093
...		
14	-14,857	no compression
15	no tension	16,756
...		

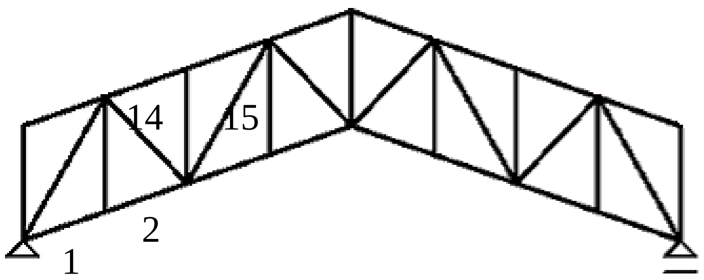


Photo: Author

$N_{Ed, min}$ – the smalles value below 0,000 (the biggest tension)

$N_{Ed, max}$ – the biggest value abowe 0,000 (the biggest compression)

Most important requirements for truss membesr according to Eurocodes:

Chords : hot-rolled I-beams or RHS or CHS (recommended for this project are CHS);

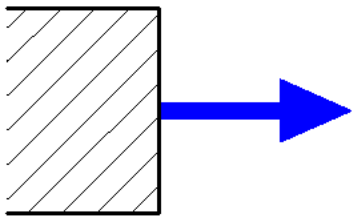
Truss bracing: RHS or CHS (recommended for this project are CHS);

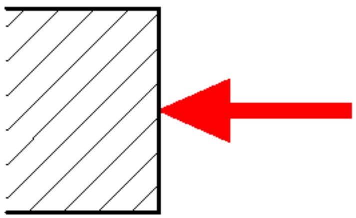
Each element at I^st or II^nd classs of cross-section;

Resistance (cross-section)

$$N_{Ed} / N_{t,\, Rd} \leq 1{,}0$$

$$N_{t,Rd} = A\, f_y / \gamma_{M1}$$





$$N_{Ed} / N_{b,Rd} \leq 1{,}0$$

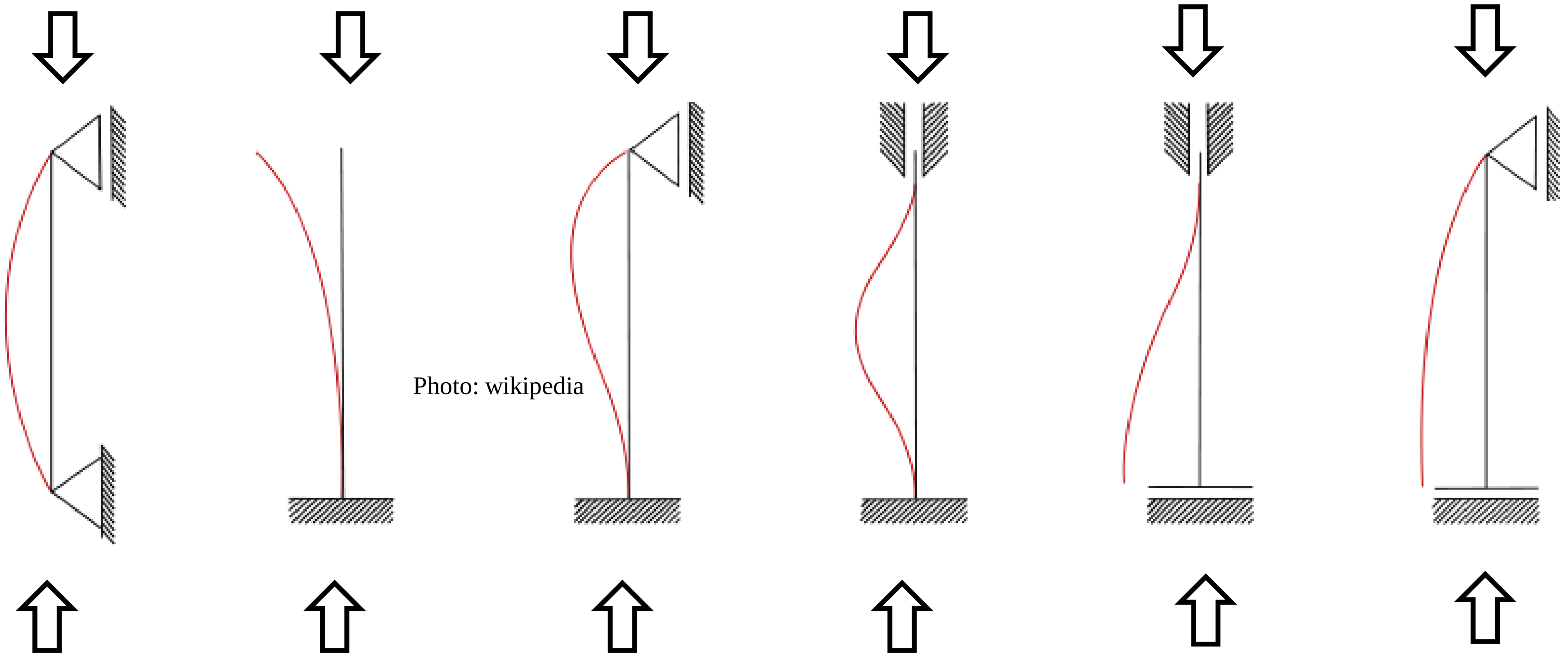
$$N_{b,Rd} = \chi\, A\, f_y / \gamma_{M0}$$

Resistance (cross-section)
Instability; flexural buckling (element)

Photo: Author

<u>Critical length</u> is very important for buckling

Critical length L_{crit} : theoretical distance measured along the member, depending on distance between supports L and support conditions (factor), important in the analysis of loss of stability.



L_{crit} = 1,0 L L_{crit} = 2,0 L L_{crit} = 0,7 L L_{crit} = 0,5 L L_{crit} = 1,0 L L_{crit} = 2,0 L

Distance between supports for truss members is depend on plane of analysis and part of structure. For web members, in both planes distance between supports = distance between nodes.

Flexural buckling of chords:

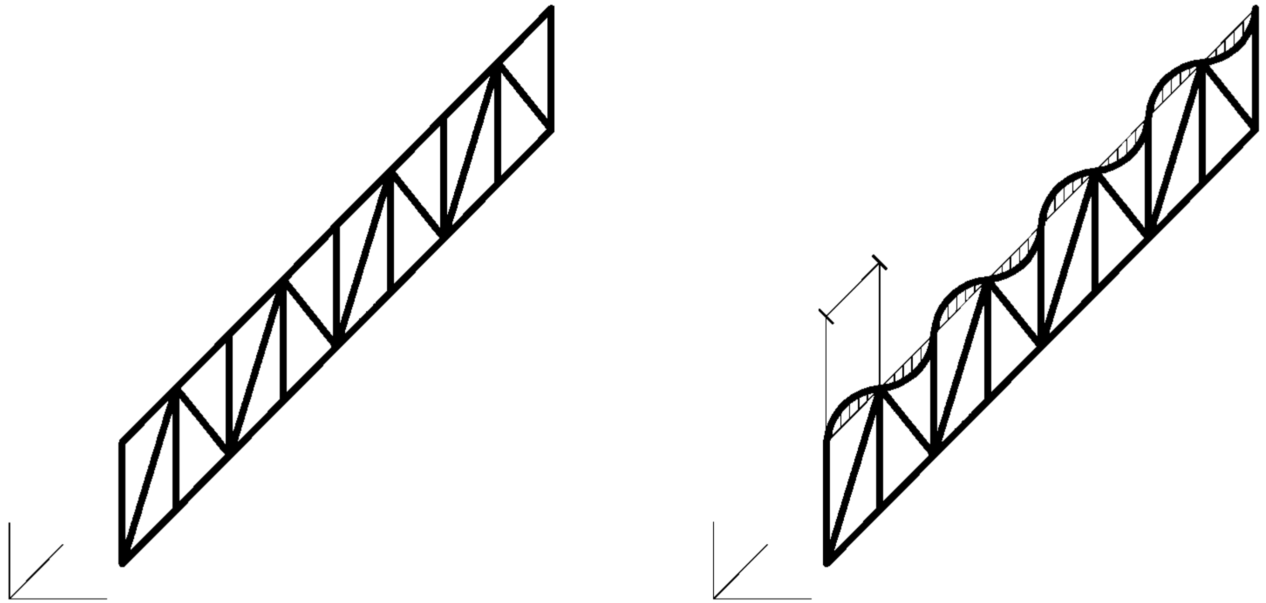


Photo: Author

Top chords in compression; buckling in plane: distance between supports = distance between nodes

Flexural buckling of chords:

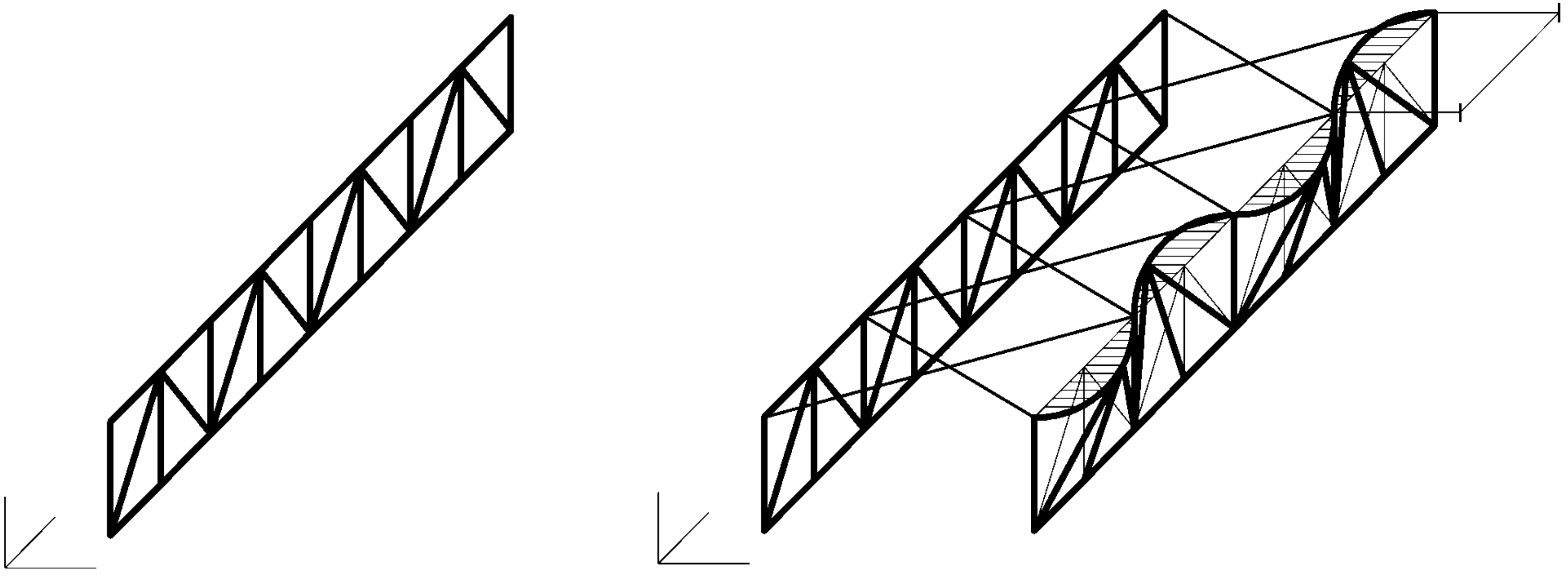


Photo: Author

Top chords in compression; buckling out of plane: distance between supports = distance between horizontal bracings

Flexural buckling of chords:

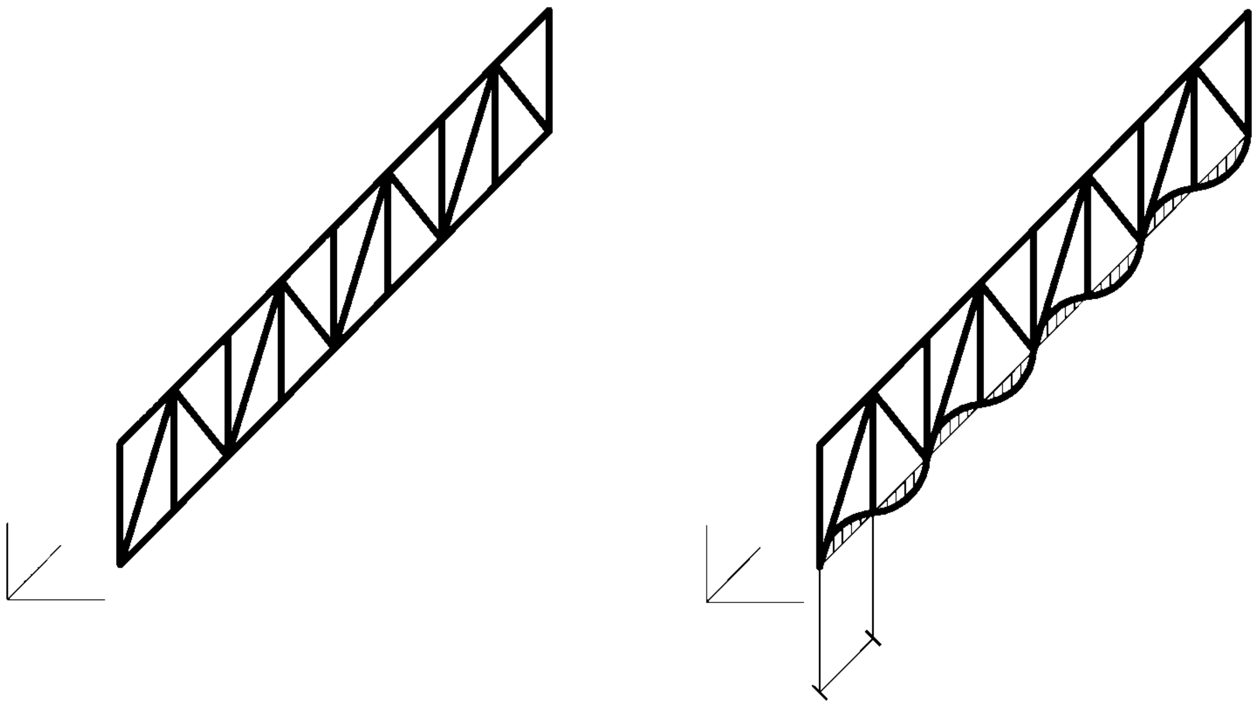


Photo: Author

Bottom chords in compression; buckling <u>in plane</u>: distance between supports = distance between nodes

Flexural buckling of chords:

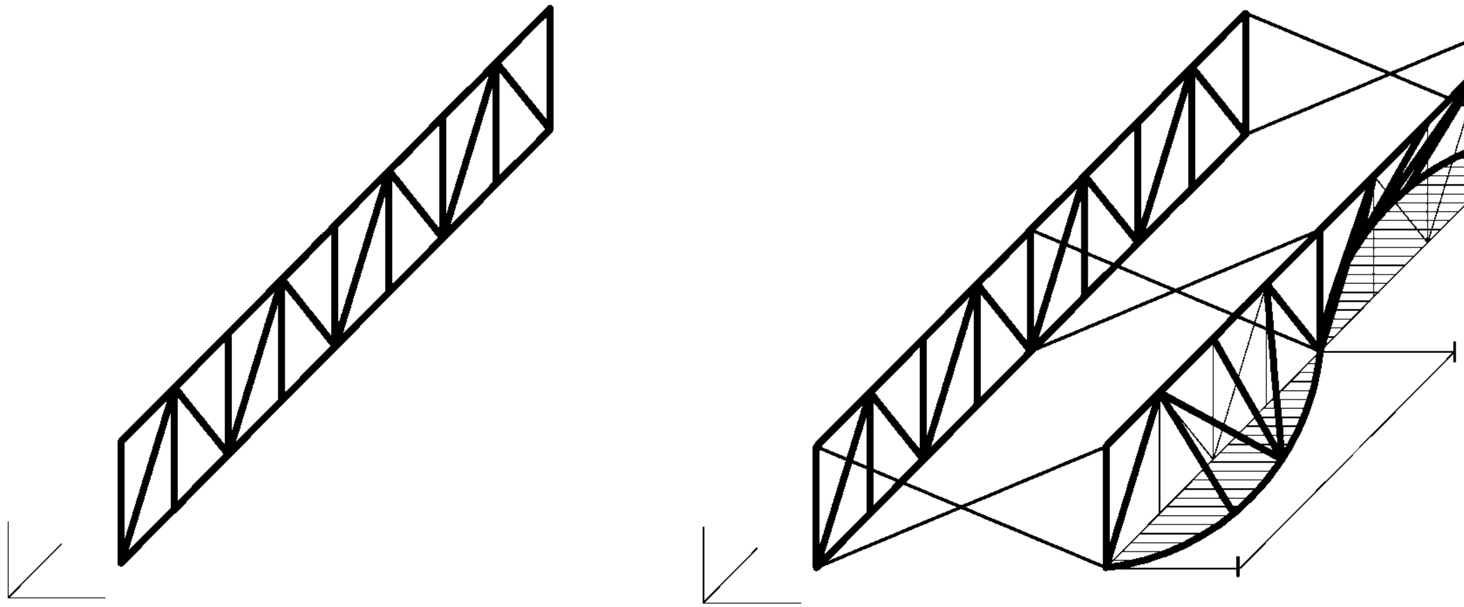


Photo: Author

Bottom chords in compression; buckling <u>out of plane</u>: distance between supports = distance between vertical bracings

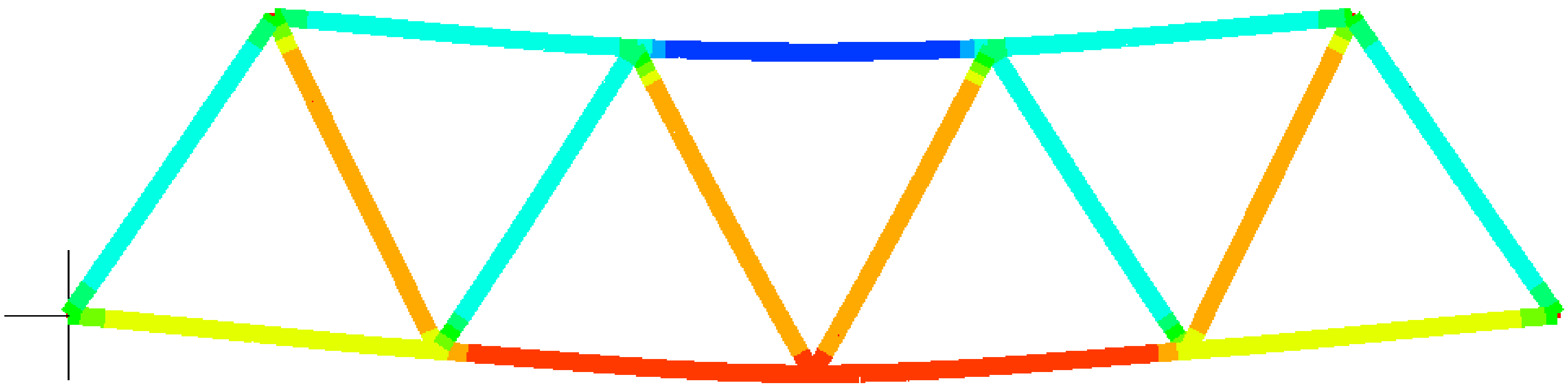
Eurocode gives critical length factor („type of support”) in dependence of type of cross-sections:

Chord	In plane	I H	0,9
		RHS CHS	0, 9
	Out of plane	I H	1,0
		RHS CHS	0, 9
Truss bracing	In plane	RHS CHS	0, 9 (0,75)
	Out of plane	RHS CHS	1,0 (0,75)

Value in brackets: (chords parallel, $d_{truss\ bracing} / d_{chord} < 0,6$)

Deflection

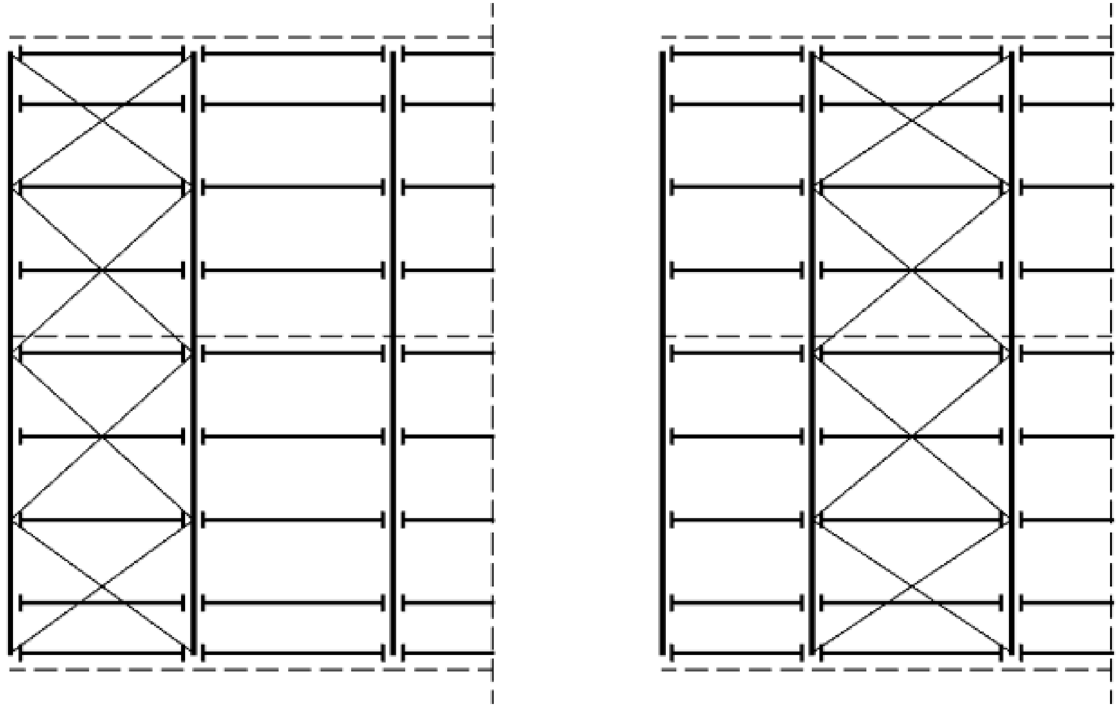
$f_{max} \rightarrow$ EN 1993-1-1 N.A. 22



Truss chord is III^rd example of calculations in Example Part

Horizontal bracings

Photo: Author



Loads:

- wind action on front wall;
- equivalent effects from imperfection of truss;
- equivalent effencts from instability of truss.

Three various types of actions must be analised.

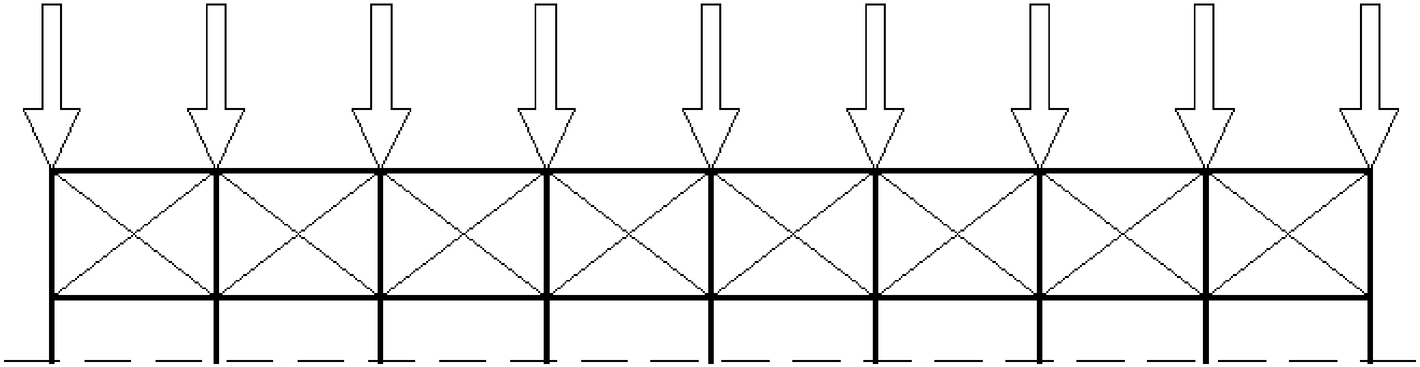


Photo: Author

1. Wind action (pressure on winward wall + suction on leeward wall + wind friction). Load depends on area of front wall and wind pressure.

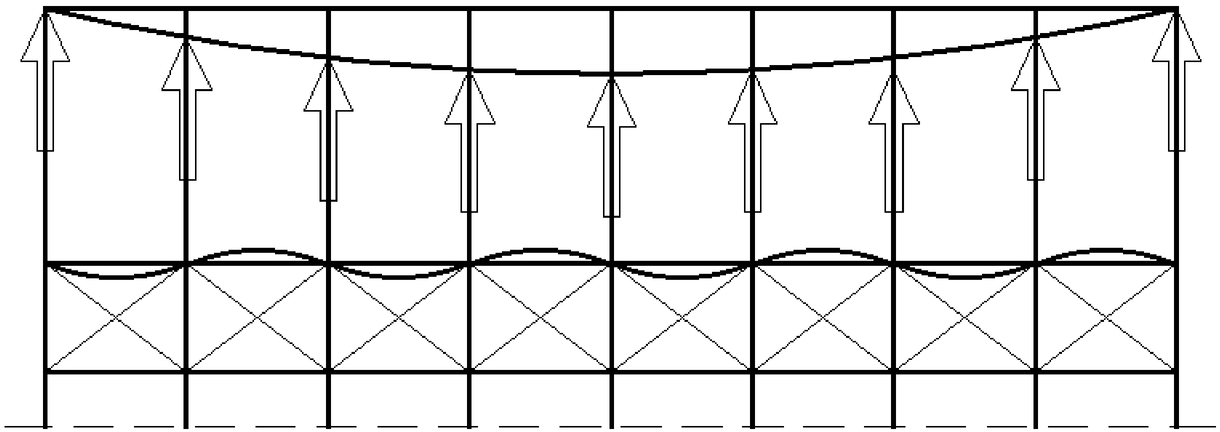
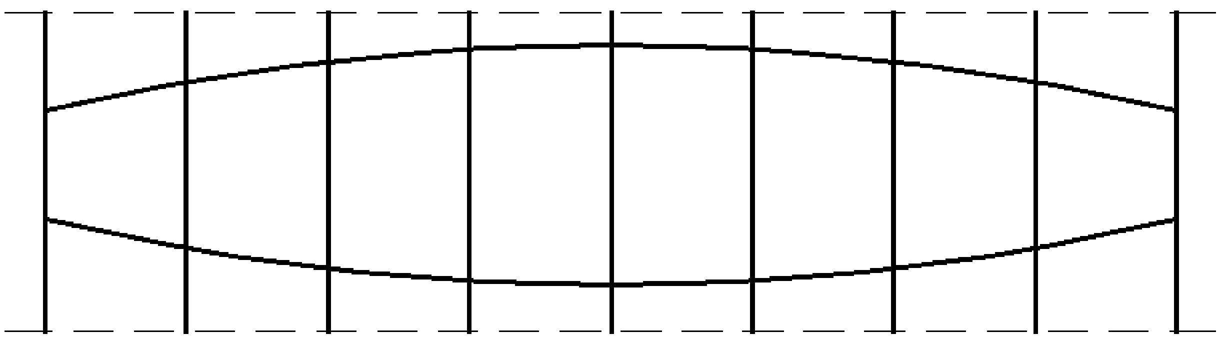


Photo: Author



2. Instability of roof girders.
Bracing prevent roof girder from instability out of truss plane. Witout them, buckling of girder occurs on total length. Bracings act as complex of forces, make girder more straight. These forces – as reaction – must be applied to bracings. Walue of these forces is **equivalent load**, in proportion to compressive force in girder.

Girders lose stability randolmy, in left or right direction. Total effect for entire roof is not: (single effect) · (number of girders m)
but: (single effect) · (reduction factor α_m).

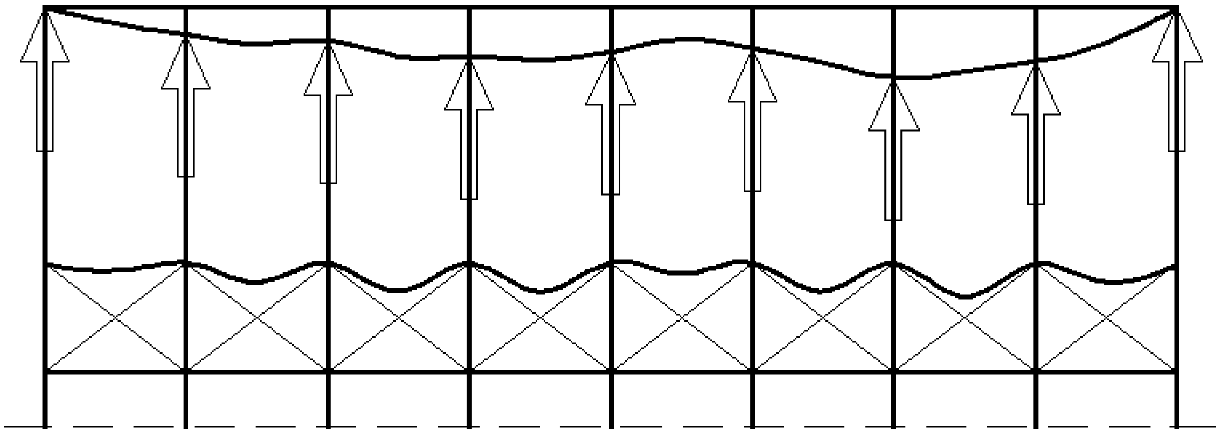
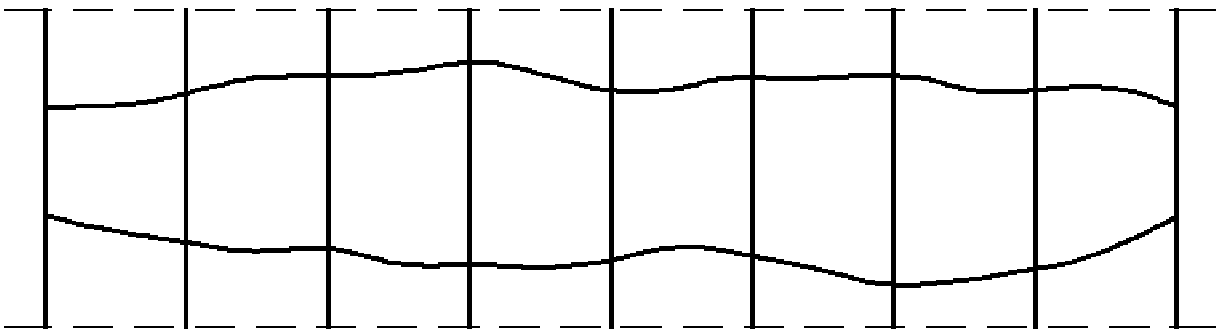


Photo: Author



3. Imperfections of roof girders.

Roof girders are not perfectly straight. Bracings act as complex of forces, make girder more straight. These forces – as reaction – must be applied to bracings. Walue of these forces is **equivalent load**, depends on initial bow imperfection of girder and compresive force in girder.

Girders are imperfected randolmly, in left or right. Total effect for entire roof is not: (single effect) · (number of girders m)
but: (single effect) · (reduction factor α_m).

Two types of equivalent loads:

- from instability of girder

  and

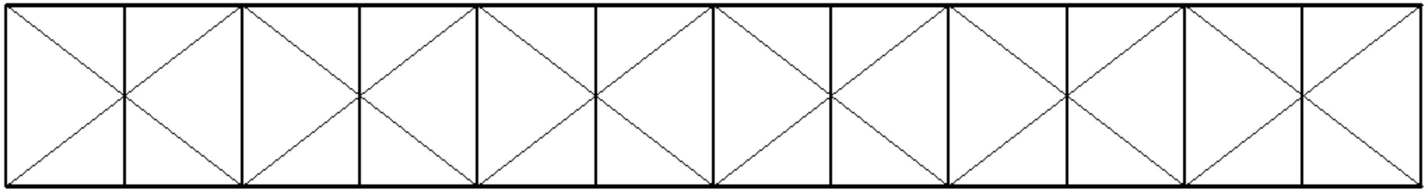
- from imperfection of girder,

are analysed. Force from one roof girder for equivalent forcefrom istability:

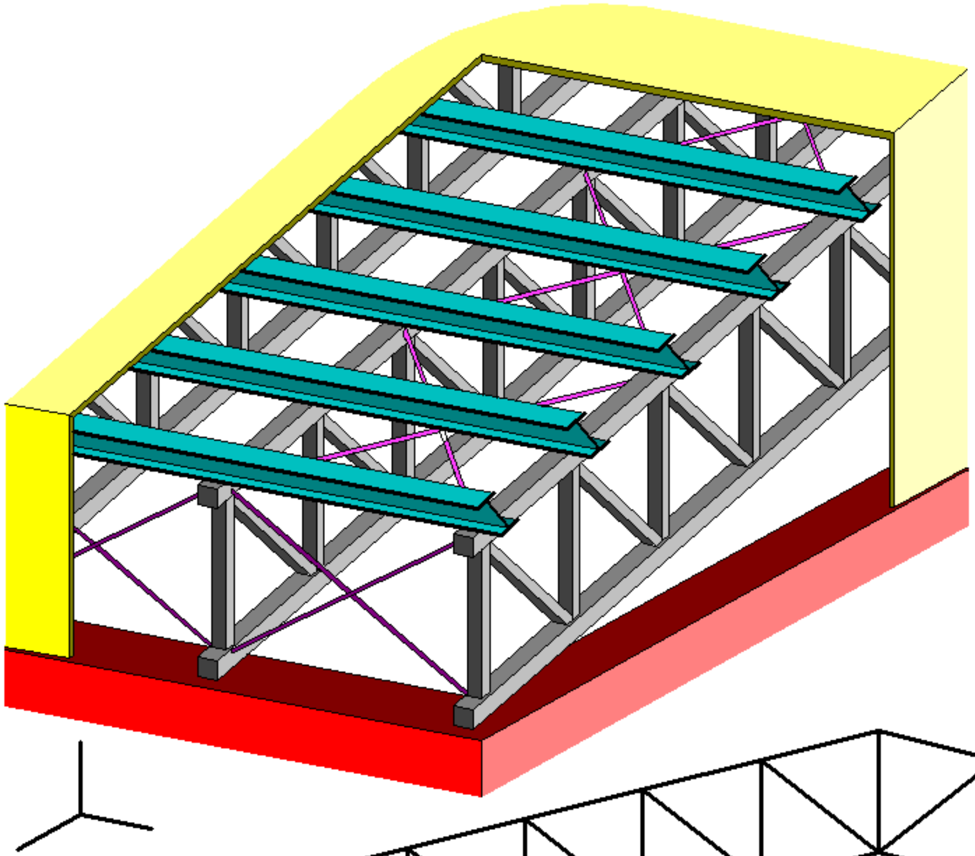
$$\text{Equivalent load} = (\text{compressive force in girder}) \cdot (\text{special factor})$$

This means, that algoritm is as follow:

- truss girder (verical truss) must be analysed;
- compressive force in top cord must be found;
- equivalent load is calculated, based on compression in top chord;
- bracings (horizontal truss) is calculated.

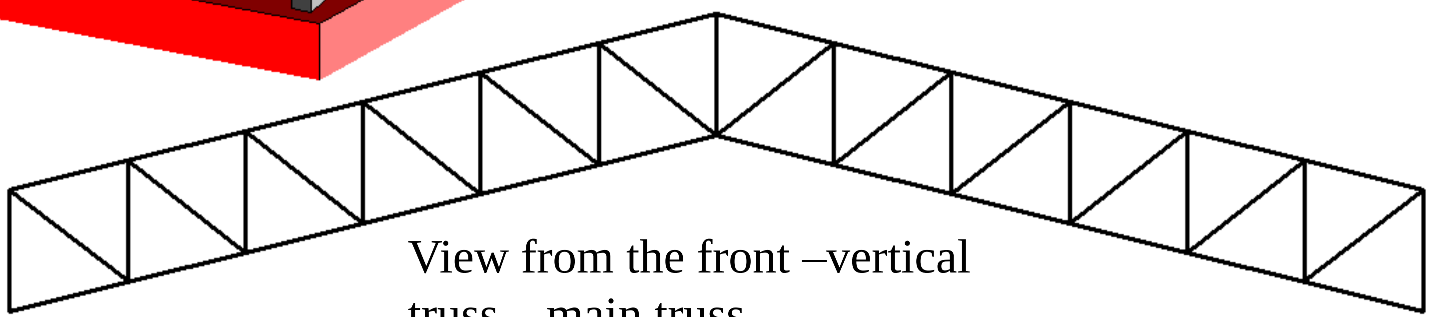


View from the top – horizontal truss – bracing system.

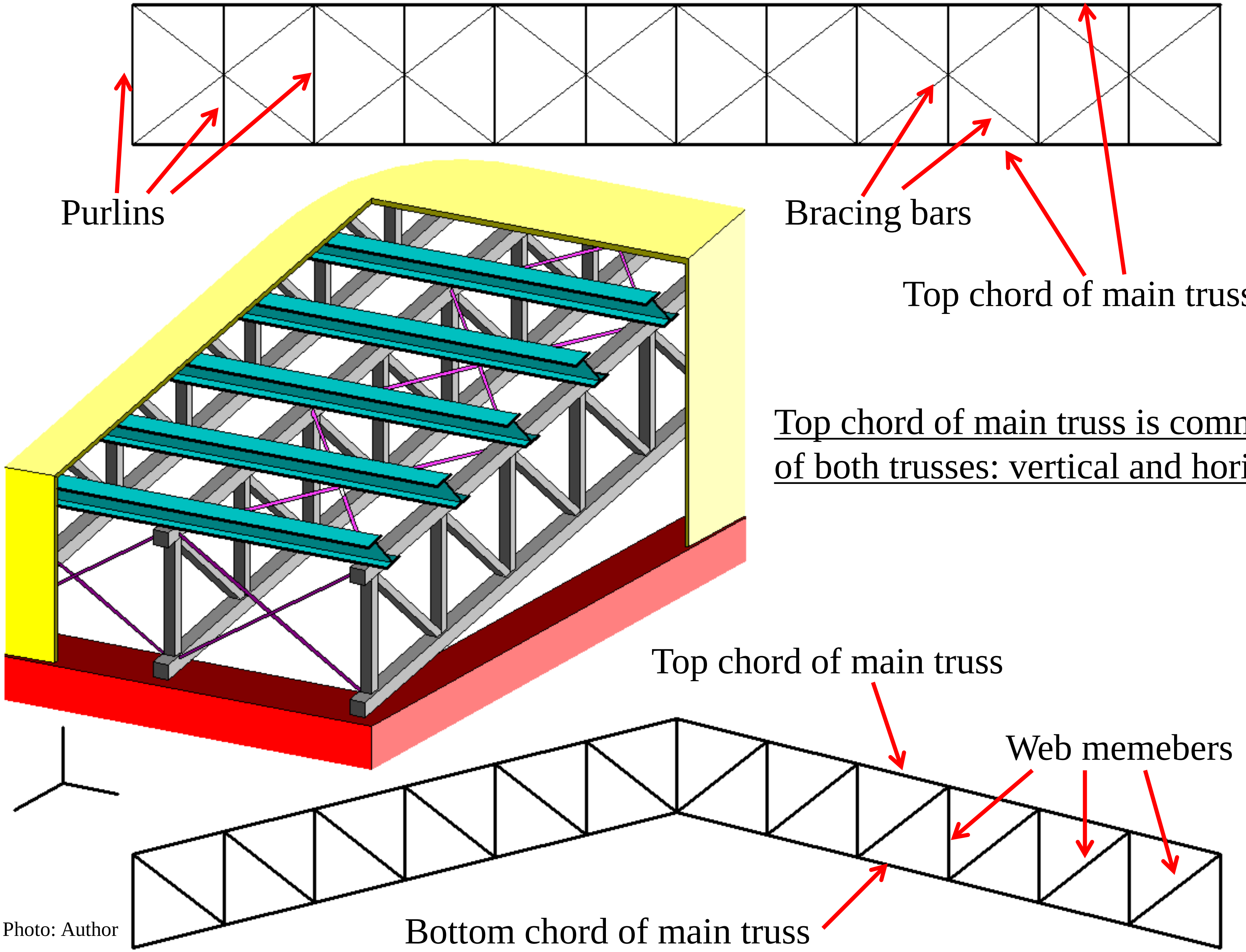


Truss roof gidrer is complicated, spatial structure.

Photo: Author



View from the front –vertical truss – main truss.



Top chord of main truss is common part of both trusses: vertical and horizontal.

Static analysis of vertical truss

⇩

Forces in top and bottom chords of vertical truss

⇩

Checking resistance and stability members of vertical truss

⇩

Forces in chords of horizontal truss – this means additional value of force in top chord of vertical truss

⇩

Checking resistance and stability members of horizontal truss

⇩

New value of force in top chord of vertical truss

⇩

Once again checking resistance and stability top chord of vertical truss

The forces applied to the horizontal bracing depend on the compression forces in the upper chord of the vertical truss. At the same time, the spatial cooperation of all elements results in additional forces appearing twice - in the purlin (→ #t / 42) and in the upper chord of the horizontal truss (→ #t / 66) - coming from the cooperation of braces with these elements.

This problem can be solved at the stage of the numerical model in two ways:
- accurately in a 3D model;
- approximately in a flat 2D model.

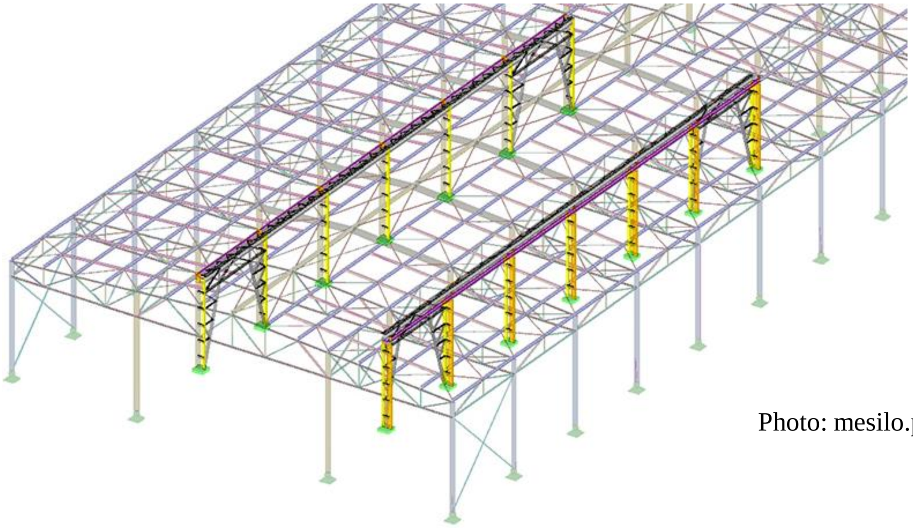


Photo: mesilo.pl

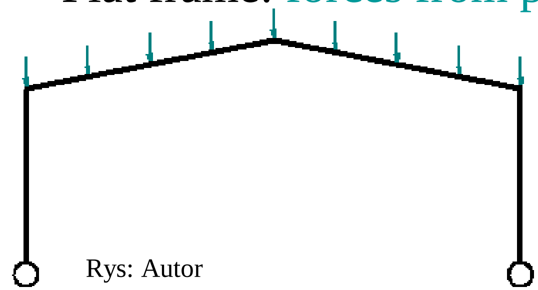
3D model in FEM calculations: we have full information about cooperation between trusses, purlins and bracing bars right away. Calculation is made in two steps:

- initial calculation: dead weight, climatic actions, live loads etc.
- equivalent forces: from imperfections of trusses and from prevention of instability of trusses. Values of these forces are calculated based on forces in trusses after initial calculations.

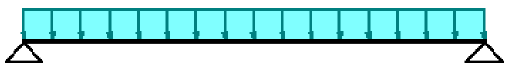
Final effect: forces in chords from initial calculations and equivalent forces is final result of static calculations.

2D model (method of equivalent flat frames) is much more complicated:

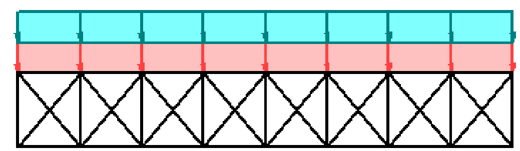
Flat frame: forces from purlins



Purlin: bi-axial bending

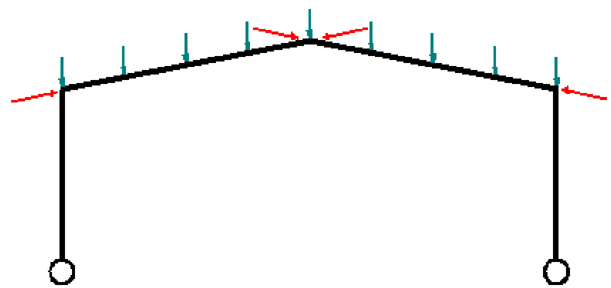


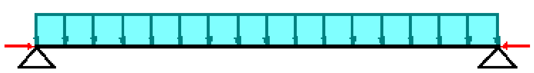
Roof bracings: horizontal truss



Wind acrion
Equivalent forces from instability and imperfection

Cooperation frame-bracings: additional forces in purlins, additional forces in frame.

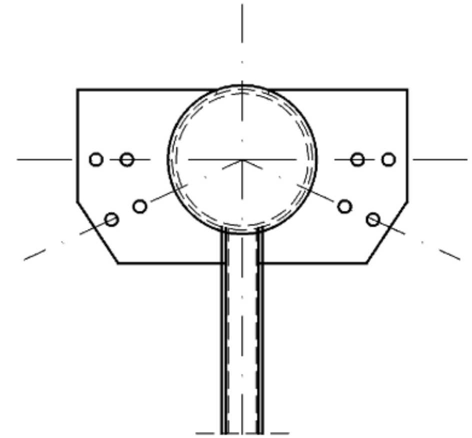




Purlin: bi-axial bending + compressive axial force (recalculation)

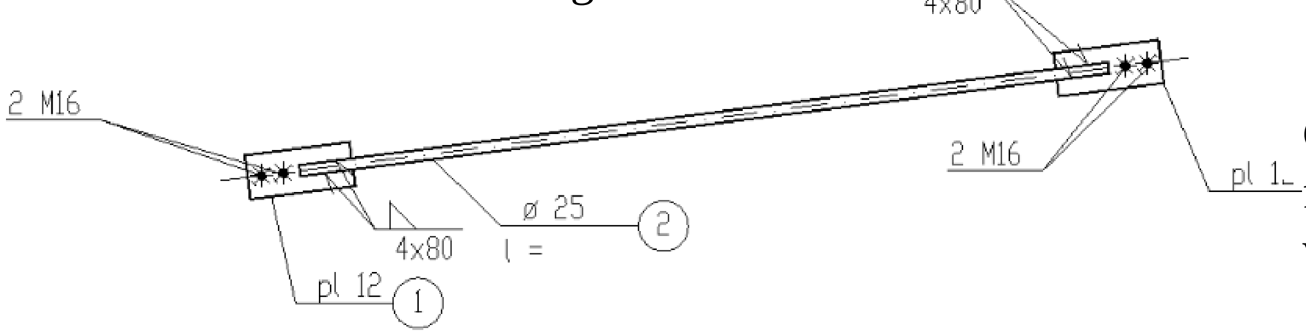
Frame: additional axial forces from cooperation with bracings (recalculation)

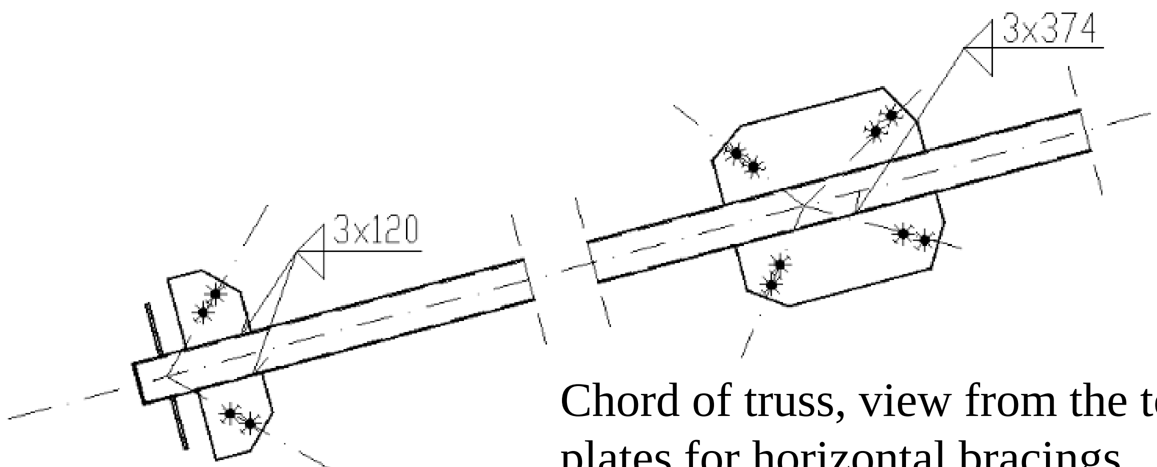
Recommendation for bracing bars: thickness of gusset plates 12 mm, 2x M16, round bar ϕ 25.



Chord of truss, view from the front – gusset plates for vertical bracings

Bracing bar





Chord of truss, view from the top – gusset plates for horizontal bracings

Photo: Author

Horizontal bracing is IVth example of calculations in Example Part

Verical bracings

They must be shown in the initial drawing - their location defines buckling lengths of truss chords. They are not obligatory in Your range of project; can be taken the same as horizontal bracings

Joints

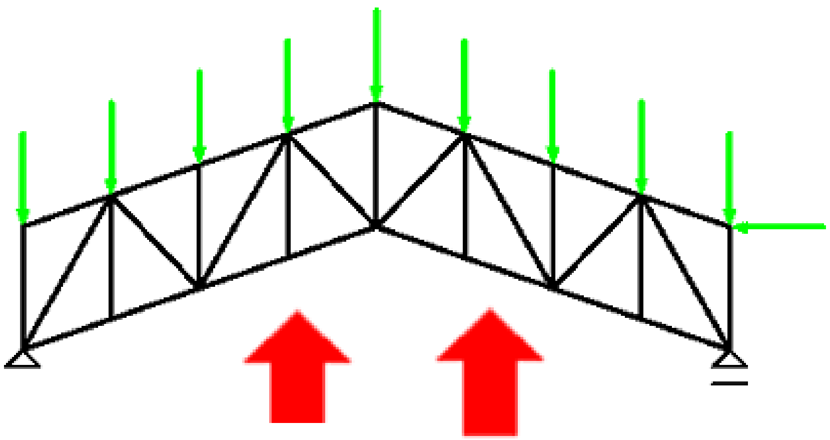
- Supports for purlins
- Joints truss - bracing
- Nodes (joints between truss bars)
  - Welds
  - Stiffness
  - Resistance
- Joints between transport members
  - Welds
  - Stiffness
  - Resistance
- Support for truss

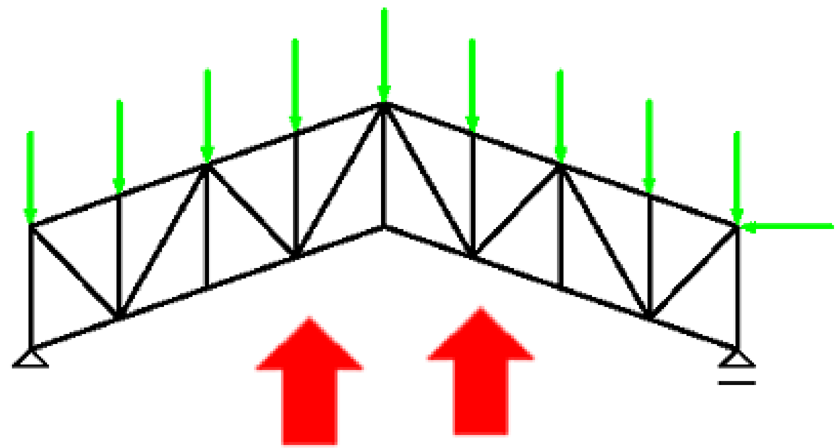
Stiffness of joint in second, besides resistance, parameter important for joints. According to Eurocode, we must check, if our assumption about joint - rigid or hinged - is true for real geometry and real cross-sections of members. Sometimes, because of big difference betweem assumption and real behaviour of joint, we must make static calculations once again.

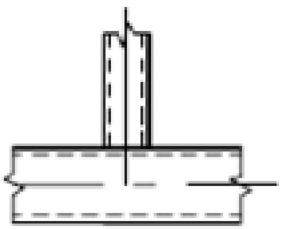
Part of structure	Condition	
	Resistance	Stifness
Member	ULS	SLS (deflection)
Joint	ULS	Qualification for different type of joint (hinged, semi-rigid, rigid)

Analysis or stifness and resistance is made based on components method (more information will be presented on lecture #14).

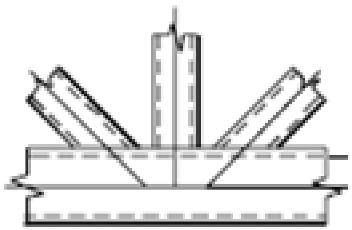
Nodes







T joint



KT joint

Photo: EN 1993-1-8 fig. 7.1

Photo: Author

Resistance of truss joint depends, among others, on its shape. Among many joints in truss, You obligatory analise joints types T and KT.

Welds

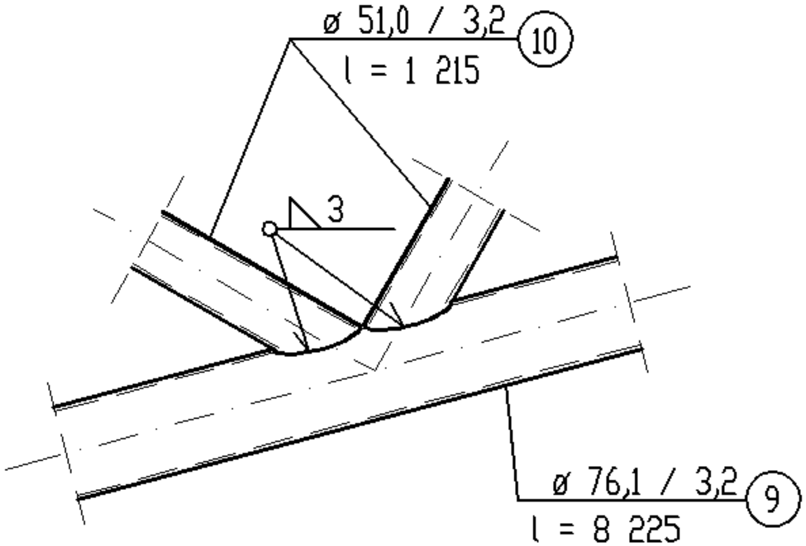


Photo: Author

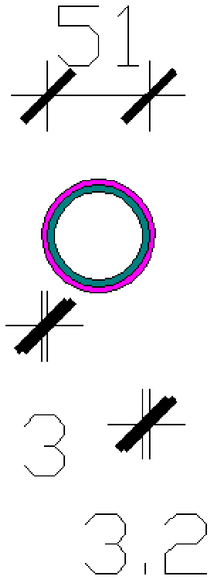


Photo: Author

Recommended for project : 3 mm

Stiffness

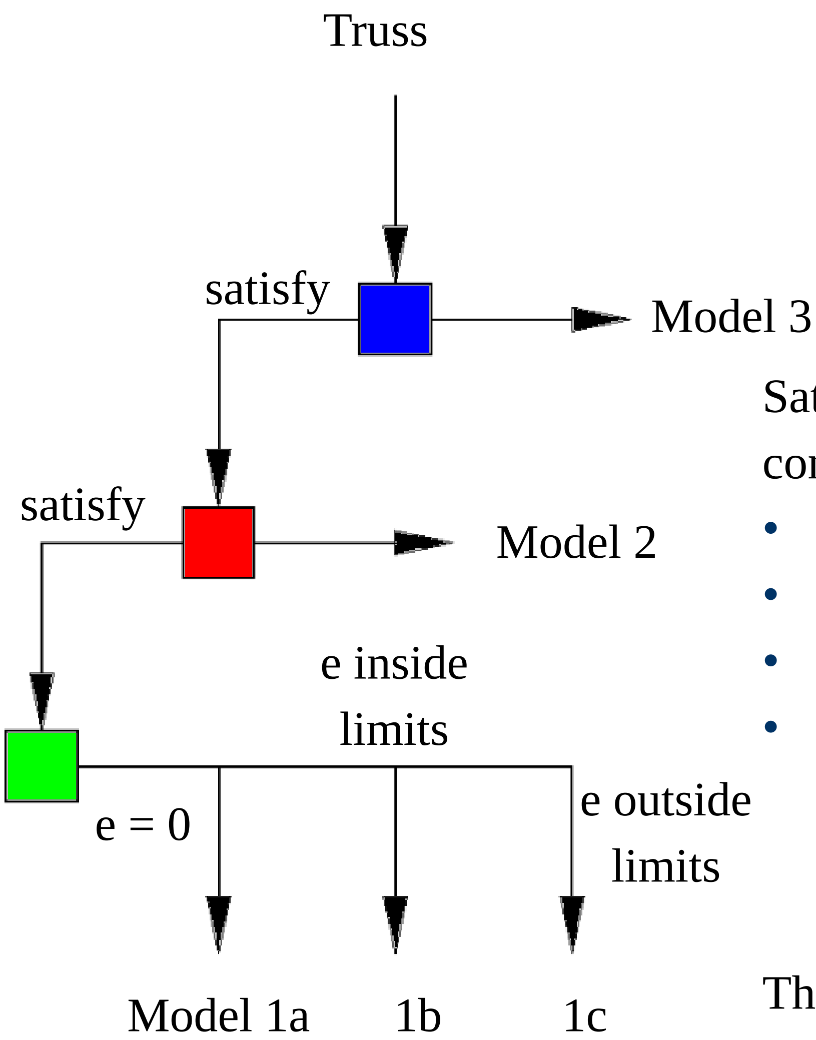


Photo: Author

Satisfaction or dissatisfaction of three groups of conditions qualifies truss nodes as:

- all rigid;
- rigid and pinned;
- all pinned with secondary bending moments;
- all perfectly pinned.

Third group of condition („green” condition) will be analysed in Your range of project only.
More information will be presented on lecture #9.

Resistance

Photo: eqclearinghouse.org

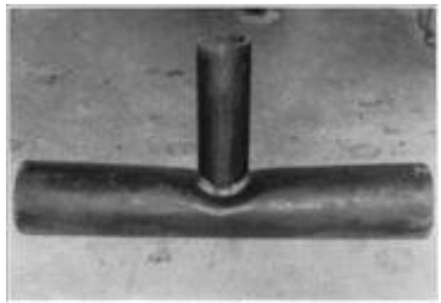


Photo: offshoremechanics.asmedigitalcollection.asme.org

Photo: scielo.br

Various ways of <u>local</u> destruction.

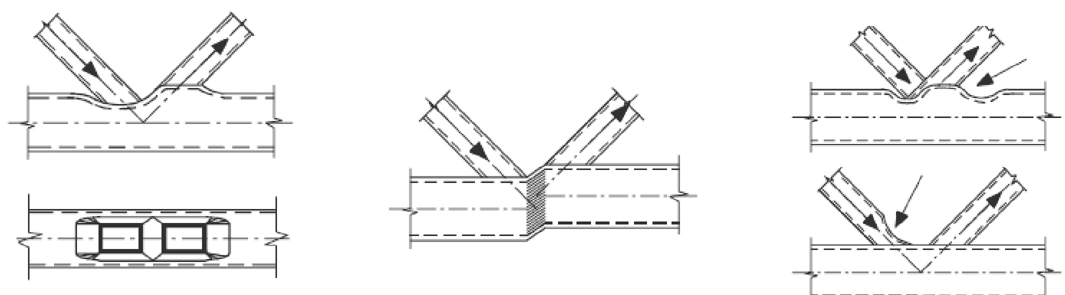


Photo: EN 1993-1-8 fig 7.3, 7.4

Node is Vth example of calculations in Example Part

<u>Field splices</u>

(joint for transport members)

Photo: encrypted-tbn0.gstatic.com

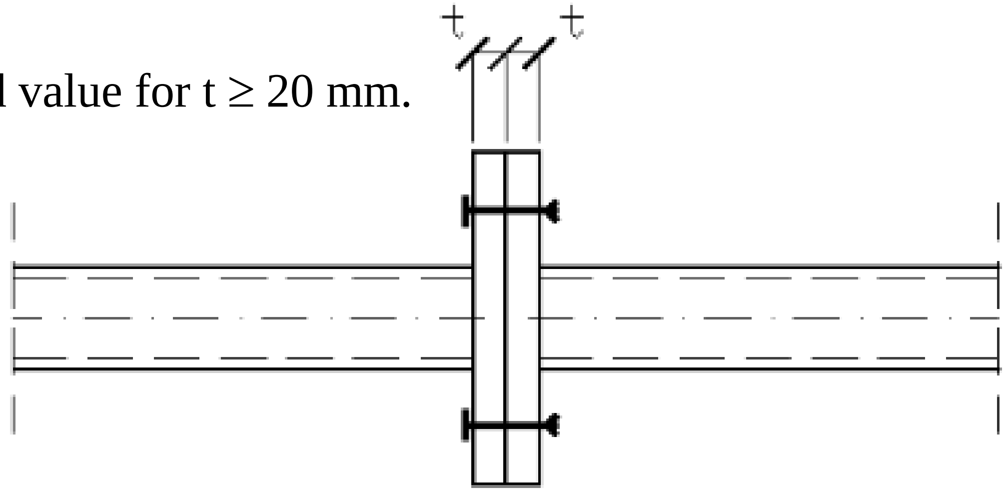
Photo: en.wikiarquitectura.com

Joints between transport members of trusss

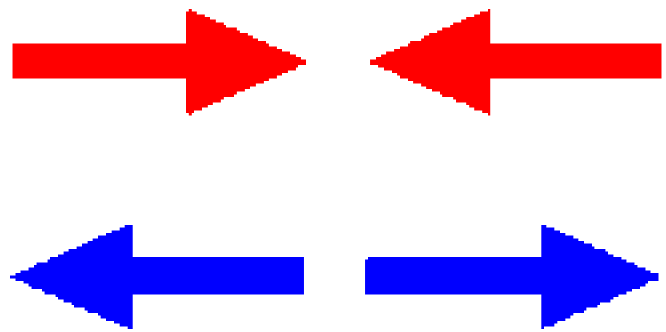
Photo: hamanufacturers.com.au

Initial assumptions

Recommended value for t ≥ 20 mm.



Compression in cord of truss: by contact between plates. Plates should be adjusted each other by grinding. This information should be put on drawing.



Tension in cord of truss: by bolts in field splice. Recommended bolts: class 8.8, M24.

Photo: Author

Field splices connect two parts of truss. What about diagonal bar - to which part of the truss belongs, left or right?

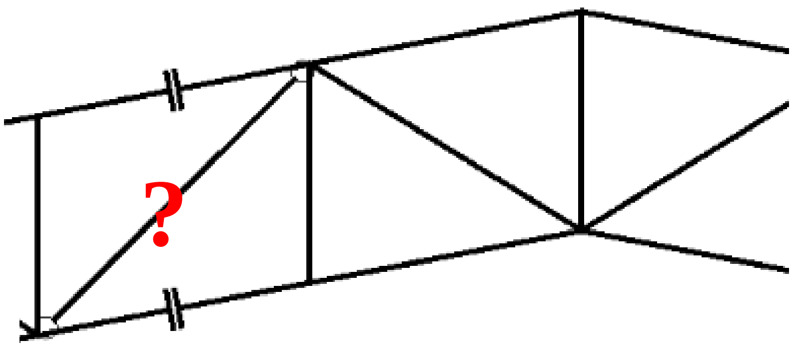
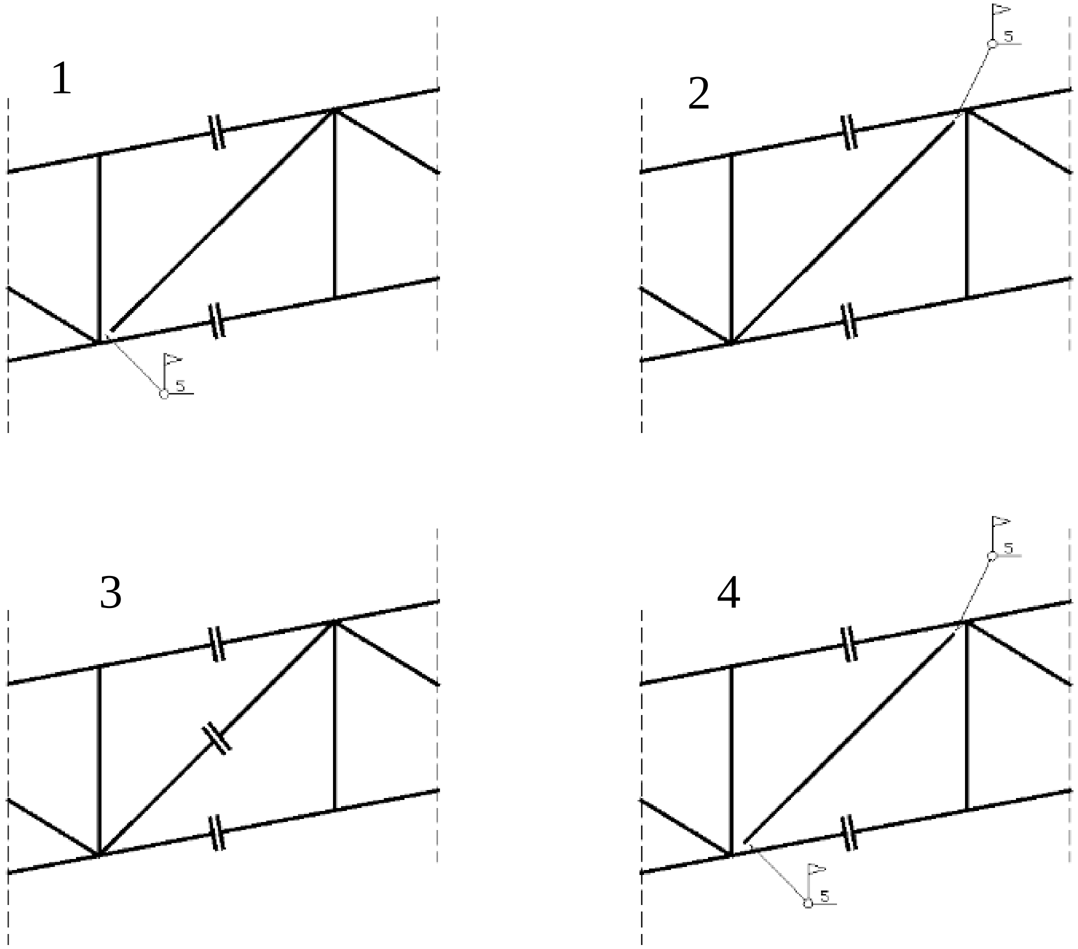


Photo: Author



Four possibilities:

1. Belongs to right, on left assembly weld;
2. Belongs to left, on right assembly weld;
3. Divided by two parts, connected by bolted splice joint;
4. Separated element, assembly welds on both ends.

Problem for solutions 1, 2, 3 – diagonal bar is connected with the rest part of structure by weld only. Such a long element can behave as pendulum during transport. Vibrations during transport make cracks of welds.

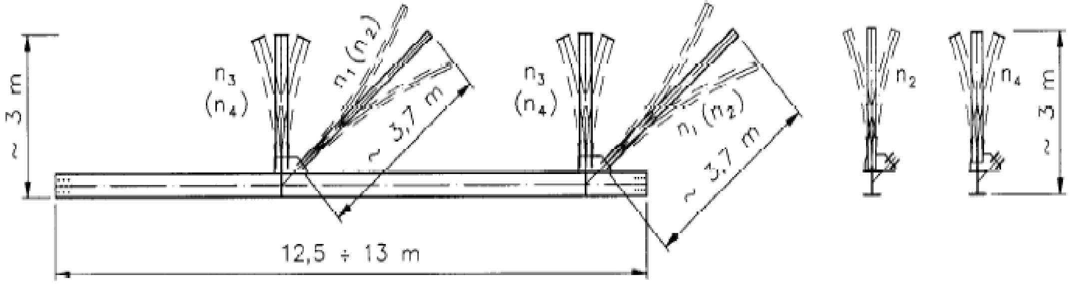


Photo: Awaryjne zagrożenie stalowej konstrukcji dachu hali widowiskowo-sportowej w Sopocie, E. Hotała et all, Awarie Budowlane 2009

Prevention: temporary support for free-end bar. Steel plate welded to diagonal bar and chord of truss. The plate is removed during the assembly of the structure.

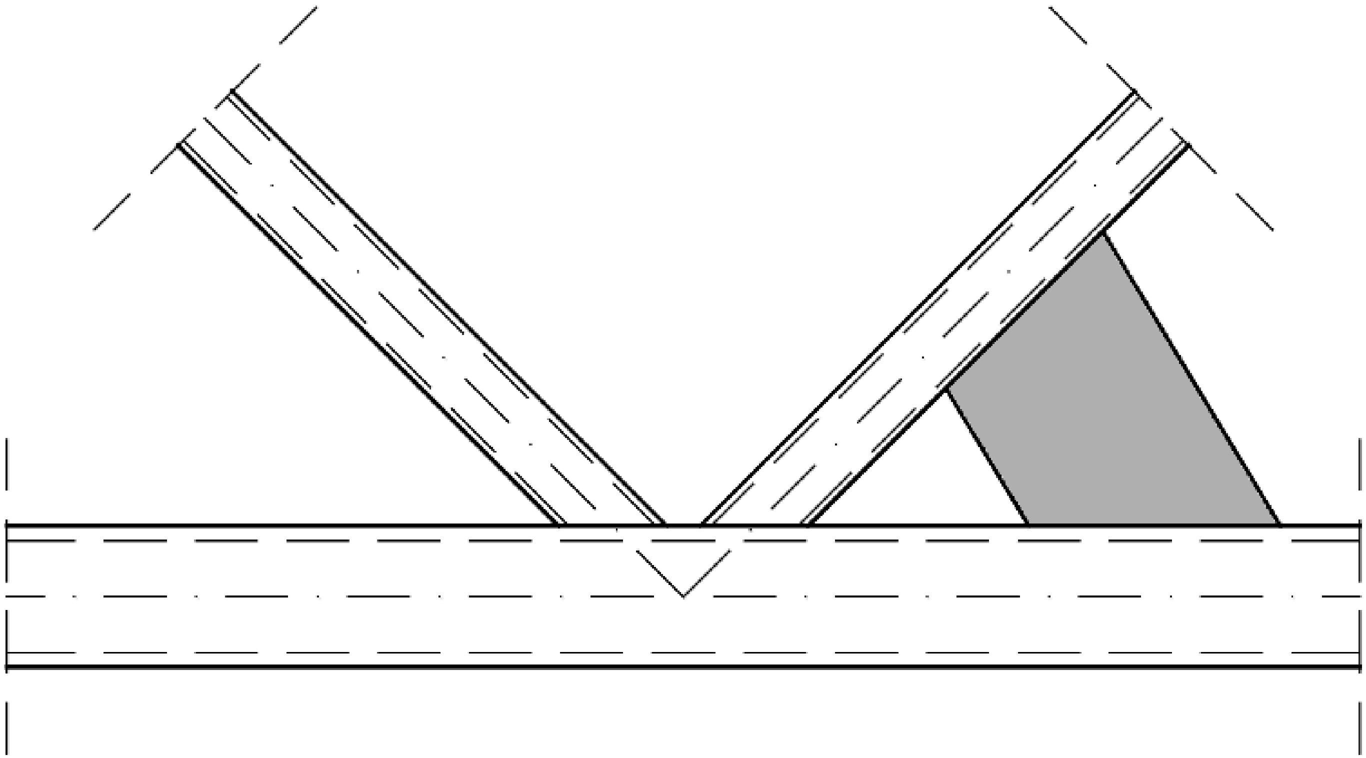


Photo: Author

Side effect of welding the bar only at one end and use of temporary plate: imperfections. Even minor misalignment of the diagonal bar (rotation by 1^{o} - 2^{o}) may make impossible to connect the truss.

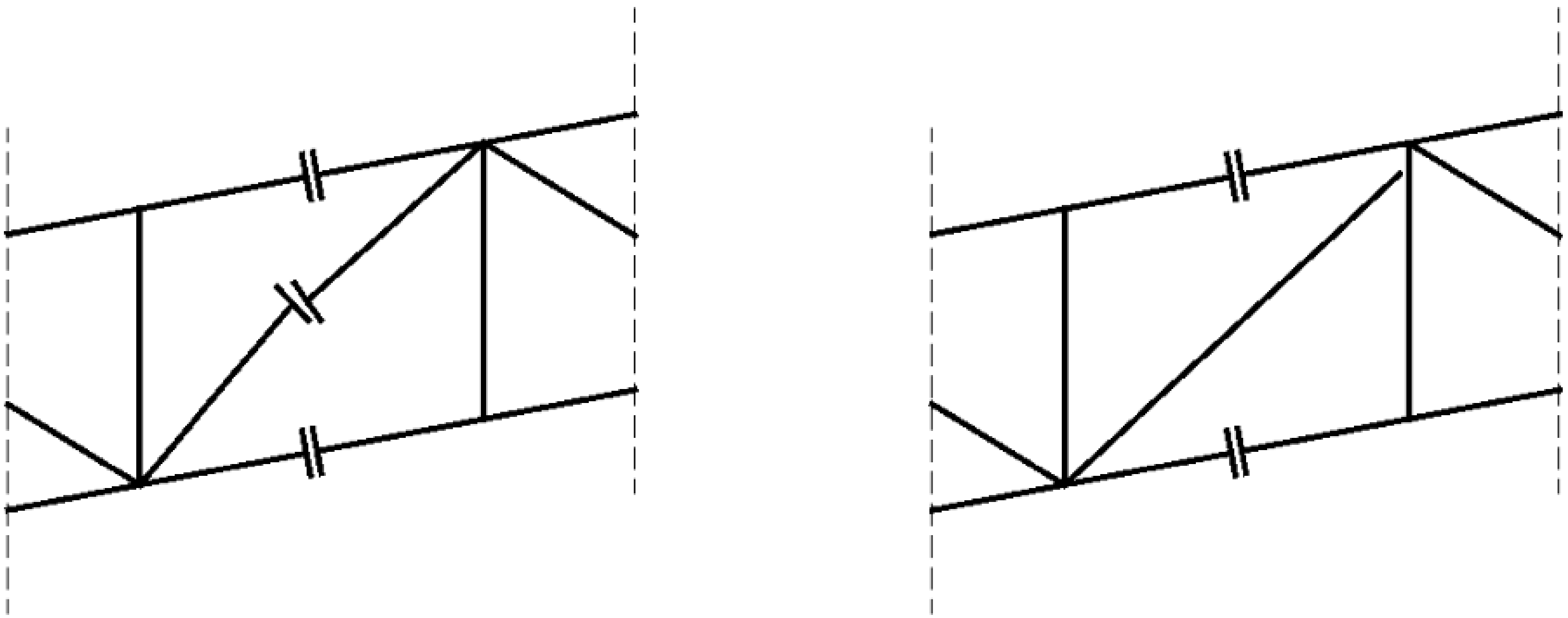


Photo: Author

Because of these problems, separated element with assembly welds on both ends is solution often used.

This is not fully in line with the principles of erecting steel structures. At the assembly, we prefer bolted joints, but sometimes it is not possible.

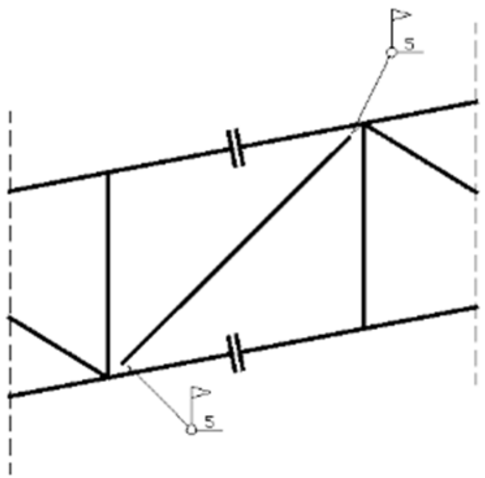


Photo: Author


Photo: tboake.com


Photo: tboake.com

Similarites an differences for bolted and welded joints will be presented on Lec #8.

Welds

Non obligatory in Your range of project; more information will be presented on lecture #17.

Stiffness

Field splice connect two parts of chord into one rigid element. So, it should be rigid joint. In Your range of calculation rigidity will be assumed without initial analysis. More information will be presented on lecture # 21.

Resistance

Photo: knkmpk.blogspot.com

Photo: forgemag.com

Resistance of such type of joint is the smallest walue of:

- plate destruction (but bolts are safe);
- bolts destruction (but plate is safe);
- common destruction of bolts and plate;

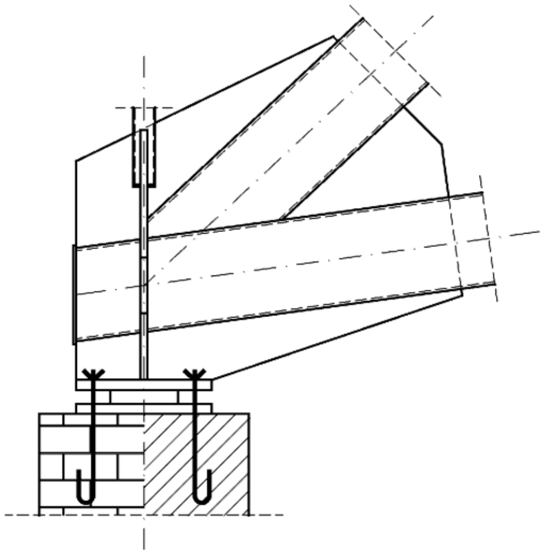
Field splice is VI[th] example of calculations in Example Part

Support (on drawing only)

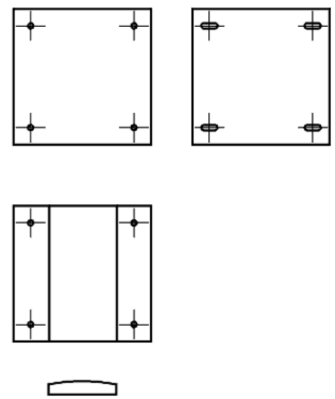
Top plate

Rocker

Bottom plate



Top plate – round holes or slotted holes for bolts, depending on the type of support (pinned, roller).
Bottom plate – round holes.



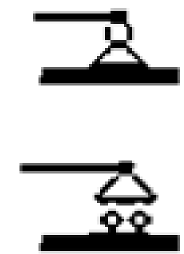


Photo: Author

Calculation of such type joint will be detaily calculated in IInd design project.

Drawings and list of materials

	UNIT	SYMBOL OF ELEMENT	NAME OF ELEMENT	DIMENSION [mm]	UNIT MASS [kg/m2; kg/m; kg/1000pieces]	MASS OF ELEMENT [kg]	NUMBER OF ELEMENTS	MASS OF ELEMENTS [kg]	UNIT MASS [kg]	NUMBER OF UNITS	TOTAL MASS [kg]
2		1	pl. 6	80x190	48,01	0,73	2	1,46			
3	**S1**	3	ϕ20	2 512	2,47	6,20	1	6,20	7,66	24	184
4		M12	M12	40	49,10	-	4	-			
5		1	pl. 6	80x190	48,01	0,73	6	4,38			
6	**S2**	4	ϕ20	2 039	2,47	5,04	2	10,07	19,70	24	473
7		8	ϕ20	2 127	2,47	5,25	1	5,25			
8		M12	M12	40	49,10	-	12	-			
9		1	pl. 6	80x190	48,01	0,73	2	1,46			
10	**S3**	2	ϕ20	1 455	2,47	3,59	1	3,59	5,05	24	121
11		M12	M12	40	49,10	-	4	-			
12		1	pl. 6	80x190	48,01	0,73	6	4,38			
13		5	ϕ20	1 788	2,47	4,42	1	4,42			
14	**S4**	6	ϕ20	2 140	2,47	5,29	1	5,29	17,60	4	70
15		7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			

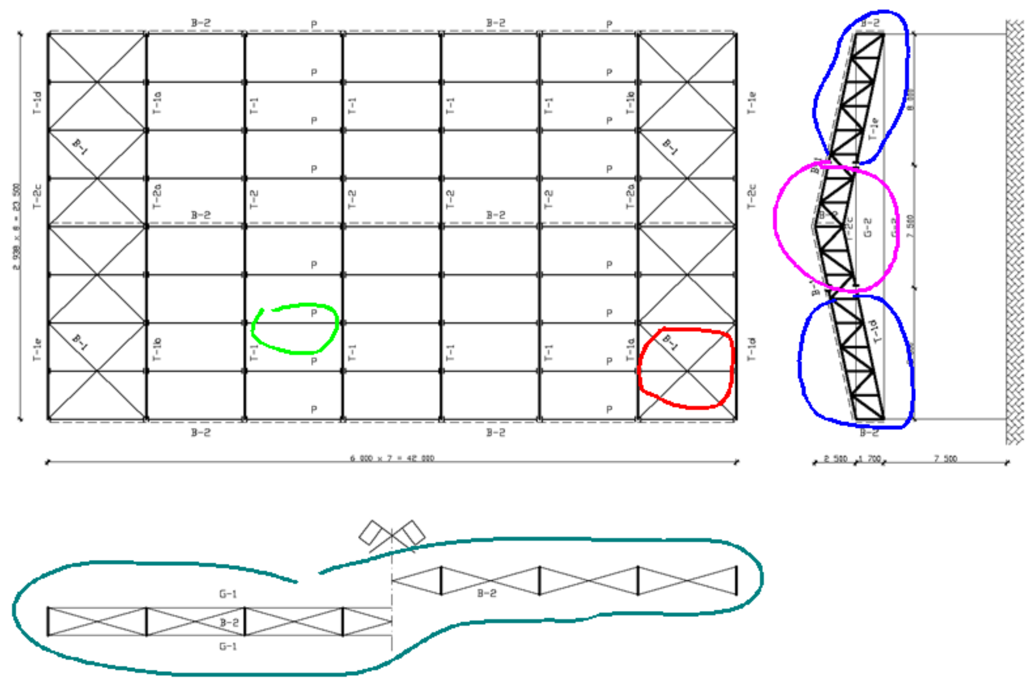
102		14	pl. 6	60x60	48,01	0,17	6	1,04			
103	**Kb1**	15	pl. 6	40x100	48,01	0,19	6	1,15	183,88	4	736
104		16	pl. 12	150x300	96,02	4,32	1	4,32			
105		17	pl. 6	54x60	48,01	0,16	1	0,16			
106		18	pl. 6	94x100	48,01	0,45	2	0,90			
107		20	pl. 6	114x130	48,01	0,71	1	0,71			
108		21	pl. 6	129x311	48,01	1,93	1	1,93			
109		23	pl. 6	130x496	48,01	3,10	1	3,10			
110		25	pl. 6	179x200	48,01	1,72	4	6,88			
111		26	pl. 6	42x76	48,01	0,15	1	0,15			
112		27	pl. 6	70x114	48,01	0,38	1	0,38			
113		33	pl. 6	253x100	48,01	1,21	1	1,21			
114		34	pl. 6	43x86	48,01	0,18	2	0,36			
115		35	pl. 6	31x62	48,01	0,09	1	0,09			
116		M16	M16	500	834,00	-	2	-			
117									Sum		6 789
118									2% for welds		136
119			**Bolts**	M12 kl 4.8 40 mm	49,1 kg / 1000 pieces				852 p.		42
120				M16 kl 4.8 500 mm	834 kg / 1000 pieces				48 p.		40
121									**TOTAL [kg]**		**7 006**
122											
123											

	UNIT	SYMBOL OF ELEMENT	NAME OF ELEMENT	DIMENSION [mm]	UNIT MASS [kg/m2; kg/m; kg/1000pieces]
2		1	pl. 6	80x190	48,01
3	S1	3	ϕ20	2 512	2,47
4		M12	M12	40	49,10
5		1	pl. 6	80x190	48,01
6	S2	4	ϕ20	2 039	2,47
7		8	ϕ20	2 127	2,47
8		M12	M12	40	49,10
9		1	pl. 6	80x190	48,01
10	S3	2	ϕ20	1 455	2,47
11		M12	M12	40	49,10
12		1	pl. 6	80x190	48,01
13		5	ϕ20	1 788	2,47
14	S4	6	ϕ20	2 140	2,47

Photo: Author

First column – unit. This is symbol of transport members of truss. For example, structure can be divided into:

- central part of truss;
- side part of truss;
- purlins;
- horizontal bracings;
- vertical bracings.



Drawing – according to technical drawing requirements

Paper size

A0 = 1189 x 841 mm (area = 1 m^2, proportion $\sqrt{2}$ x 1)

A1 = 840 x 594 mm

A2 = 594 x 420 mm

A3 = 420 x 297 mm

A4 = 297 x 210 mm

For design projects: A1.

For laboratories: A4.

In horizontal position only.

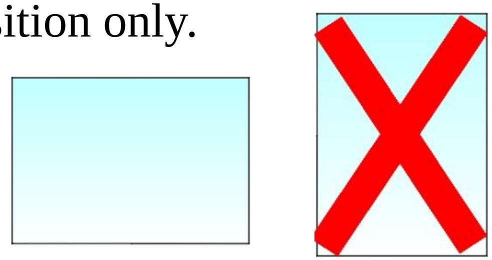


Photo: Author

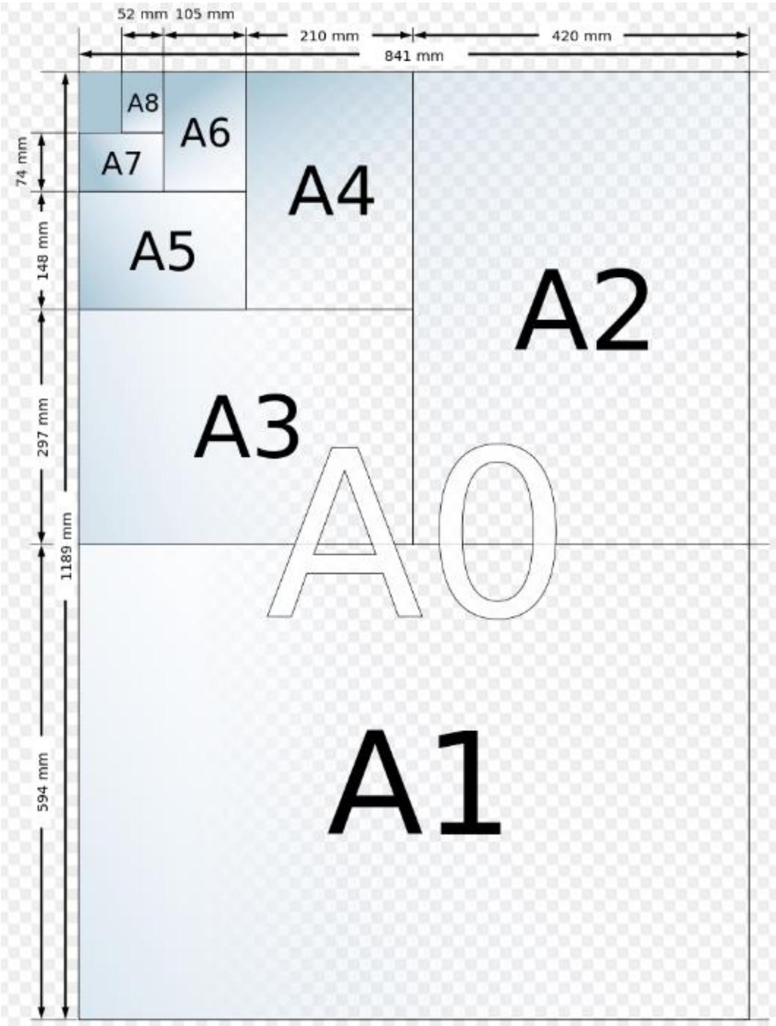


Photo:wikipedia

Thickness of lines

Group A:

Axial lines, cutting lines, dimensions, hatch, symbols, descriptions.

Group B:

View of elements, very important descriptions.

Group C

Cross-sections of elements, most important descriptions.

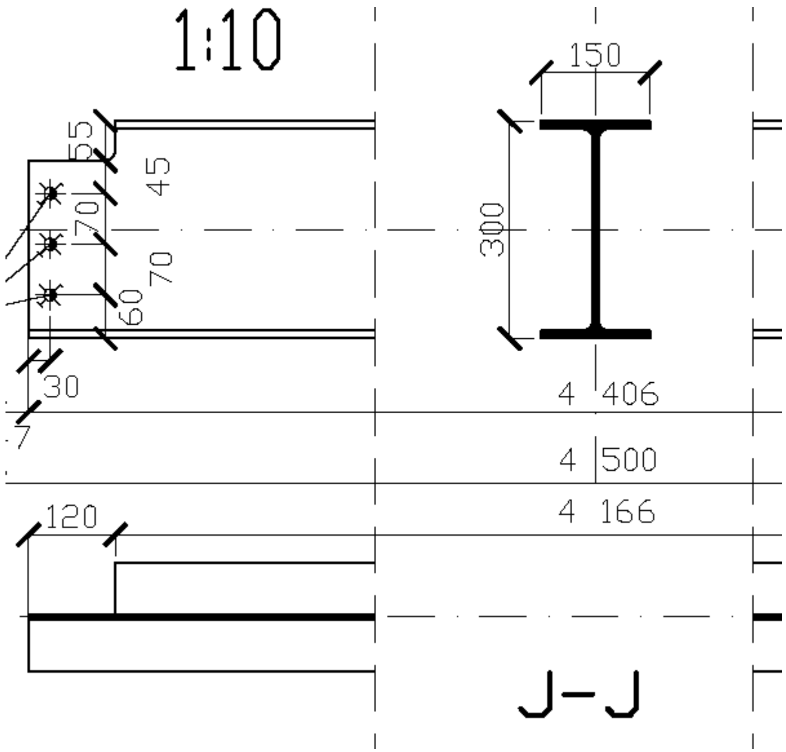


Photo: Author

A : B : C

1 : 2 : 4

For example

0,18 mm : 0,35 mm : 0,70 mm

Symbols

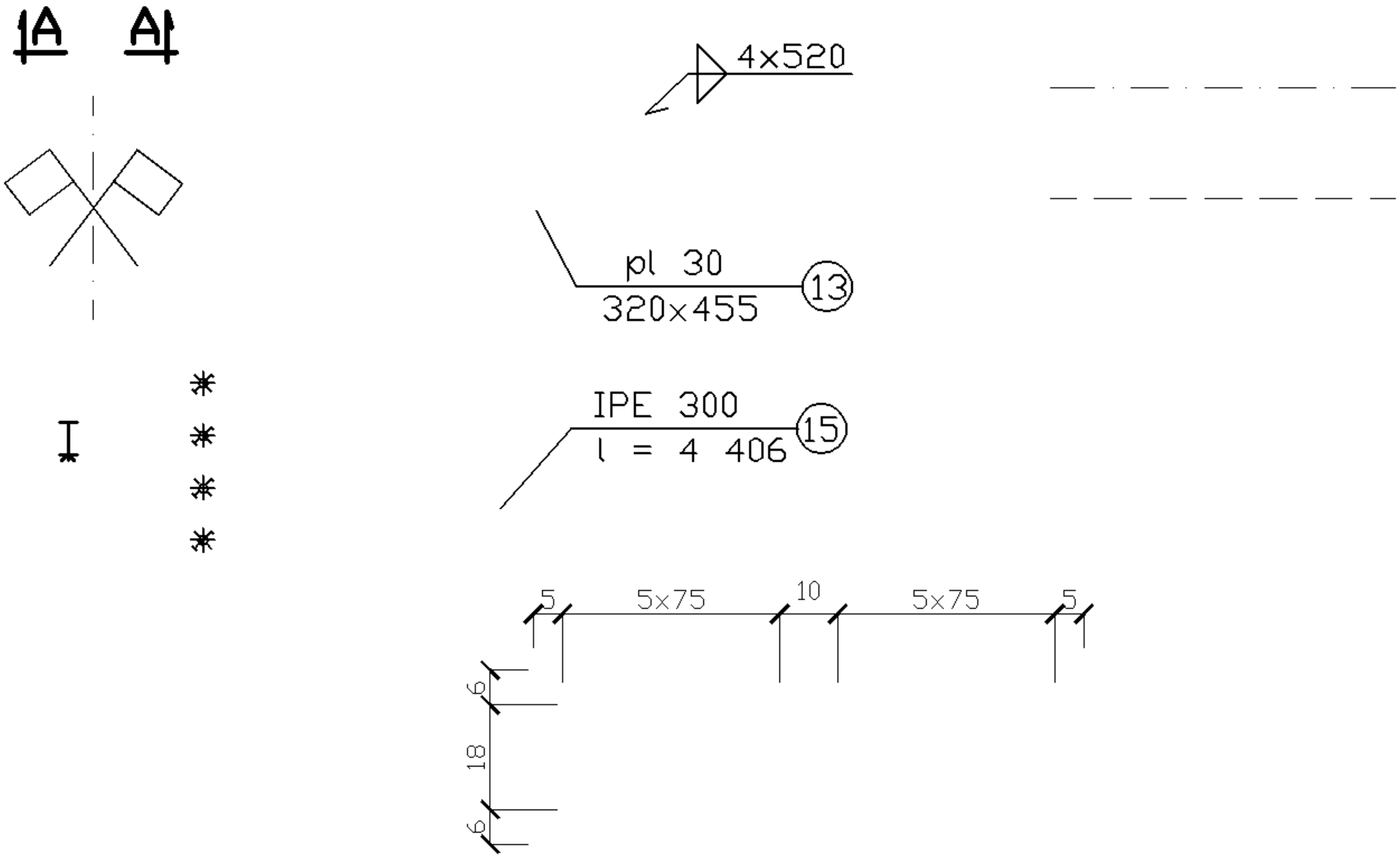


Photo: Author

Roofing - pokrycie dachu

Purlin - płatew

Girt - rygiel

Bracing - stężenie, skratowanie

Cross-bars - skratowanie

Field splice - styk montażowy

Chord - pas

Thank you for attention

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