Metal Structures

Lecture IX

Steel trusses

Contents

Definition

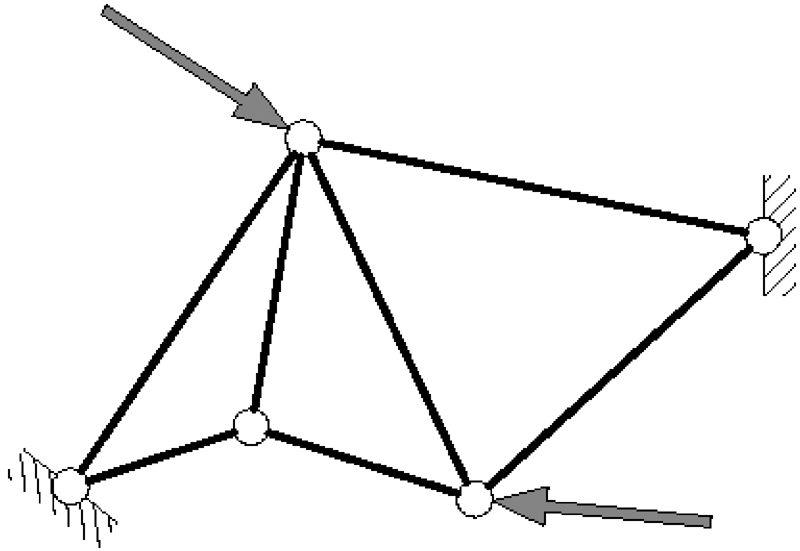

Photo: Author

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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 ($q(x) = 0$):

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

Hinges:

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

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

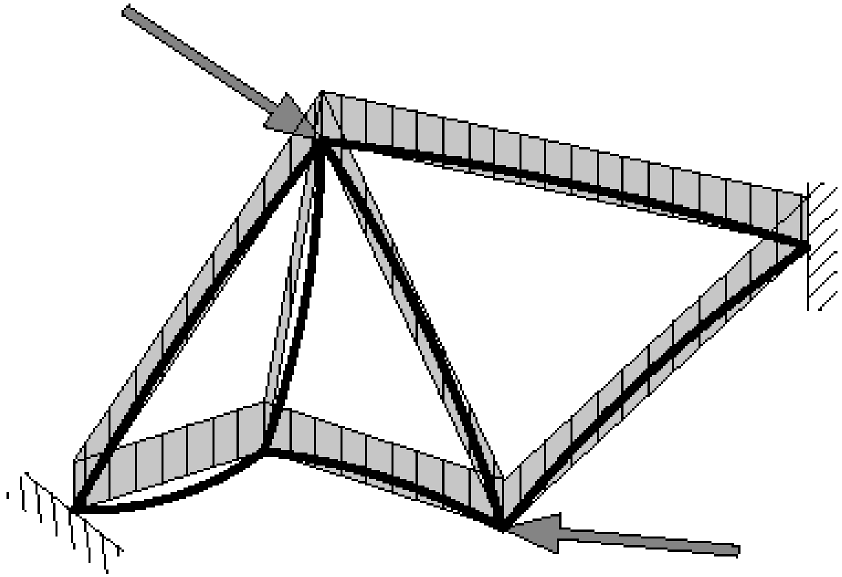

Photo: Author

Truss – real:

- Bars with imperfections;
- Gravity along bars;
- No ideal hinged joints;

It's rather frame

Effort (calculation as a truss) ≈ Effort (calculation as a frame)

Time of calculations (truss) << Time of calculations (frame)

Because of these reasons, we calculate real truss as ideal truss.

But, because of this - sometimes very small difference between truss and frame - various ideal static models (truss, truss with contionous cords, frame) are applied to calculations of real truss (→ #t / 54).

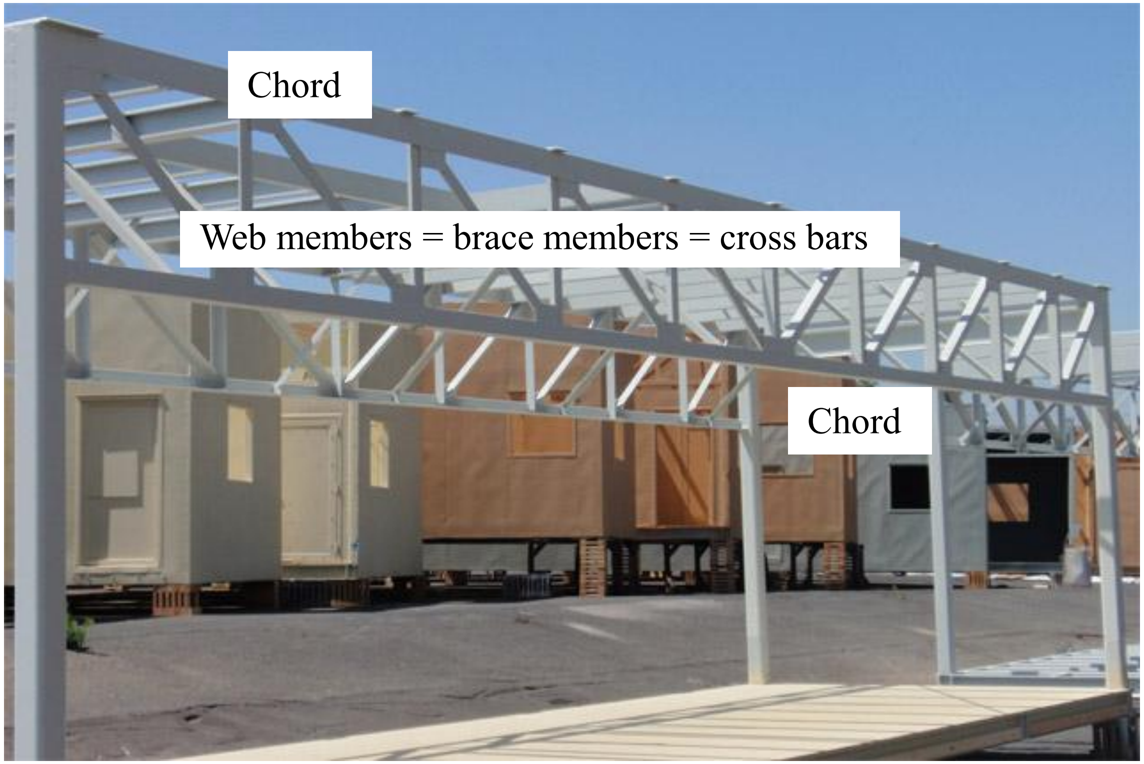

Photo: waldenstructures.com

There is common name for every not-chord bars (web member or brace member or cross bar). In Polish language exist two words: „słupki” (vertical bars) and „krzyżulce” (inclined bars). Common mistake is to design different type of cross-section only because of different name or direction - for web members important are only axial forces and lengths, not names.

Geometry and cross-section

There are many different shapes of trusses.

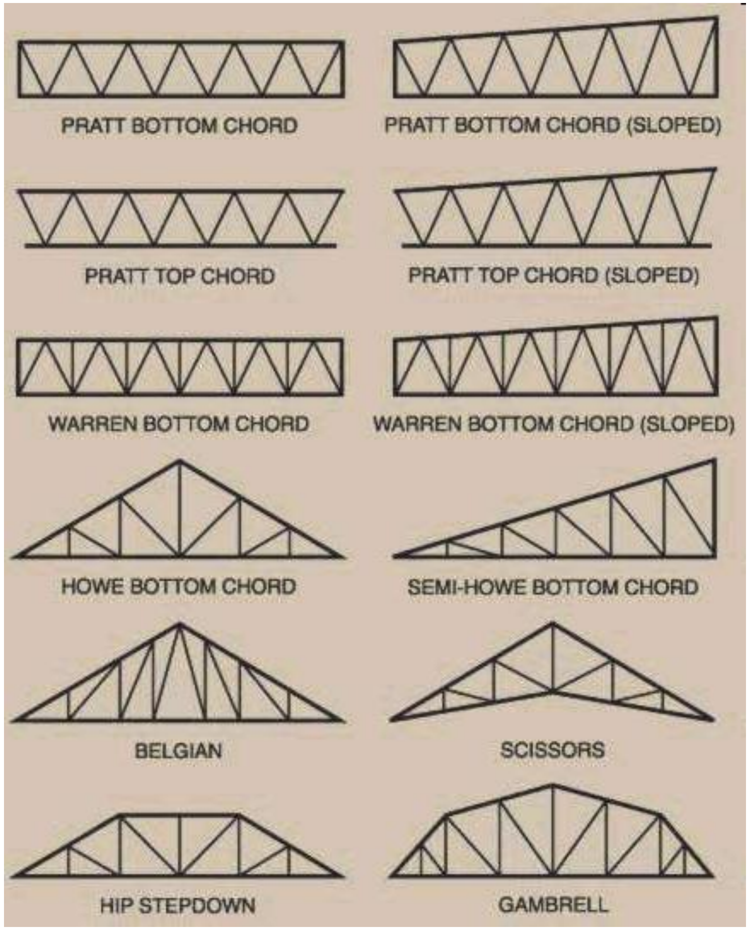

Photo: tridenttruss.com

Photo: steelconstruction.info

Photo: e-plytawarstwowa.pl

Photo: domgaz.com.pl

Photo: konar.eu

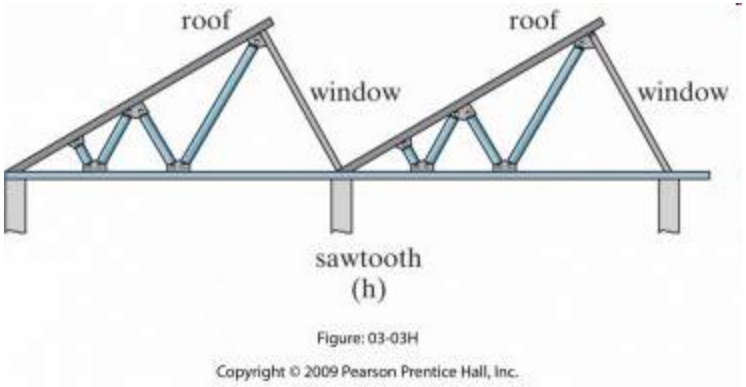

Photo: i435.photobucket.com

Photo: community.fansshare.net

Specific subtype are trusses with paralell chords. For these trusses, forces in top and bottom chord are similar.

$$|N_{Ed,\,top}| / |N_{Ed,\,bottom}| \approx 0{,}90 \div 1{,}10$$

Photo: waldenstructures.com

Photo: gillmet.com.pl

Initial assumptions about geometry:

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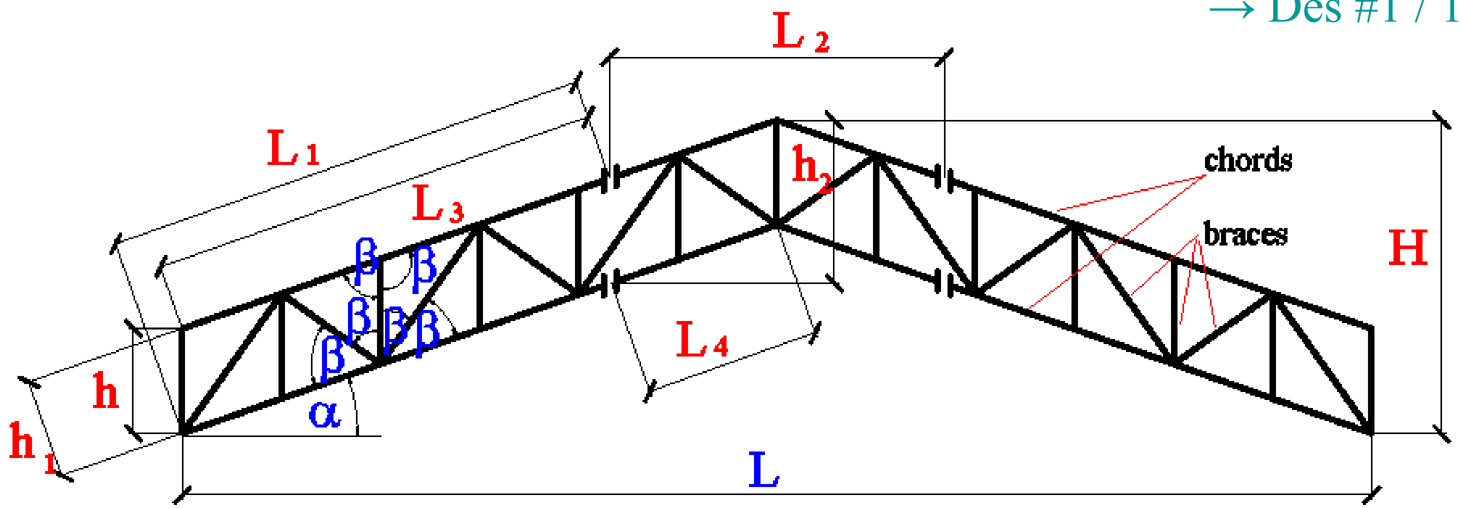


Photo: Author

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

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

$\alpha \geq 5^o$

$30^o \geq \beta \geq 60^o$ 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)

Trusses and I-beams – two types of main girders in steel structures.

Photo: Author

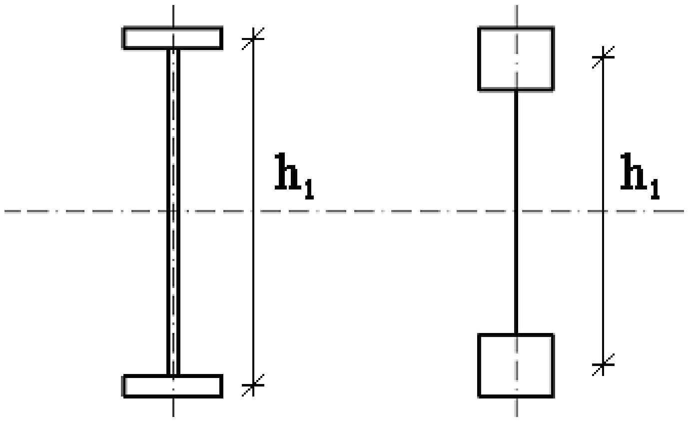
Stiffness of I-beam:

$J_{I\text{-beam}} = J_{top\ flange} + J_{web} + J_{bottom\ flange}$

For symmetrical cross-section:

$J_{top\ flange} = J_{bottom\ flange} \approx 2\ (h_{1,\ I} / 2)^2\ A_{flange}$

$J_{I\text{-beam}} \approx 0{,}5\ h_{1,\ I}^{\ 2}\ A_{flange} + J_{web}$



Stiffness of truss (Konstrukcje metalowe, M. Łubiński, A Filipiak, W. Żółtowski, Arkady 2000):

$J_{truss} \approx 0{,}7\ [A_{top\ chord} \cdot A_{bottom\ chord} / (A_{top\ chord} + A_{bottom\ chord})]\ h_{1,\ truss}^{\ 2}$

For symmetrical cross-section:

$A_{top\ chord} = A_{bottom\ chord} = A_{chord}$

$J_{truss} \approx 0{,}7\ [A_{chord}^{\ 2} / (2\ A_{chord})]\ h_{1,\ truss}^{\ 2} = 0{,}35\ h_{1,\ truss}^{\ 2}\ A_{chord}$

Stiffness is important, first of all, for SLS. SLS limits (accepted deflection) are the same for truss and beams. This means:

stiffness of I-beam = stiffness of truss: $J_{I\text{-beam}} = J_{truss}$

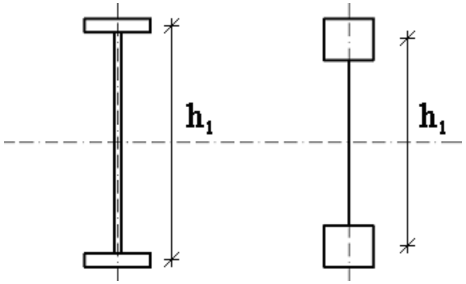
Stiffness of truss:

$J_{truss} \approx 0{,}35\, h_{1,\,truss}^{2}\, A_{chord}$

Stiffness of I-beam:

$J_{I\text{-beam}} \approx 0{,}5\, h_{1,\,I}^{2}\, A_{flange} + J_{web}$

For vatious types of I-beams, J_{web} = 7% - 25% of J_{flange}

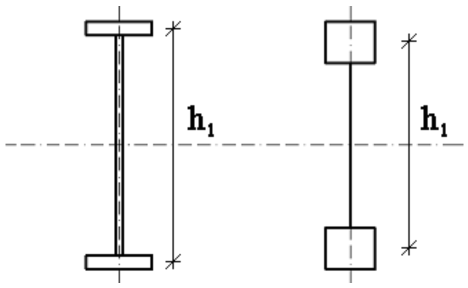


If $A_{flange} = A_{chord}$ and $h_{1,\,I} = h_{1,\,truss}$ **$J_{Ibeam} \approx 1{,}53 \div 1{,}79\, J_{truss}$**

We need $J_{I\text{-beam}} = J_{truss}$; this means: **$h_{1,\,truss} > h_{1,\,I}$** and maybe **$A_{chord} > A_{flange}$**

Photo: Author

$$h_{1,\ truss} > h_{1,\ I}$$



Initial assumptions about geometry of cross-sections:

$h_{1,\ Ibeam} = L / 20 - L / 25$; $h_{1,\ truss} = L / 10 - L / 15 \rightarrow h_{1,\ truss} > h_{1,\ Ibeam}$

Photo: Author

L [m]	$h_{1,\ Ibeam}$	$h_{1,\ truss}$
15,0	~ 650 mm	~ 1200 mm
20,0	~ 900 mm	~ 1600 mm
25,0	~ 1200 mm	~ 2000 mm

$A_{chord} \leftrightarrow A_{flange}$

L [m]	$h_{1,\ Ibeam}$	Cross-section
15,0	~ 650 mm	HEA 650 $A_{flange} = 78\ cm^2$
20,0	~ 900 mm	HEA 900 $A_{flange} = 90\ cm^2$
25,0	~ 1200 mm	HLA+ 1100 $A_{flange} = 124\ cm^2$

The same resistance:

L [m]	$h_{1,\ truss}$	Cross-section
15,0	~ 1200 mm	168,3/12,5 $A_{chord} = 61,2\ cm^2$
20,0	~ 1600 mm	193,7/12,5 $A_{chord} = 71,2\ cm^2$
25,0	~ 2000 mm	244,5/14,2 $A_{chord} = 103,0\ cm^2$

$$J_{truss} \approx 0{,}35\, h_{1,\,truss}^{2}\, A_{chord}$$

L [m]	J_{Ibeam}	J_{truss}
15,0	HEA 650 281 700 cm^4	308 500 cm^4
20,0	HEA 900 422 100 cm^4	637 950 cm^4
25,0	HLA 1100 867 400 cm^4	1 442 000 cm^4

Trusses are more stiff than I-beams, but space inside structure for trusses is bigger than for I-breams:

L [m]	$h_{1,\,Ibeam}$	$h_{1,\,truss}$
15,0	~ 650 mm	~ 1200 mm
20,0	~ 900 mm	~ 1600 mm
25,0	~ 1200 mm	~ 2000 mm

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/m^2], 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/m^3], H – height of truss (vertical distance between top and bottom chord) → [m]

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

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

a = 6,0 m, I[st] proposal, aLg_T [kN] =

q [kN / m]	L [m]		
	18,0	24,0	30,0
10,0	53,1	94,5	147,6
15,0	76,5	137,0	212,4

a = 6,0 m, II[nd] proposal, g_{T1}[kN] =

q [kN / m]	L [m]		
	18,0	24,0	30,0
10,0	48,7	86,6	135,3
15,0	73,1	129,9	202,9

Types of truss structures

Truss purlins

„Classical" trusses

Multi-chords trusses

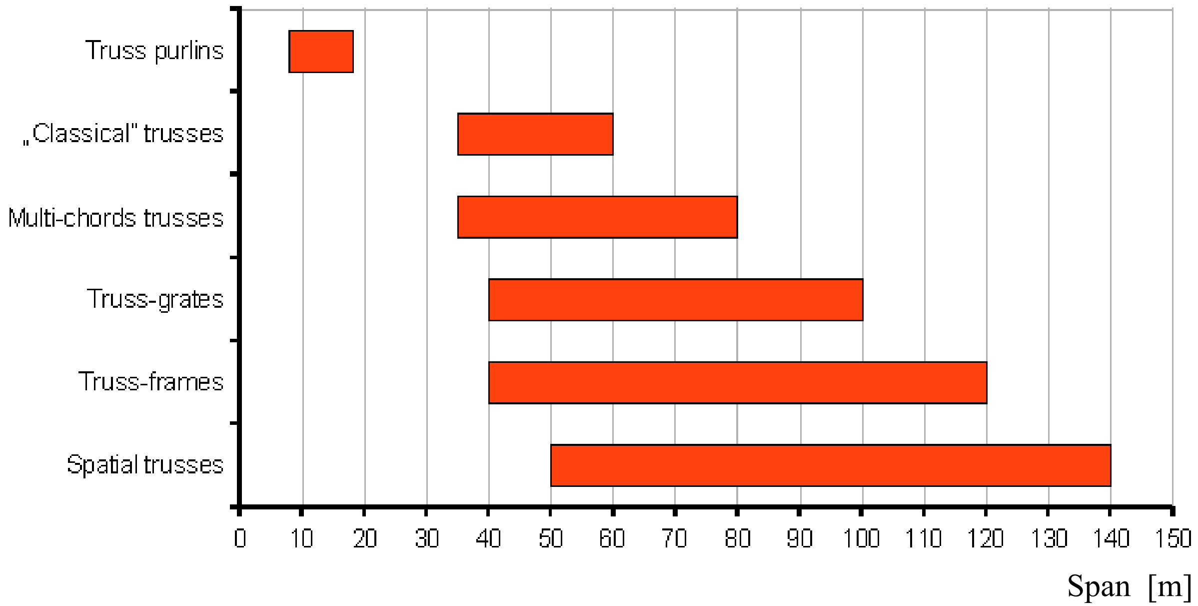
Truss-grates

Truss-frames

Spatial trusses

Laced columns

Photo: Author



Truss purlins

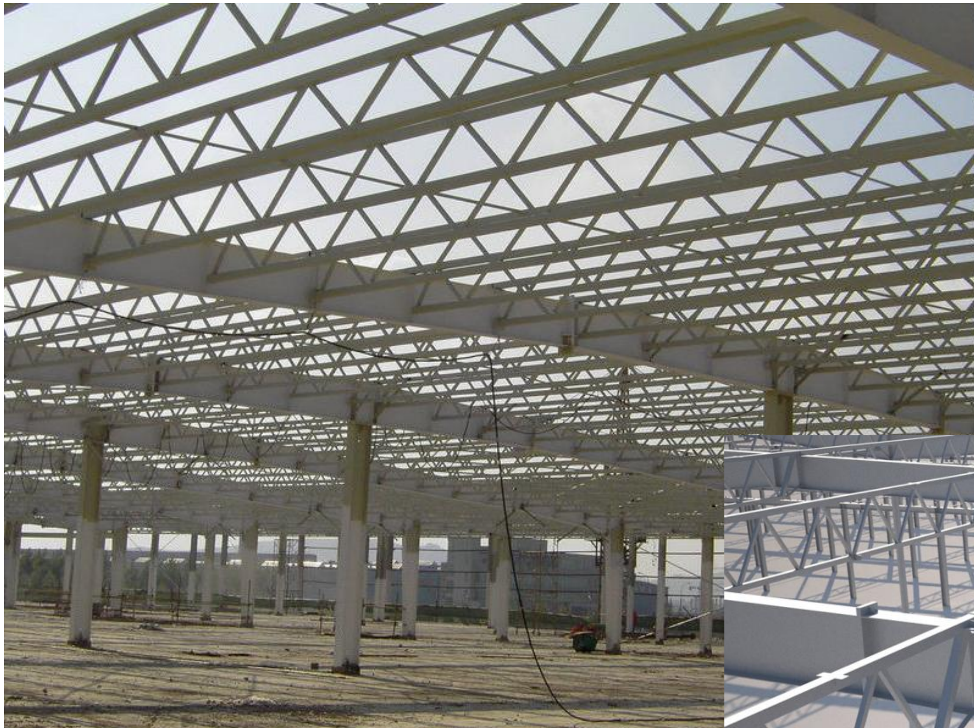


Photo: structural-steelbuilding.com

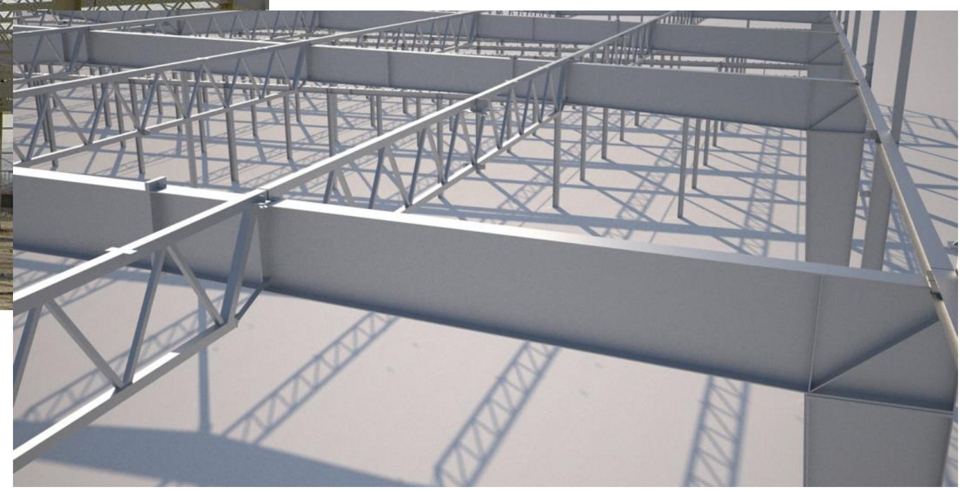


Photo: CoBouw Polska Sp. z o. o.

Truss purlin

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"Normal" truss - forces are applied in nodes; there are axial forces in chords and cross-bars only.

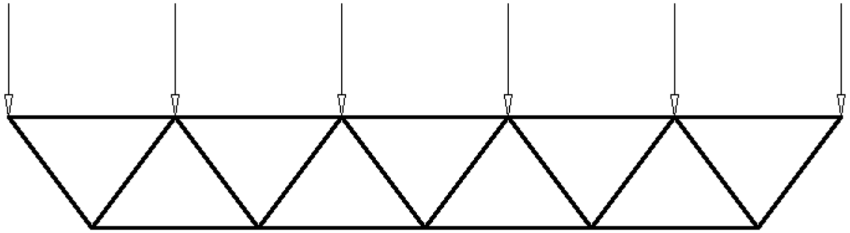


Photo: construdare.com

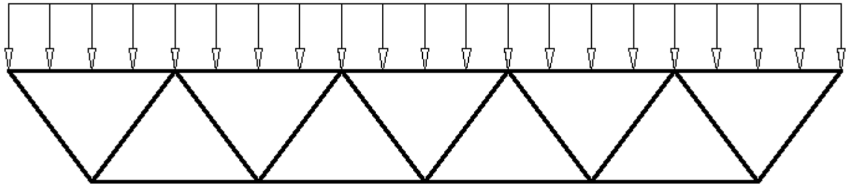
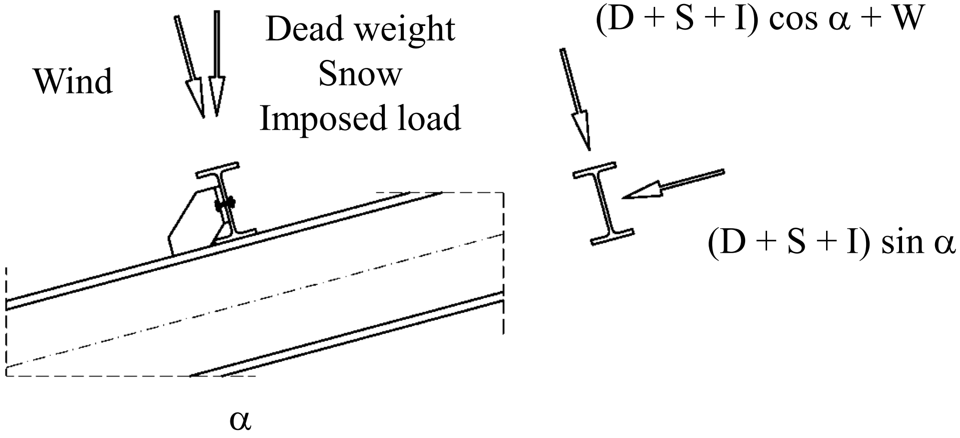


Photo: Author

Truss purlin - continuous load from roofing; there are axial forces in chords and cross-bars; in addition top chord is bending.



I-beam purlin: bi-axial bending.

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Truss purlin: horizontal force

W sin α

has very small value and can be neglected (acts on roofing, not purlins). All loads act in plane of truss. There is need wedge to install truss purlin in vertical position.

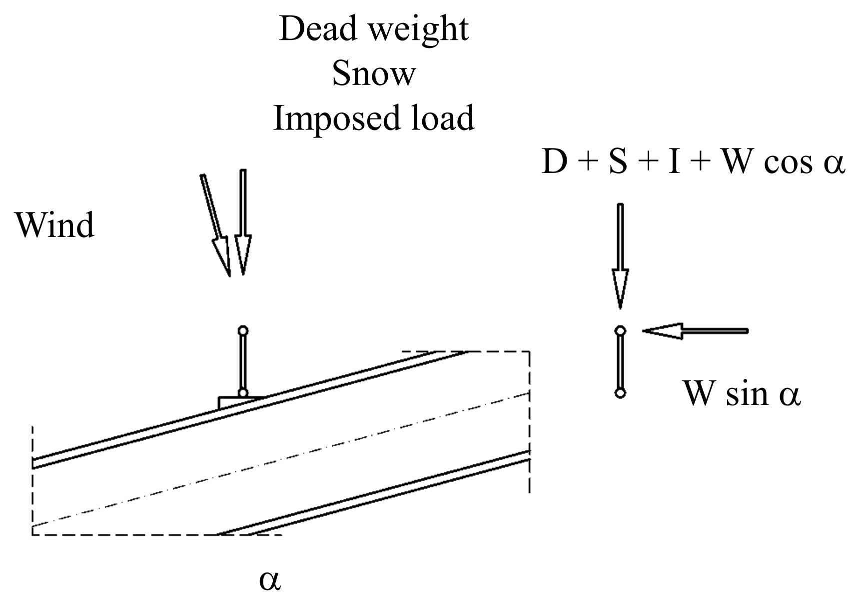


Photo: Author

„Classical” trusses

Photo: steelconstruction.info

Photo: domgaz.com.pl

Photo: waldenstructures.com

2-chords flat trusses, used as a single roof girders.

Multi-chords trusses

Photo: steelconstruction.info

Photo: multimetalgb.ca

3 or 4 trusses connected each other in triangle or square cross-section. Often used for temporary structures (bandstand) or for masts and towers.

Photo: conference-truss-hire.co.uk

Photo: rktruss.com

Photo: stretchtents.com.au

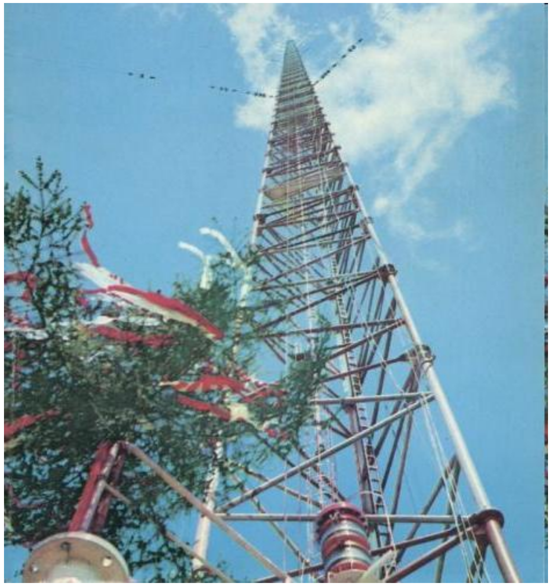


Photo: eioba.pl

Truss-grates

Photo: qdjinfei.en.made-in-china.com

Photo: cdn8.muratorplus.smcloud.net

Complex of trusses of the same height, perpendicular each other.

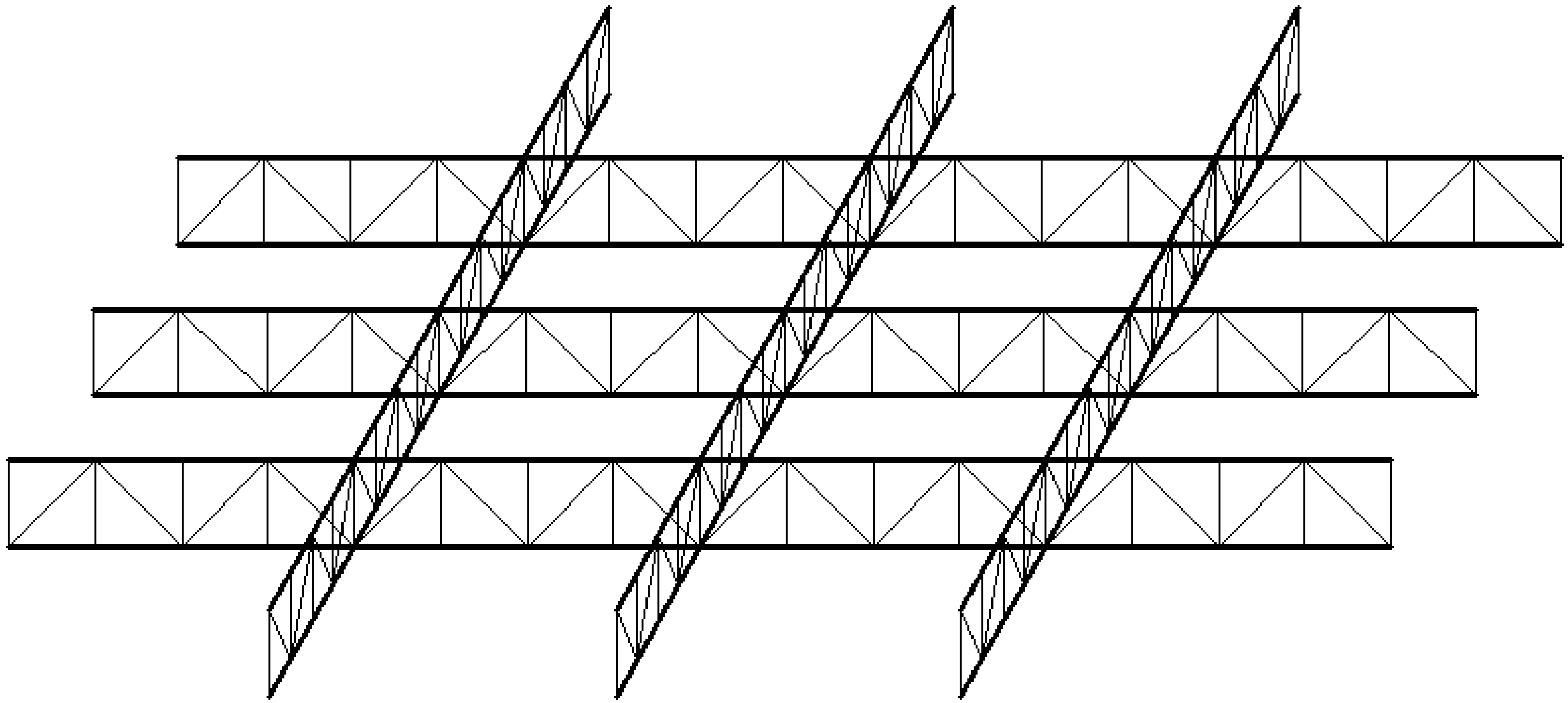


Photo: Author

Frame-truss

"Classical" portal frame (two columns and roof girder), but made of trusses, not I-beams.

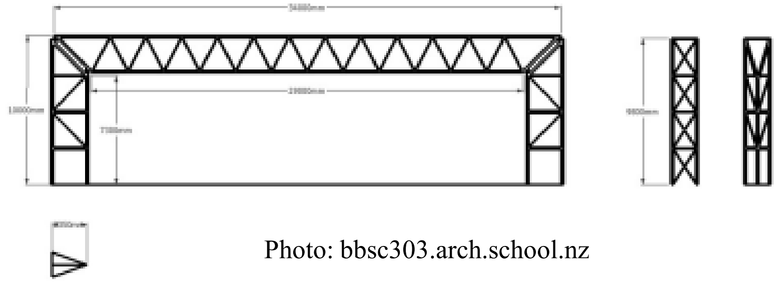


Photo: bbsc303.arch.school.nz

Photo: wikipedia

Spatial trusses

Photo: urwishengineers.com

Photo: miripiri.co.in

2 or 3 layers of bars + cross-bars between layers.

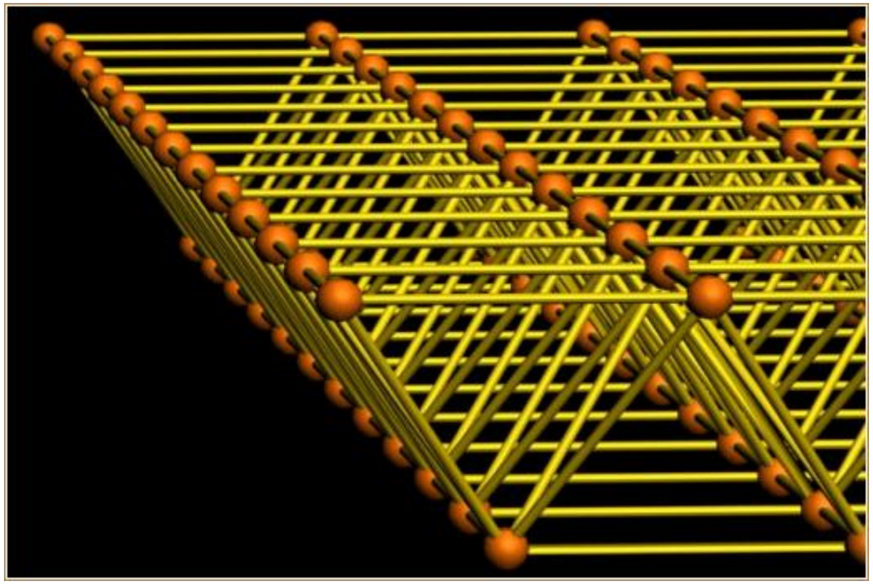
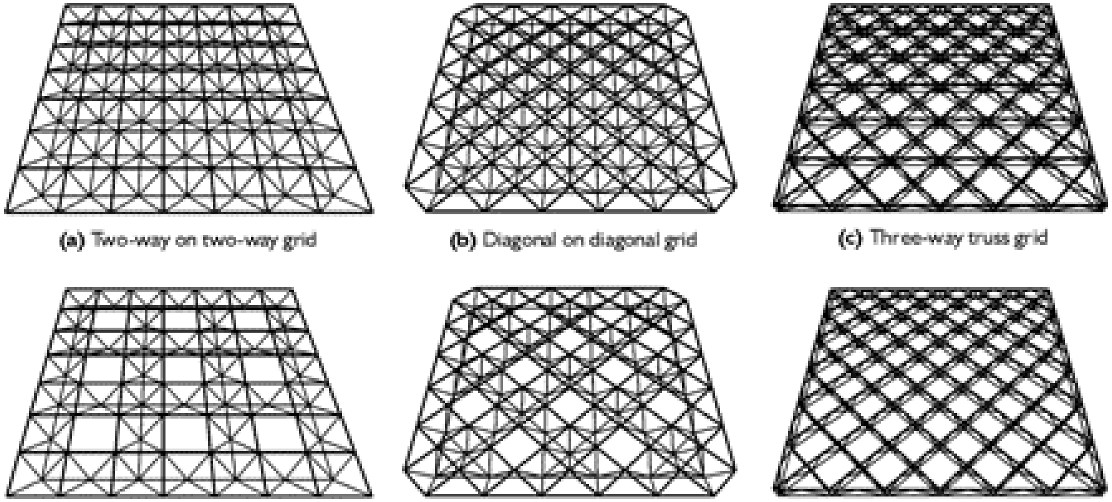


Photo: shreeengineering.in/

Photo: civiltech.ir



(a) Two-way on two-way grid

(b) Diagonal on diagonal grid

(c) Three-way truss grid

(d) Reduced two-way on two-way grid

(e) Reduced diagonal on diagonal grid

(f) Diagonal truss grid

Photo: urwishengineers.com

Layers can be flat, cylidrical or spherical. More information about this type of structures will be presented on IInd step of studies.

Photo: wikipedia

Photo: cnxzlf.com

Laced columns

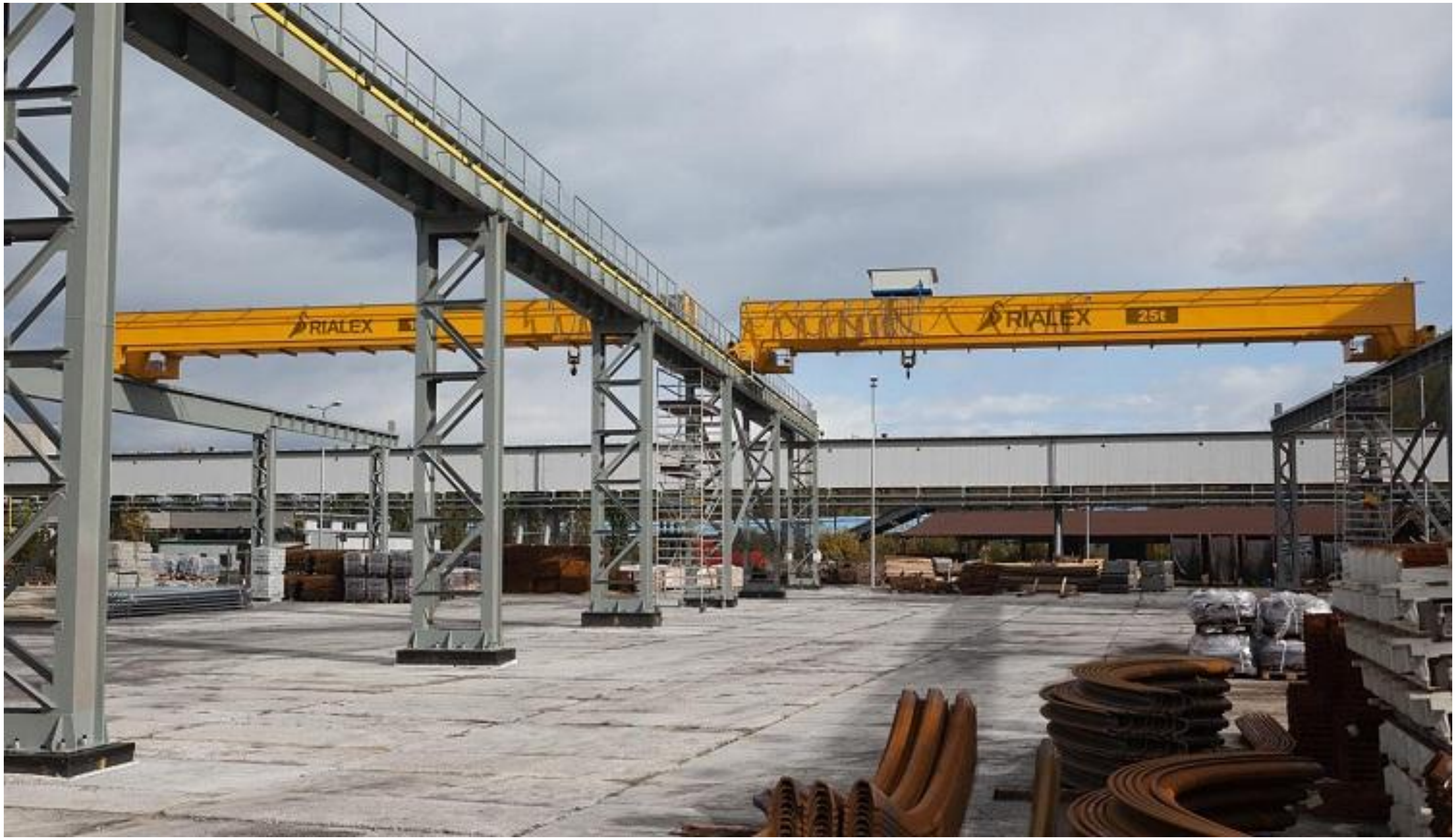
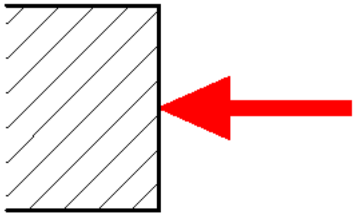


Photo: zksgrzelak.eu

Structure looks like truss, but its behaviour and calculation model is completely different than for truss.

For laced columns, battened columns and closely spaced build-up compression members we use specific algorithm of calculations. More information about this type of structures will be presented on IInd step of studies.

Calculations



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

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

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

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

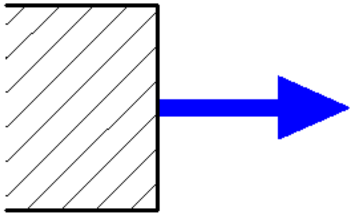


Photo: Author

χ - lecture #5:

- Flexural buckling
- Torsional buckling
- Flexural-torsional buckling

Critical length for compressed chord of truss is depend on plane of analysis. For vertical plane, critical length is equal distance between cross-bars. For horizontal plane, critical length is equal distance between bracings:

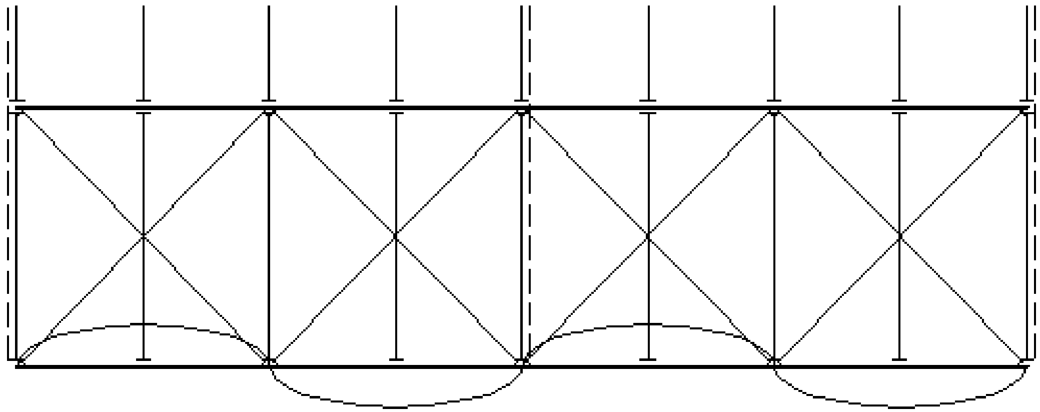
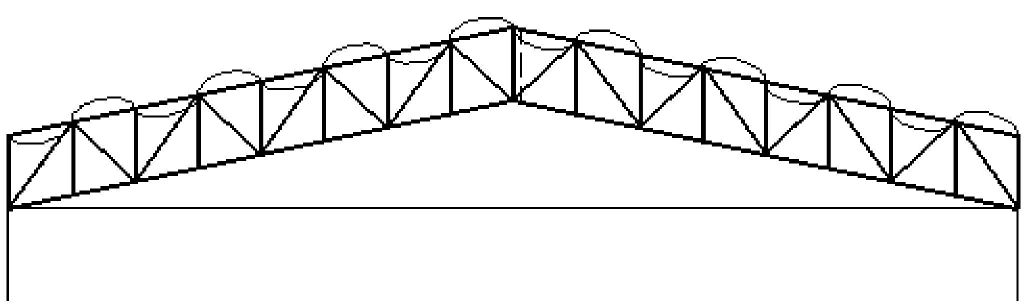


Photo: Author



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.

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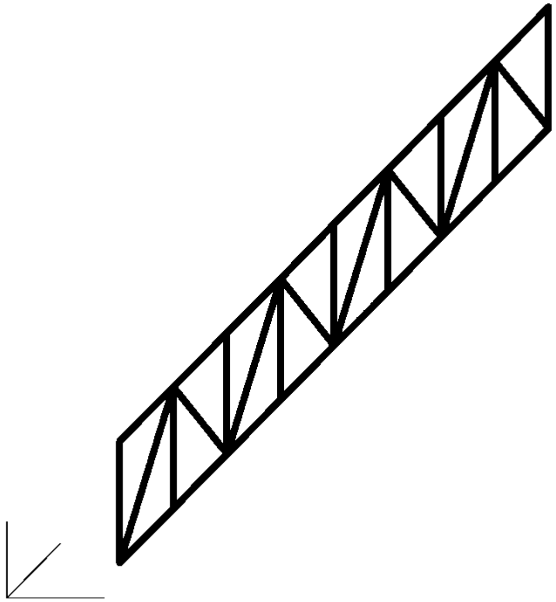
Flexural buckling of chords:



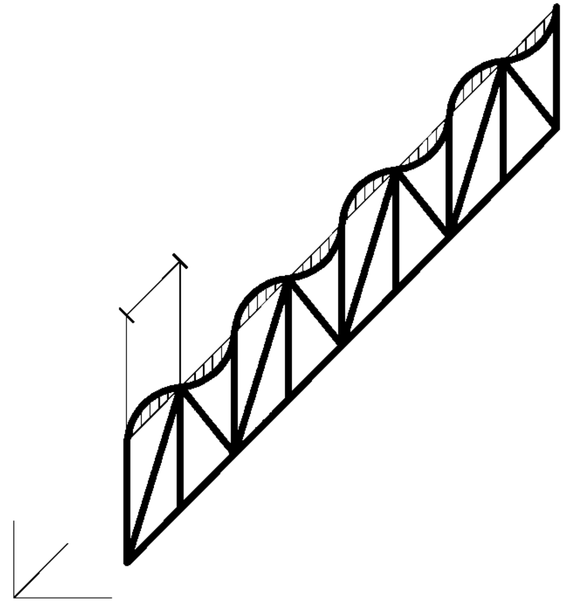


Photo: Author

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

Flexural buckling of chords:

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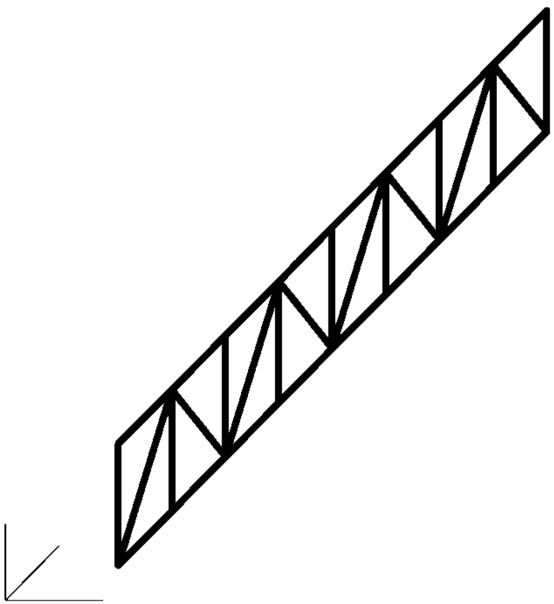

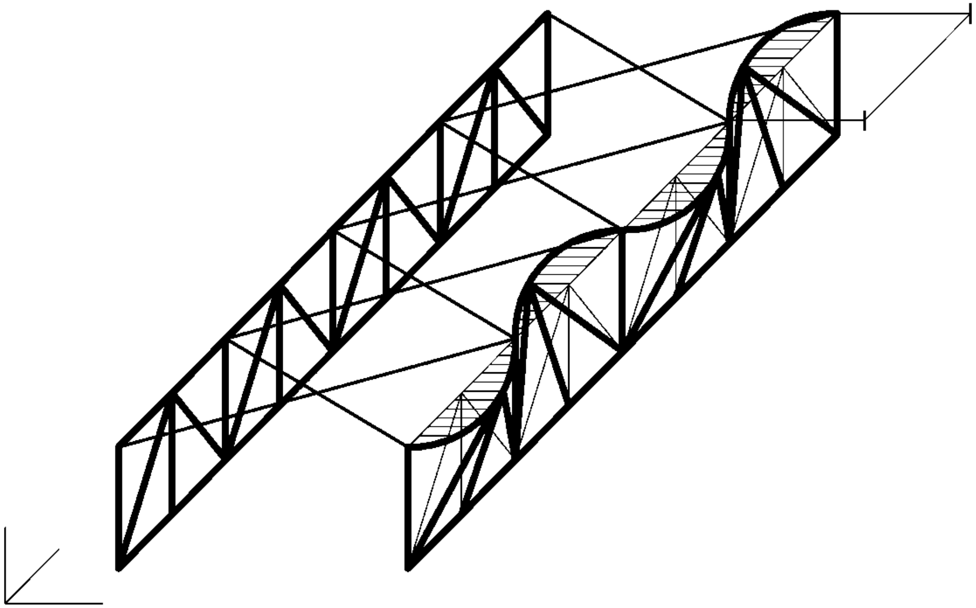

Photo: Author

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

Flexural buckling of chords:

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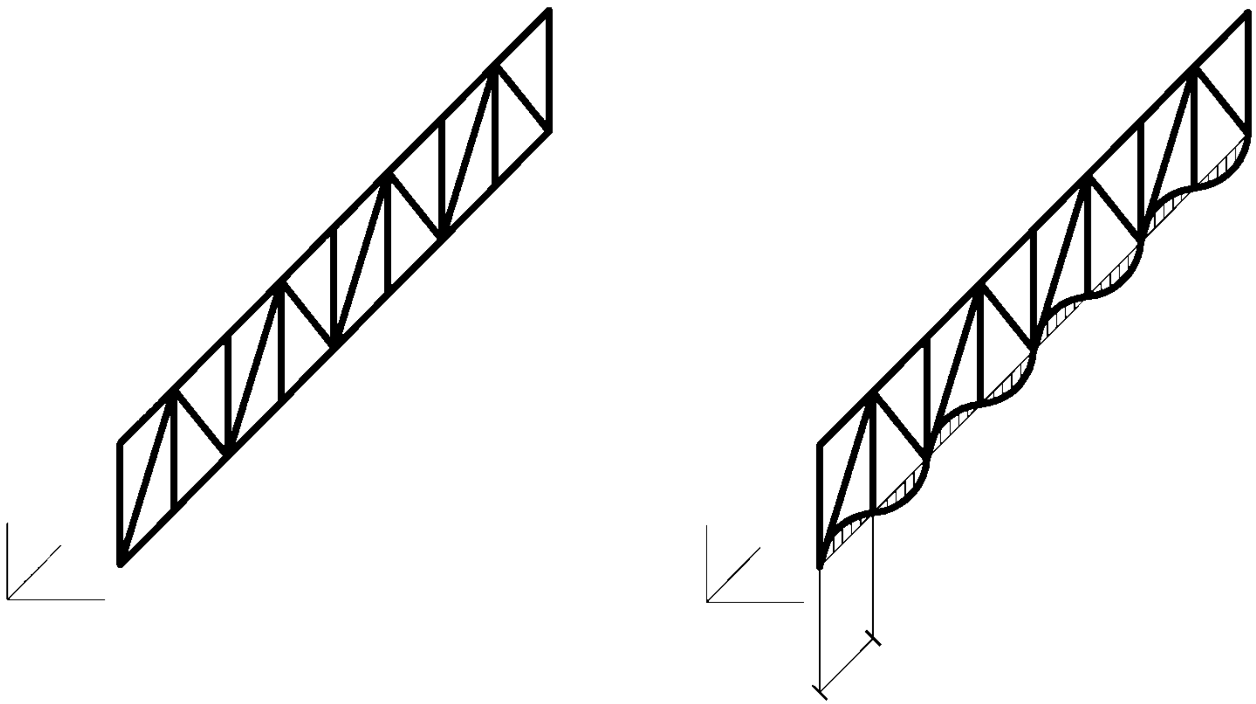

Photo: Author

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

Flexural buckling of chords:

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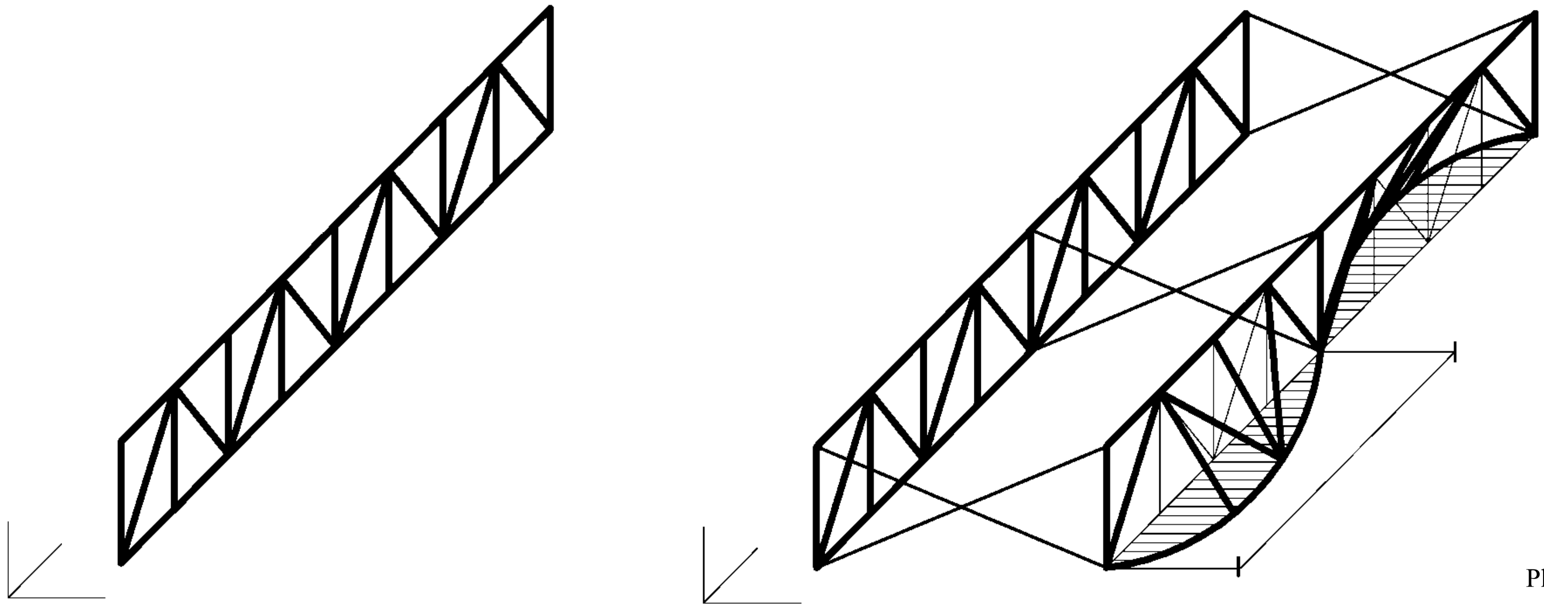

Photo: Author

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

Bracings are very important for behaviour of structures, including for trusses. For calculations, there are used special algorithms and models.

More information about bracings will be presented on lecture #10.

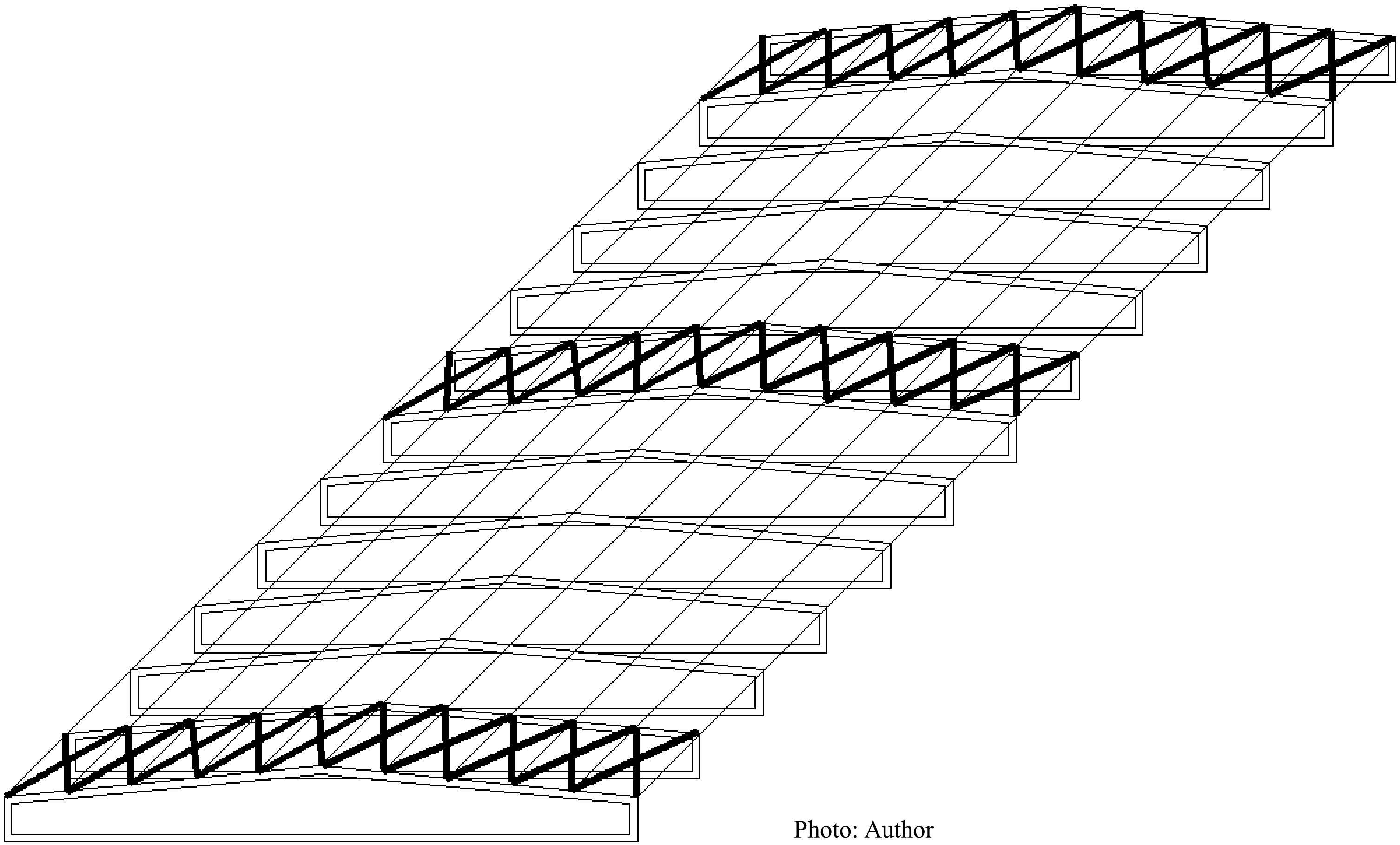

Photo: Author

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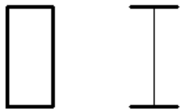
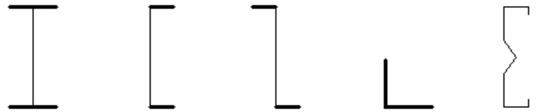
The result of calculations is buckling factor χ.

It is calculated in different way for different cross-sections.

Buckling		
Flexural		Flexural, torsional, flexural-torsional
	 (hot rolled I)	 (welded I)
$\chi = \chi_y = \chi_z$ (only if $l_{cr,\,y} = l_{cr,\,z}$)	$\chi = \min(\chi_y \;;\; \chi_z)$	$\chi = \min(\chi_y \;;\; \chi_z \;;\; \chi_T \;;\; \chi_{z,\,T})$

Cross-sections of truss members

	PN B 03200	EN 1993
Elements	Each types of cross-sections are accepted	
Joints	No additional requirements	Additional requirements → many types of cross-sections are not accepted

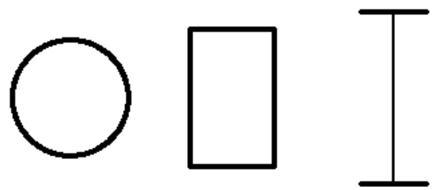
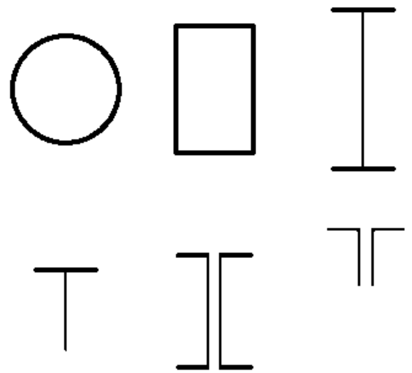
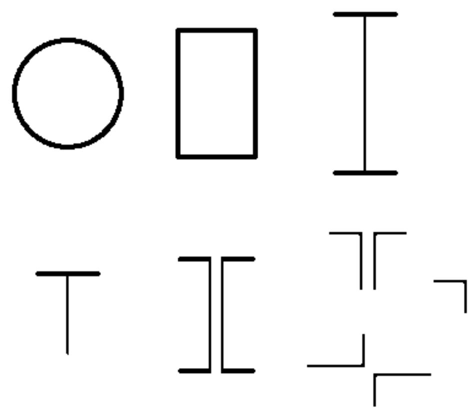
	Modern types of cross-sections (EN)	Old types of cross-sections (PN-B)
Chords		
Web members	 Photo: Author	

Photo: architectureau.com

Whenever we use hollow sections, we must hermetically close the ends by welding to prevent corrosion inside HS. Such type of corrosion can develop without apparent external symptoms and can cause damage of structure without warning signs.

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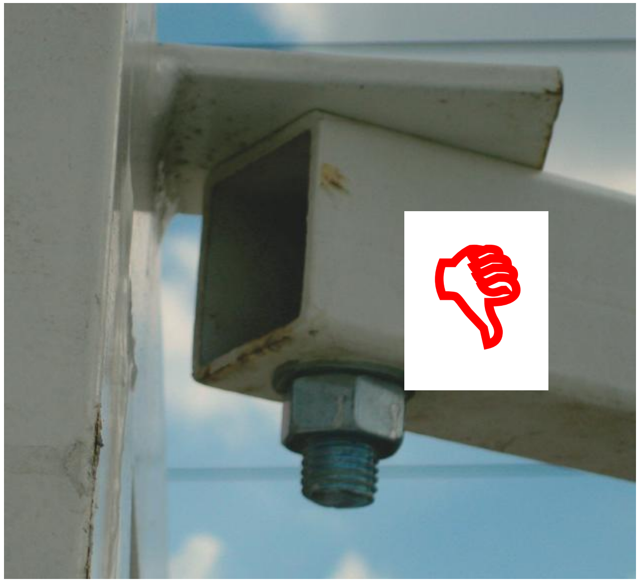


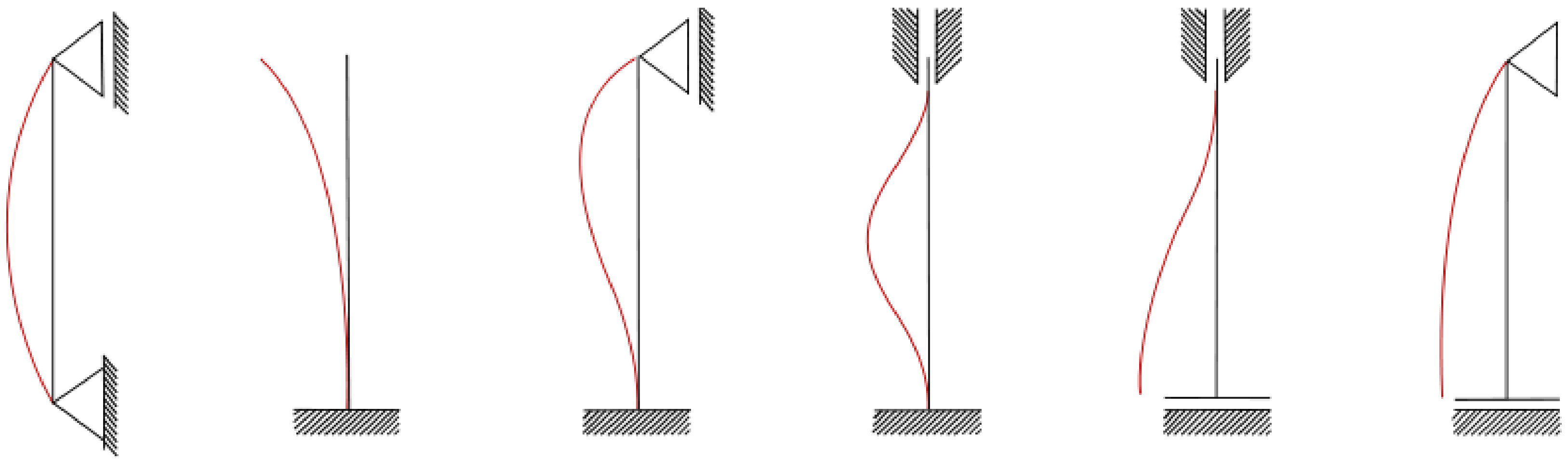
Photo: Błędy wykonawcze podczas realizacji konstrukcji stalowych, Litwin M, Górecki M, *Budownictwo i Architektura 4 (2009) 63-72*

Number of various cross-sections, designed in truss: 2 - 5:

<table>
<tr><th>Chords</th><th>Brace members</th></tr>
<tr><td rowspan="2">Top and bottom - the same I-beam
or
Two different I-beams, first for top, second for bottom</td><td>1-3 different RHS</td></tr>
<tr><td>1-3 different CHS</td></tr>
<tr><td rowspan="2">Top and bottom - the same RHS
or
Two different RHS, first for top, second for bottom</td><td>1-3 different RHS</td></tr>
<tr><td>1-3 different CHS</td></tr>
<tr><td>Top and bottom - the same CHS
or
Two different CHS, first for top, second for bottom</td><td>1-3 different CHS</td></tr>
</table>

There are different factors for different types of support

Photo: wikipedia



μ	1,0	2,0	0,7	0,5	1,0	2,0
l_{cr}	1,0 l_0	2,0 l_0	0,7 l_0	0,5 l_0	1,0 l_0	2,0 l_0

Conclusions: different types of support is important factor affecting the calculation:

$$N_{cr} = \pi^2 EJ / (\mu \, l_0)^2$$

Buckling length ratio μ for truss members:

Element	Direction	Cross-section			
		I H	pipe	closely-spaced build-up members	other
Chord	In plane	0,9	0,9	1,0	1,0
	Out of plane	1,0	0,9	1,0	1,0
Brace	In plane	0,9	0,9; 1,0; 0,75	1,0; A	1,0; A
	Out of plane	1,0	1,0; 0,75	1,0; A	1,0; A

Bolted connections

Chords parallel and $d_{truss\ bracing} / d_{chord} < 0,6$

EN 1993-1-1 BB.1.1

L sections:

$\bar{\lambda}_{eff,\ i} = 0,5 + 0,7\ \bar{\lambda}_i \quad i = y, z$

$\bar{\lambda}_{eff,\ v} = 0,35 + 0,7\ \bar{\lambda}_v \quad v = u, v$

Not recommended type of cross-sections because of requirements for joints

Additional requirements during analysis of truss / frame behavior can be divided into three groups (EN 1993-1-8 5.1.5):

- General and additional requirements, permissible shapes of joints (→ #t / 47 - 50);
- Loads according to definition of ideal truss, in nodes only (→ #t / 50);
- Acceptable values of eccentricities (→ #t / 47, 51 - 53).

Consequences of satisfaction / dissatisfaction (partial satisfaction) are various, in dependence of group of requirements. Generally, 5 various static models of truss / frame is taken into consideration.

The more conditions are dissatisfied, the static model of the truss is getting closer to the frame with rigid joints.

Additional requirements for truss nodes

(EN 1993-1-8 7.1):

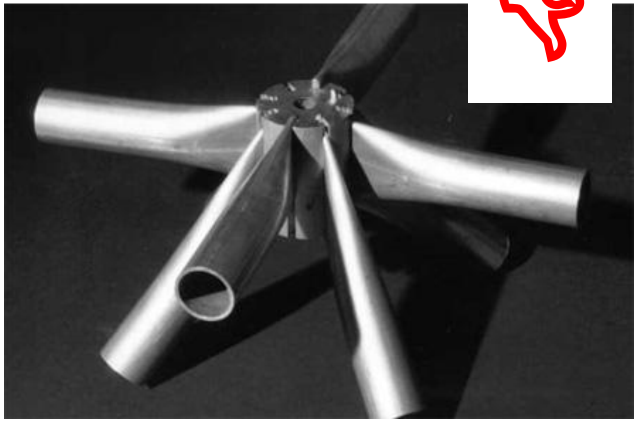


Photo: tatasteelconstruction.com

- Chords → ▯ □ ○ I ;
- Web members → ▯ □ ○ ;
- Deformation ends of element are not accepted;
- f_y (▯ □ ○) ≤ 460 MPa;
- f_y (▯ □ ○) > 355 MPa → $f_{y,\ design}$ = 0,9 f_y;
- t (▯ □ ○) ≥ 2,5 mm;
- t_{chord} (▯ □ ○) ≤ 25 mm;

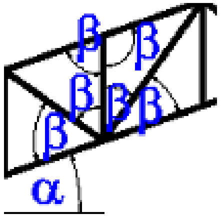
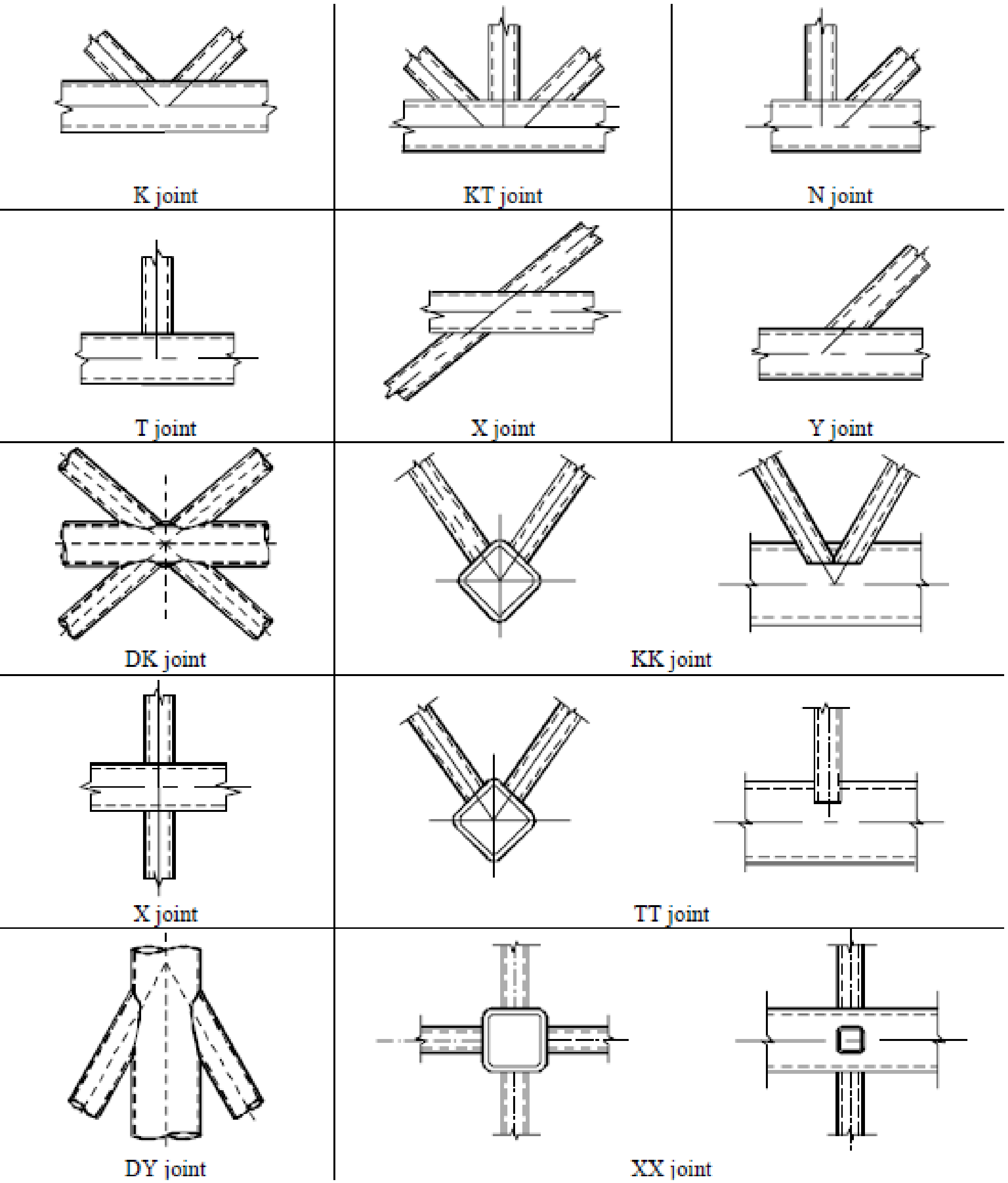


Photo: Author

- Compressed chords and web memebers → I[st] or II[nd] class of cross-section;
- $\beta_i \geq 30^o$;
- Distances between web members (eccentricities) must be respected (→ #t / 51 - 53);
- Shape of joints must be respected (EN 1993-1-8 fig. 7.1), (→ #t / 48);
- (Length of member) / (depth of member) > 6 (EN 1993-1-8 5.1.5.(3));



Types of permissible joints

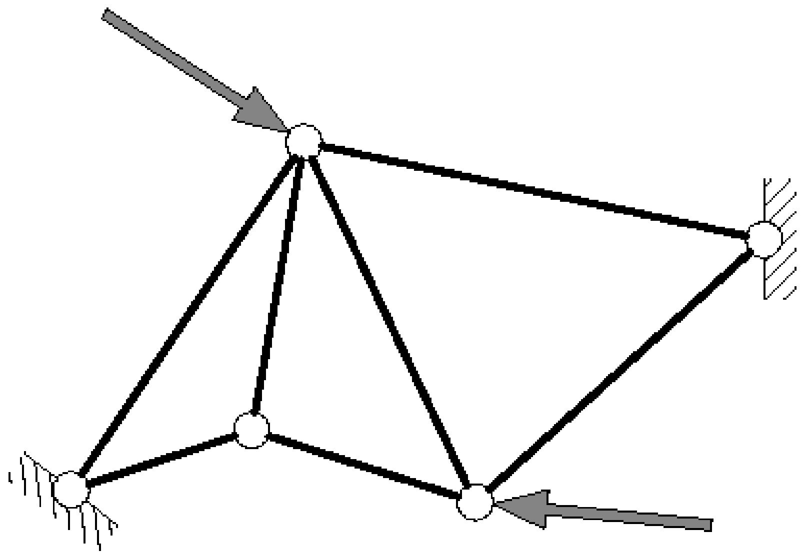
Photo: EN 1993-1-8 fig. 7.1

For each type of joint, many additional requirements must be satisfied. These requirements are presented in few tables in EN 1993-1-8; symbols are explained in EN 1993-1-8 1.5.(4), (5), (6).

Joint		Table	Comments
Chord	Web members		
CHS	CHS	7.1	-
RHS	CHS, RHS	7.8, 7.9	-
I-beam	CHS, RHS	7.20	-
C-section	CHS, RHS	7.21	C-section for chord is acceptet, but in this situation local bending moments must be taken into consideration (this means, this structure is not ideal truss).

Geneally, requirements presentes in tables, are as follow:

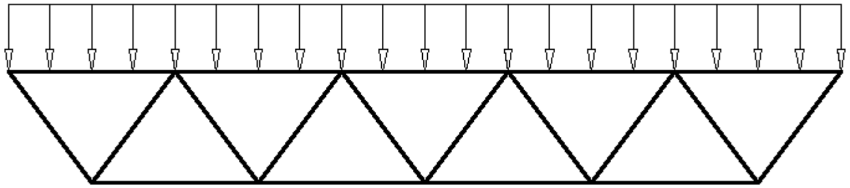
$$\min \leq (\text{depth of HS}) / (\text{thickness of its wall}) \leq \max$$



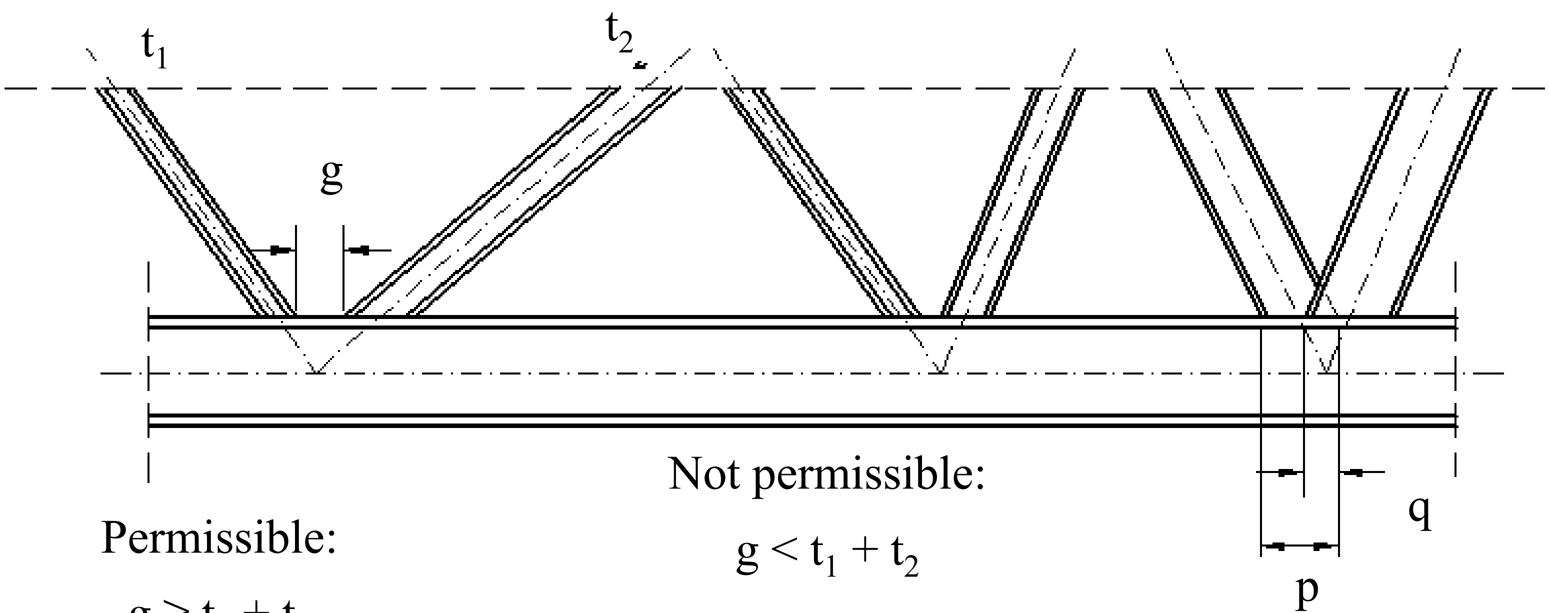
Truss – theory (idealization):

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

Photo: Author



Truss purlin not satisfy requirement „forces in joints only”. The same in case of force applied out of joint.



Not permissible:

$g < t_1 + t_2$

or

$q / p < 0{,}25$

Permissible:

$g \geq t_1 + t_2$

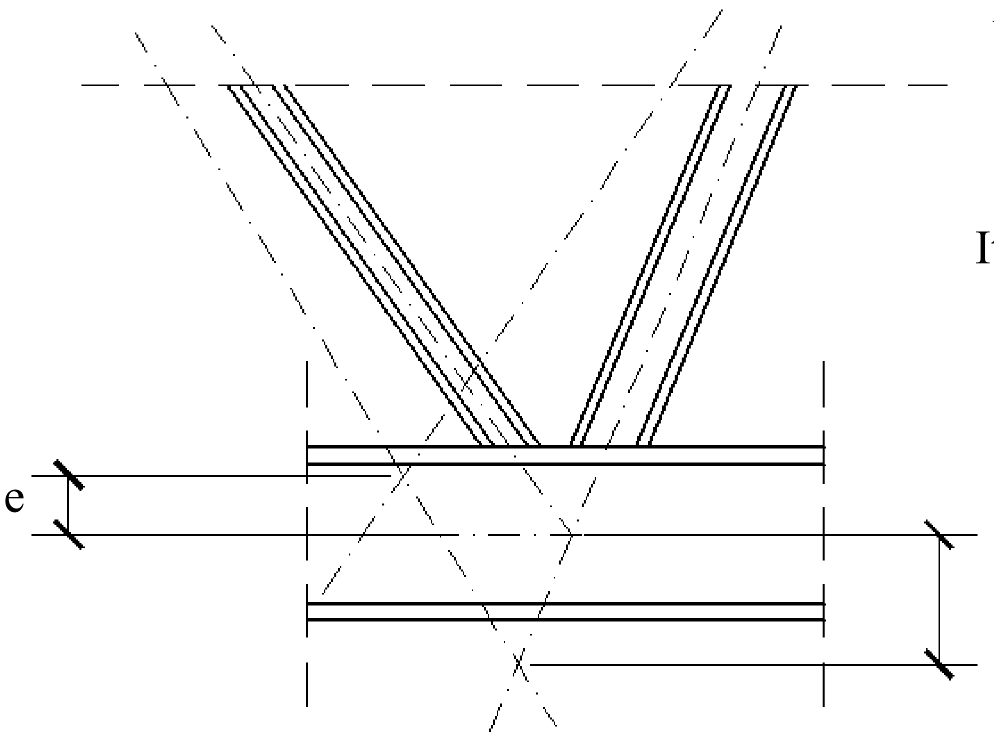
Permissible:

$q / p \geq 0{,}25$

EN 1993-1-8 7.1

Photo: Author

Results:



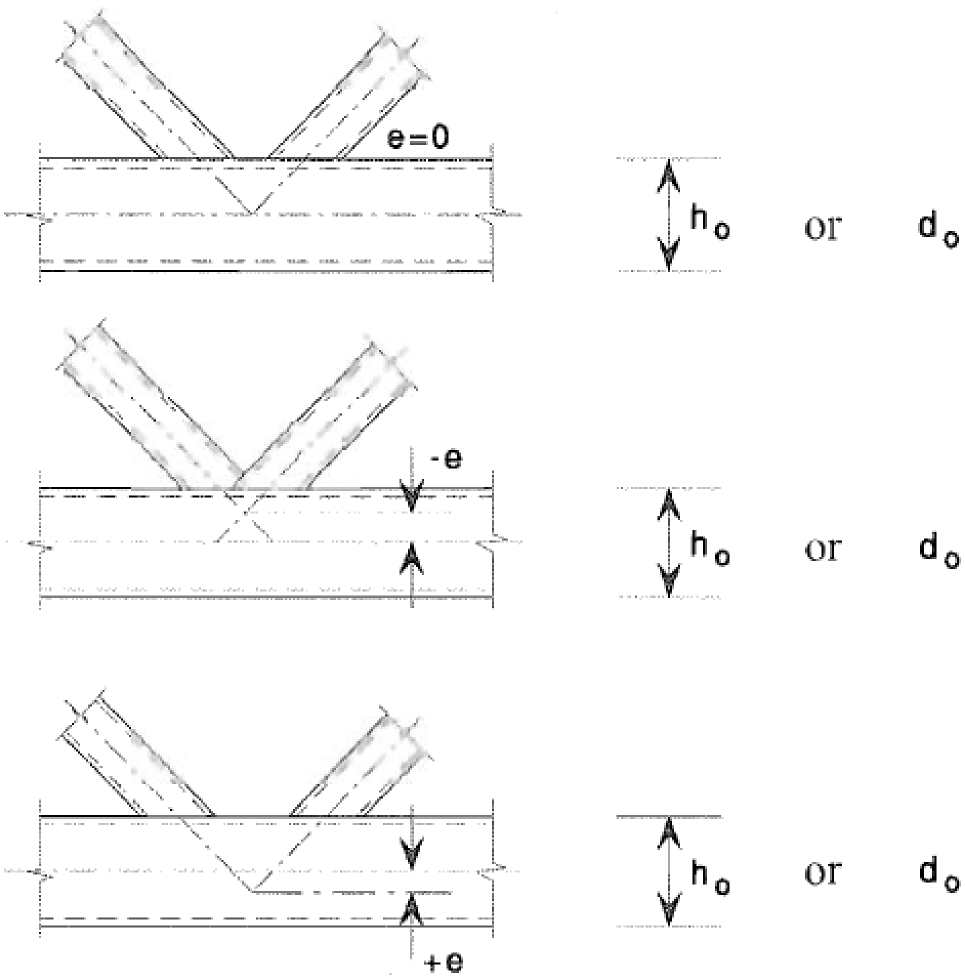
There is possible, that we must trace other axis of member to satisfy requiremen for

$$g \geq t_1 + t_2 \text{ or } q / p \geq 0{,}25$$

It makes eccentricities. Eccentricities make <u>non-zero values of bending moment.</u>

Photo: Author

Photo: EN 1993-1-8 fig. 5.3



Acceptable limits for eccentricities:

$-0,55\ a_0 \leq e \leq +0,25\ a_0$

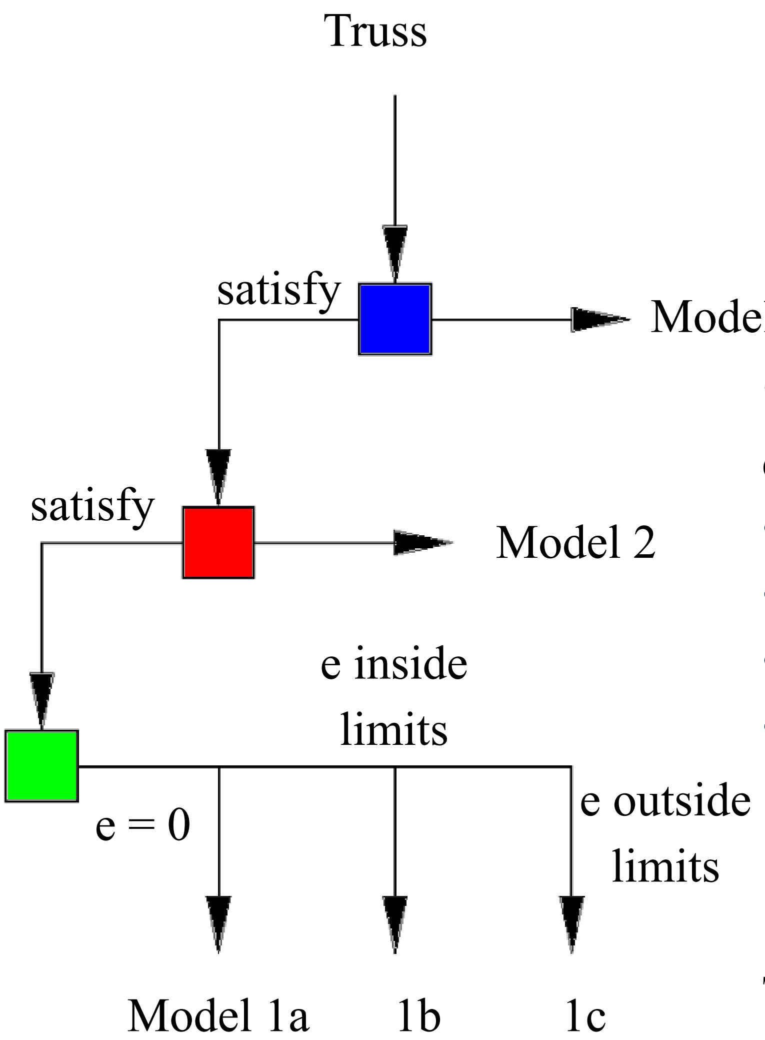
$a_0 = h_0$ or d_0

EN 1993-1-8 (5.1a), (5.1b)

Three possibilities must be taken into accout:

- no eccenticities;
- eccentricities inside limits;
- eccentricities outside limits,

Stiffness



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.

→ Des #1/ 76

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

Photo: Author

Photo: Author

5 various models of truss behavior:

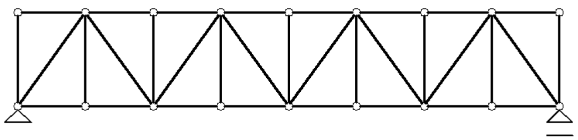
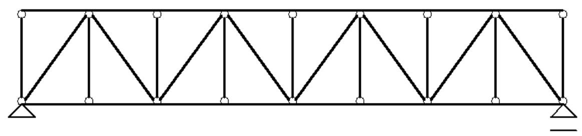
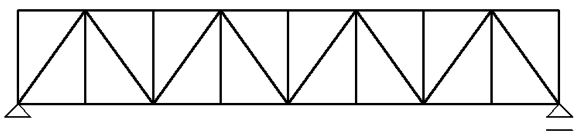
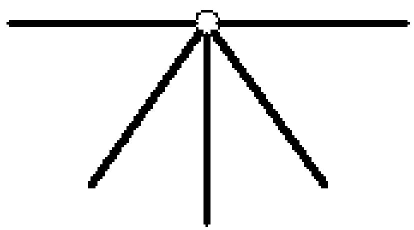
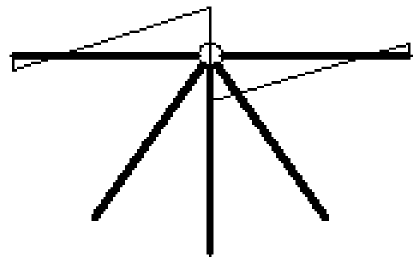
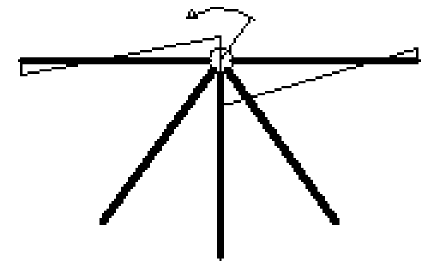
		
1. Ideal truss.	2. Continous top / bottom chord.	3. Frame.
Subtypes: 1a, 1b, 1c.	No subtypes.	No subtypes.
Hinged joints only.	Hinged and rigid joints.	Rigid joints only.
Axial forces for each element; bending moments and shear forces for part of joints and elements in dependence of subtypes.	Axial forces for each element; bending moments and shear forces for part of joints and elements in dependence of type of neighboring joints (hinged / rigid)	Axial forces, bending moments and shear forces for each element and joint

Photo: Author

3 subtypes of ideal truss (model 1):

		
1a. No bending moments.	1b. Bending moments (axial force · eccentricity) act on chord only.	1c. Bending moments (axial force · eccentricity) act on joint and chord.
Ideal truss: axial forces only for elements and joints.	Axial forces only for most part of elements; Axial forces, bending moments and shear forces for part of chords; Axial forces for joints.	Axial forces only for most part of elements; Axial forces, bending moments and shear forces for part of chords; Axial forces and bending moments for joints.

→ #3 / 96

Algorithm

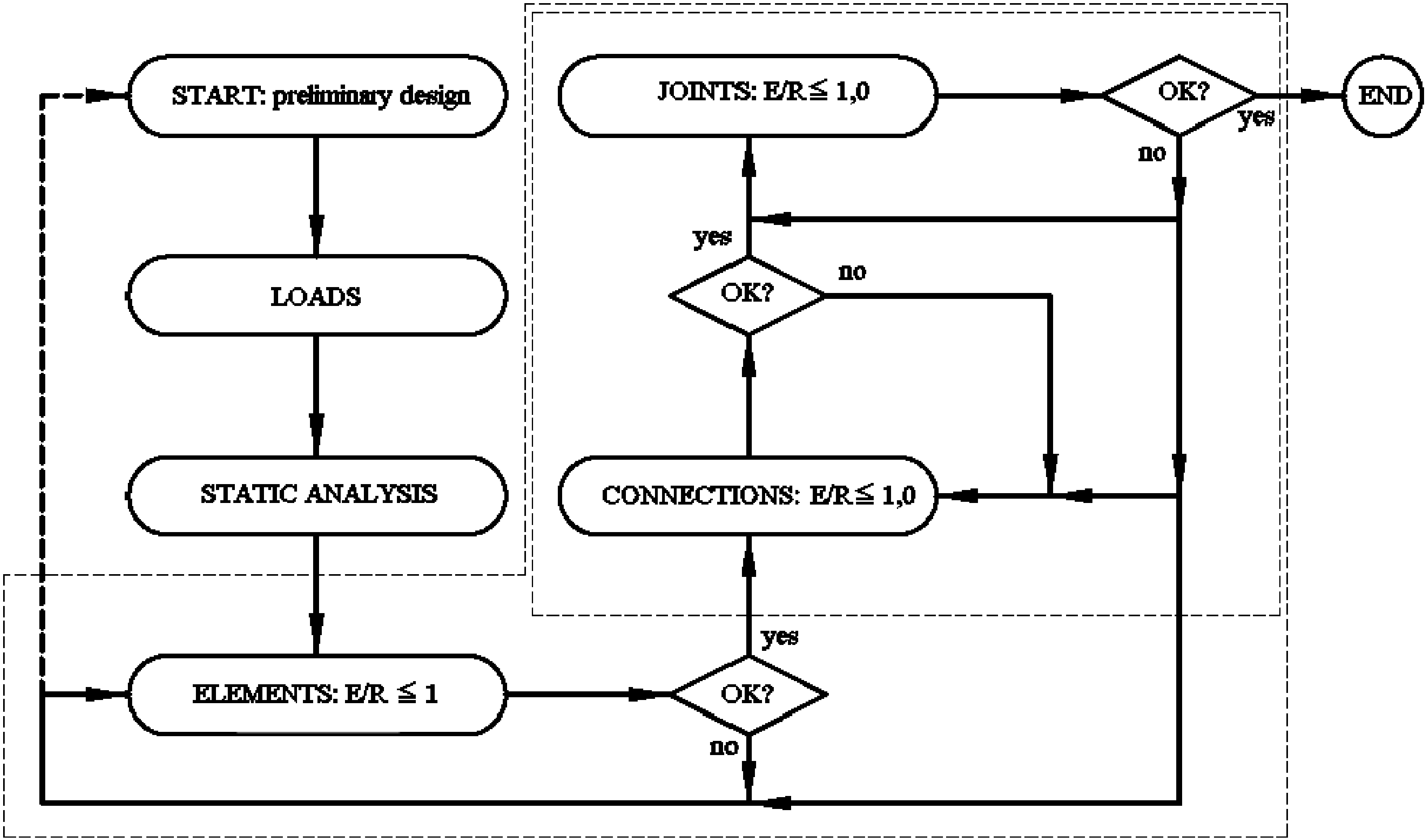


Photo: Author

Deformation ends of element are not accepted – what about systems for spatial trusses (Mero, SDC, Pyramitec, Unibat, Tesep, Tridimatec…)? In many cases ends of elements are deliberately deformed to connection with prefabricated nodes.

System solutions are tested in laboratories and manufacturer take guarantee, that such structure ids safe.

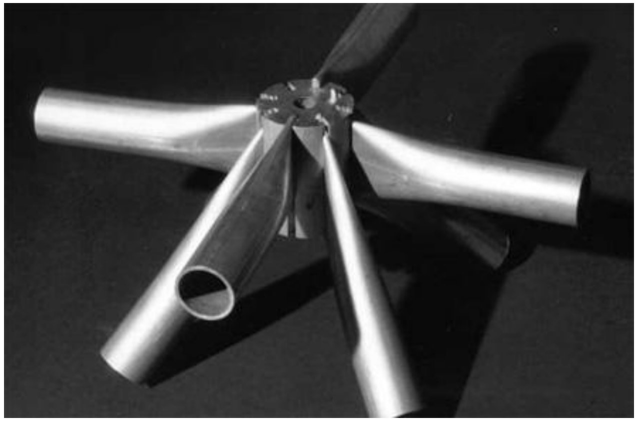


Photo: tatasteelconstruction.com

The provision prohibiting deformation of elements concerns „mormal" designers who do not have the opportunity to make full-test their solutions before erection.

Photo: altechsaudi.net

The same about system solutions of trusses, based on cold-formed sections. Manufacturers tested such structures – elements and joints – before application in construction sites. „Normal” designers do not have opportunity (lack of time, lack of money, lack of technical possibility) to make these tests.

Photo: kcse.com

Manufacturing details

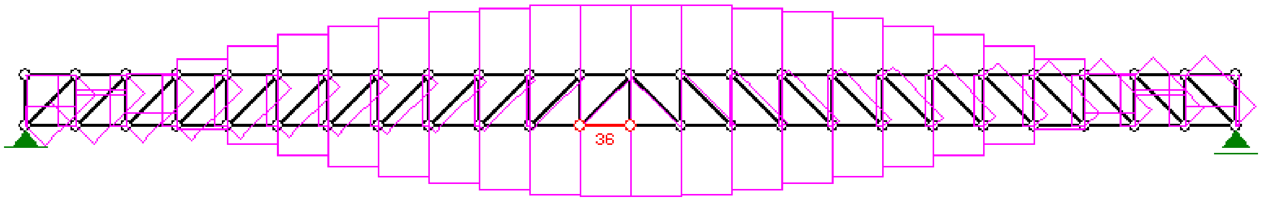


Photo: Author

Condition E / R should be as close 1,0 as possible because of economic reasons. Both cords could have smaller one cross-sections close to both ends of truss.

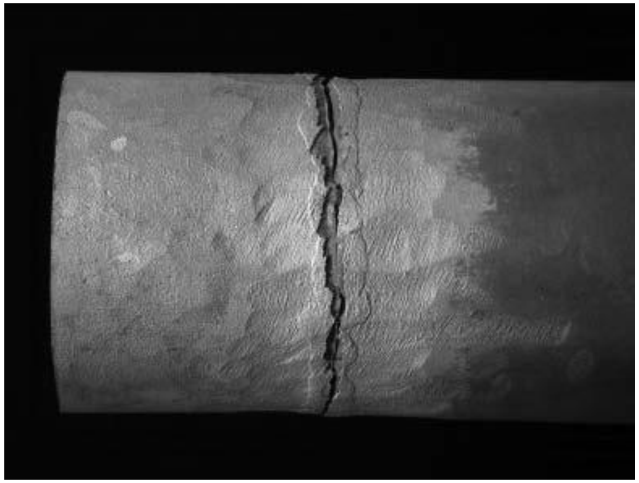


Photo: D. Kowalski, Problemy realizacji inwestycji z zakresu konstrukcji stalowych, Inżynieria Morska i Geotechnika 2013 / 5

But applying such solution can make croacking of welds, even if resistan of welds is enough.

Fatigue resistance

the amplitude or range of cyclic stress that can be applied to the material without causing fatigue failure

This is not the same as strength of material

Strength → static load

Fatigue resistance → cyclic (dynamic) load

This phenomenon is important for structures exposed to dynamic and cyclic loads. There is possible, that even little loads, but in many cycles (> 10 000) can destroy structure.

→ #2/ 78

On each elements exist imperfections and notches (holes, welds, micro-cracks). There is concentration of stress around each notches.

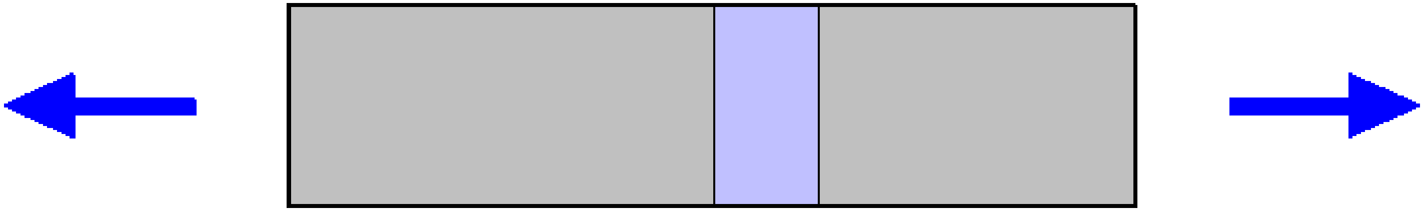
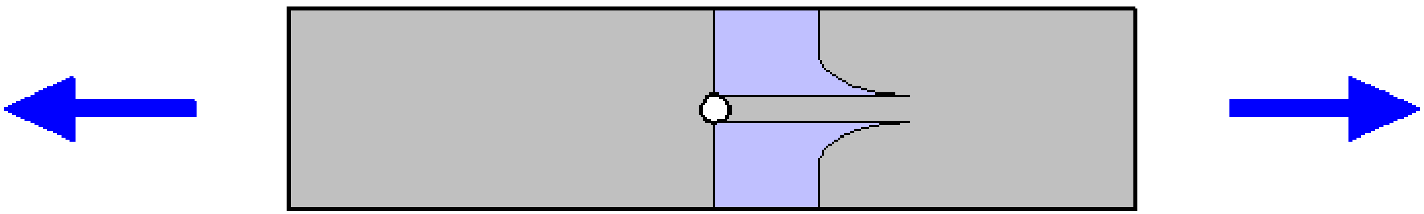


Photo: Author



$$\mu \, \sigma_{Ed} \leq f_y$$

→ #2/ 79

μ stress concentration factor

σ_{Ed} stress as for ideal cross-section

Additional effects of welding process (#6 / 26 – 29): secondary pollutions (gas bubbles, ash) introduced during welding, local deformation of plates, cracks as effect of thermal shrinkage...

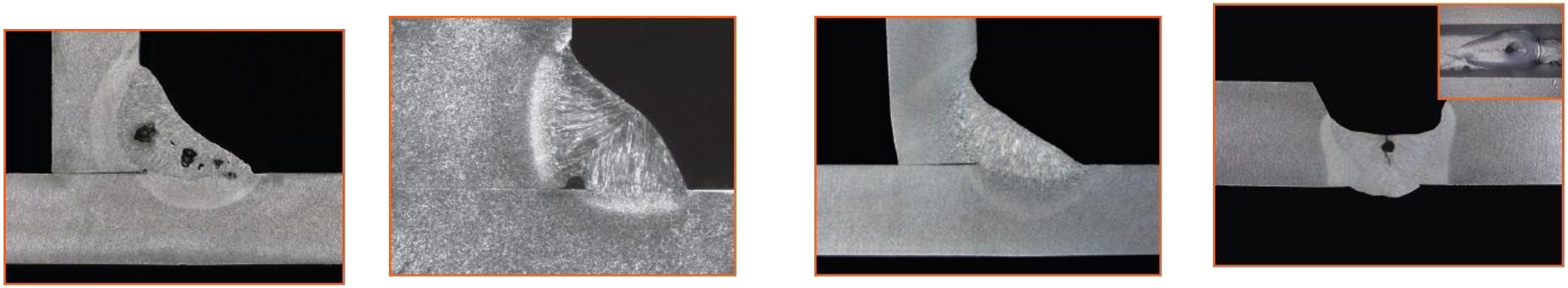


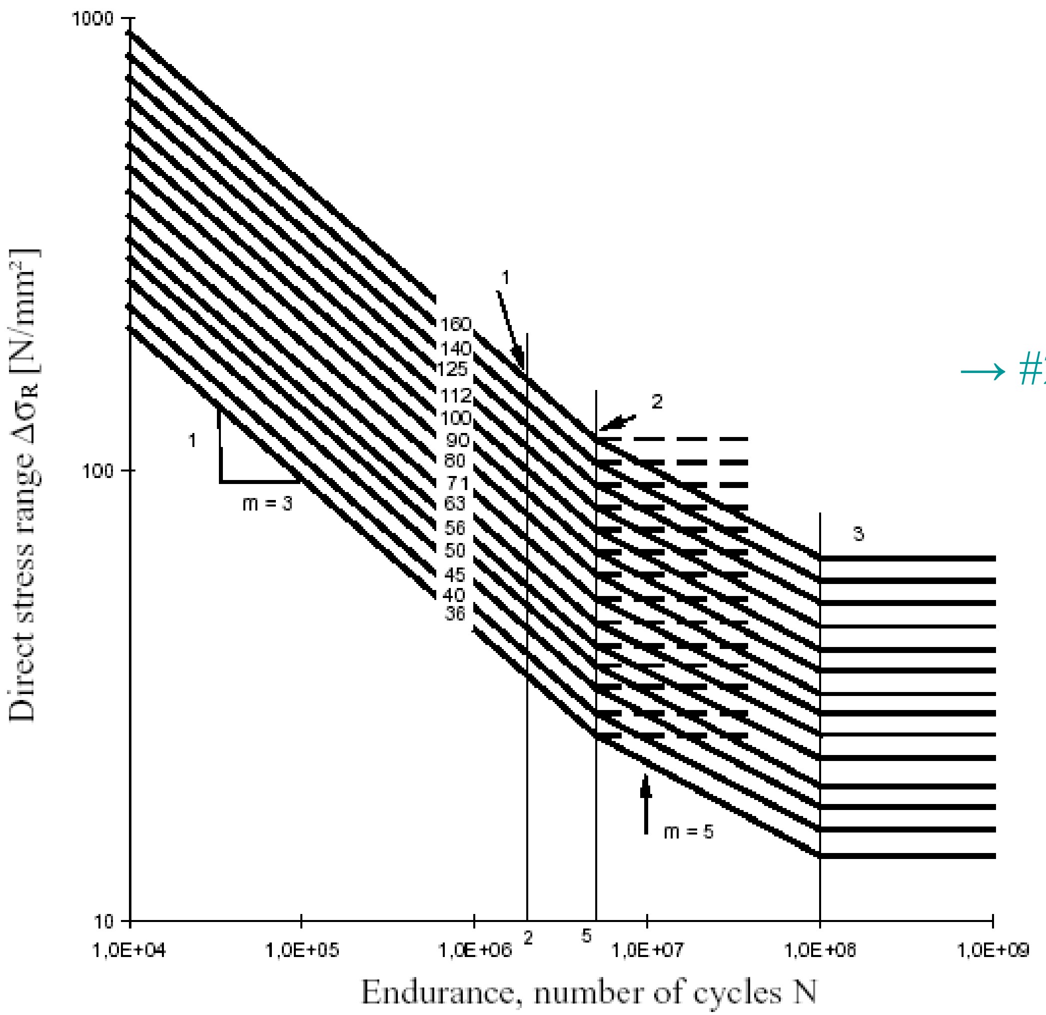
Photo: figel.pl

Ability and experience of worker ↓ → number of welding imperfection ↑ → quality level of welds ↓

→ #6 / 32

Accepted number of welding imperfection is limited by Execution Class. (→ #6 / 47).

Photo: EN 1993-1-9 fig 7.1



→ #2 / 82

1 Detail category $\Delta\sigma_C$

2 Constant amplitude fatigue limit $\Delta\sigma_D$

3 Cut-off limit $\Delta\sigma_L$

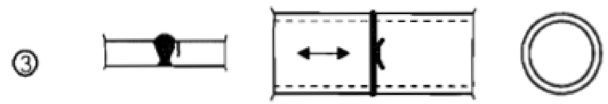
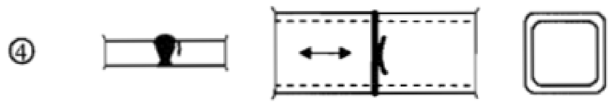
71		Transverse butt welds: 3) Butt-welded end-to-end connections between circular structural hollow sections.
56		4) Butt-welded end-to-end connections between rectangular structural hollow sections.

Photo: EN 1993-1-9 Tab. 8.6

Fatigue resistance for transverse welds for R/C HS is not very high.

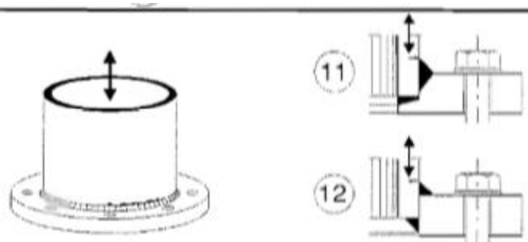
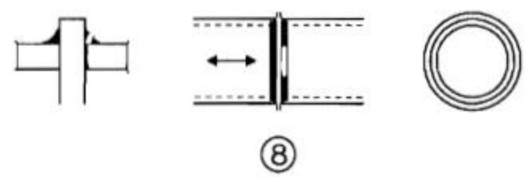
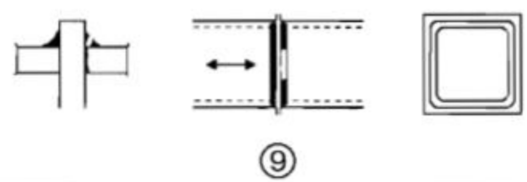
71		11) Tube socket joint with 80% full penetration butt welds.
40		12) Tube socket joint with fillet welds.

Photo: EN 1993-1-9 Tab. 8.5

Photo: EN 1993-1-9 Tab. 8.6

40		8) Circular structural hollow sections, fillet-welded end-to-end with an intermediate plate.
36		9) Rectangular structural hollow sections, fillet-welded end-to-end with an intermediate plate.

Fatigue resistance for welds between R/C HS and intermediate plate is even smaller.

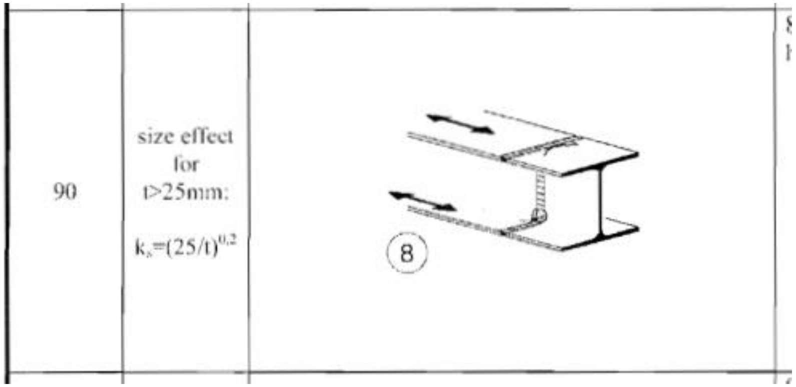


Photo: EN 1993-1-9 Tab. 8.3

Fatigue resistance for transverse welds I-beams is higher.

Conclusions:

Photo: en.wikiarquitectura.com

Photo: encrypted-tbn0.gstatic.com

Joint with longitudinal stiffeners is better (longer welds → smaller stresses → smaller amplitude of stresses) because of fatigue than joint without stiffeners.

Problems with fatigue for I-beams are smaller than for R/C HS.

Photo: tboake.com

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

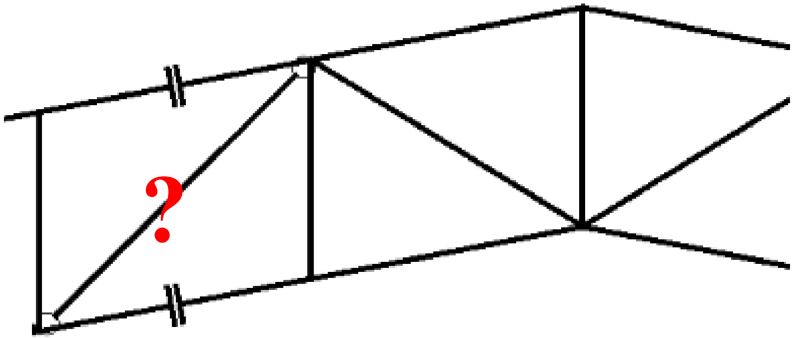
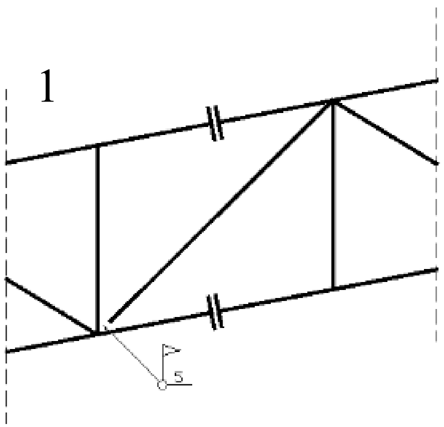
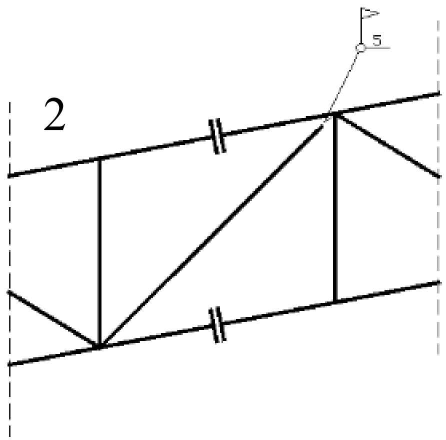
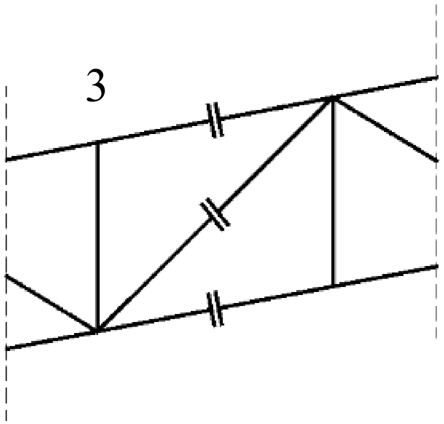


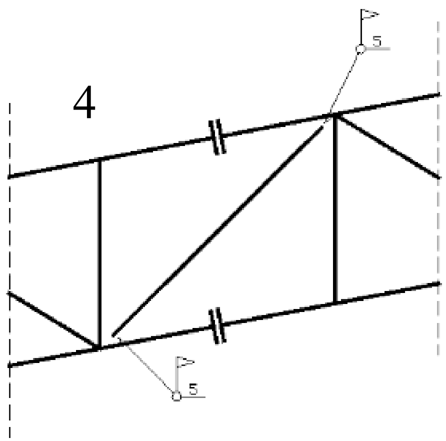
Photo: Author





→ Des #1/ 80





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.

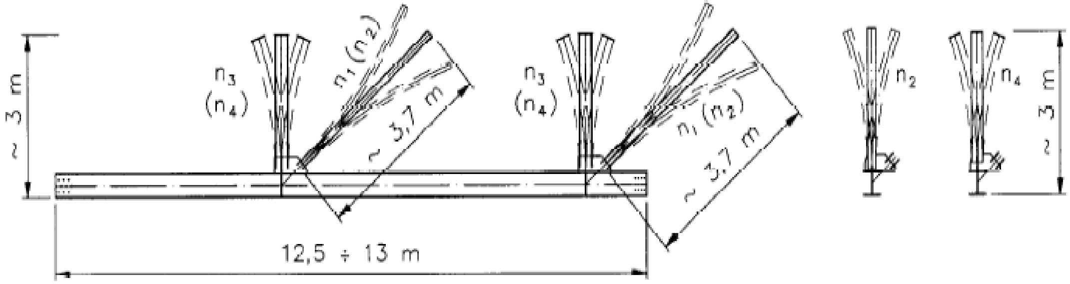


Photo: Awaryjne zagrożenie stalowej konstrukcji dachu hali widowiskowo-sportowej w Sopocie, E. Hotała et all, Awarie Budowlane 2009

→ Des #1/ 81

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.

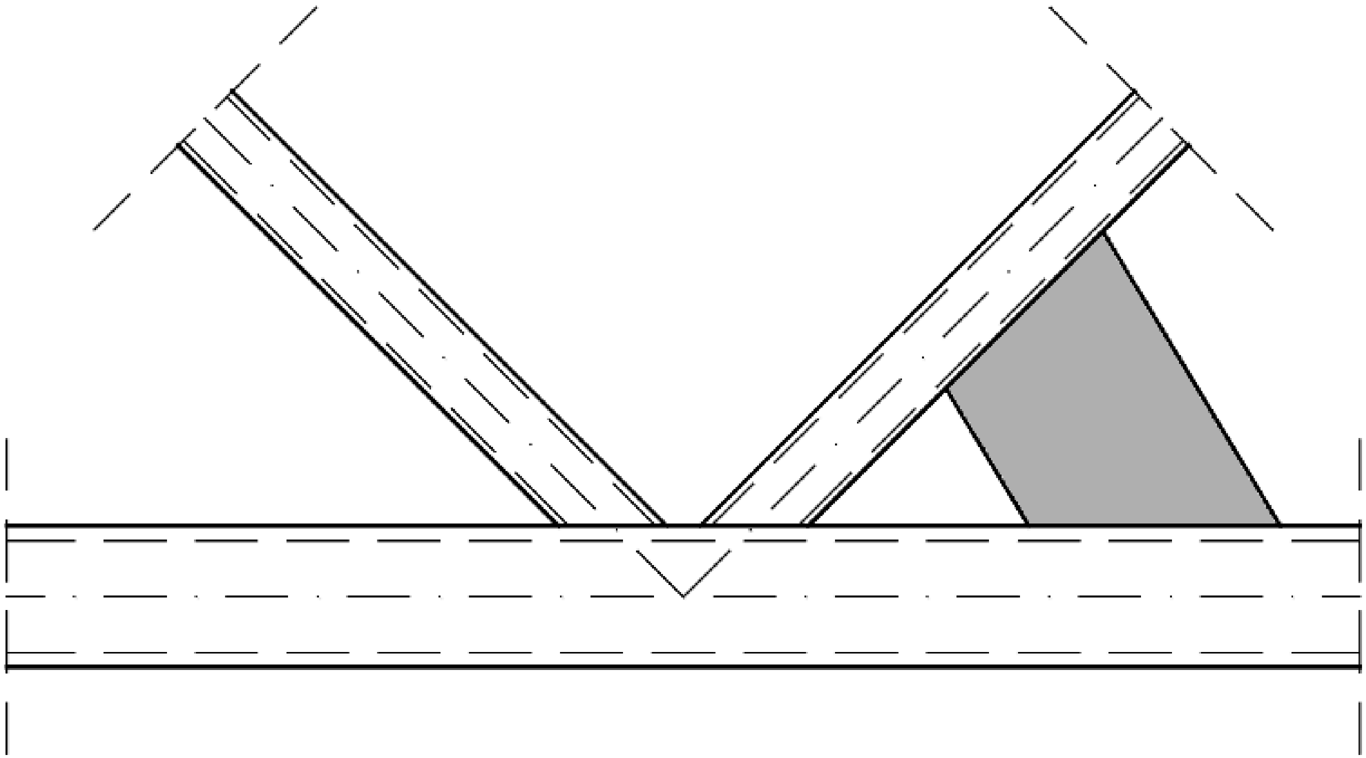
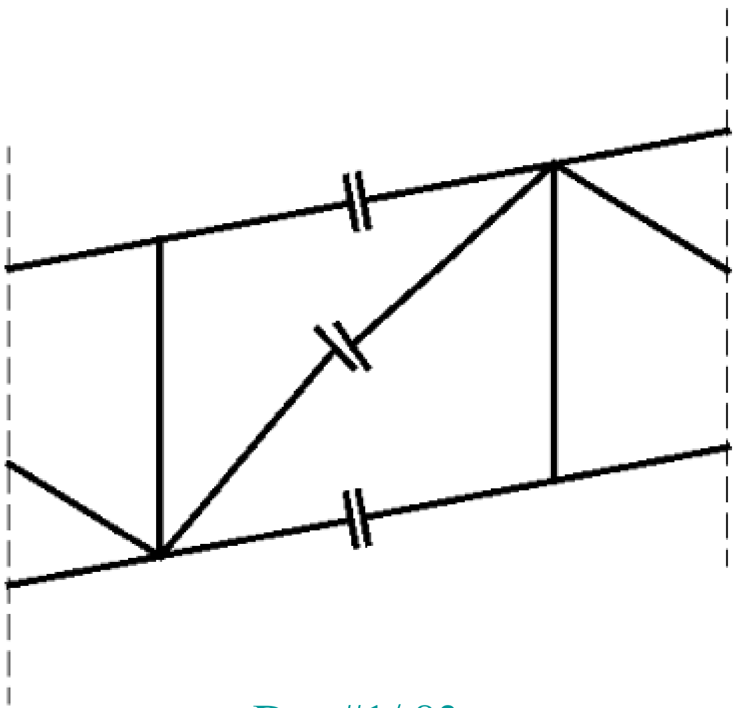
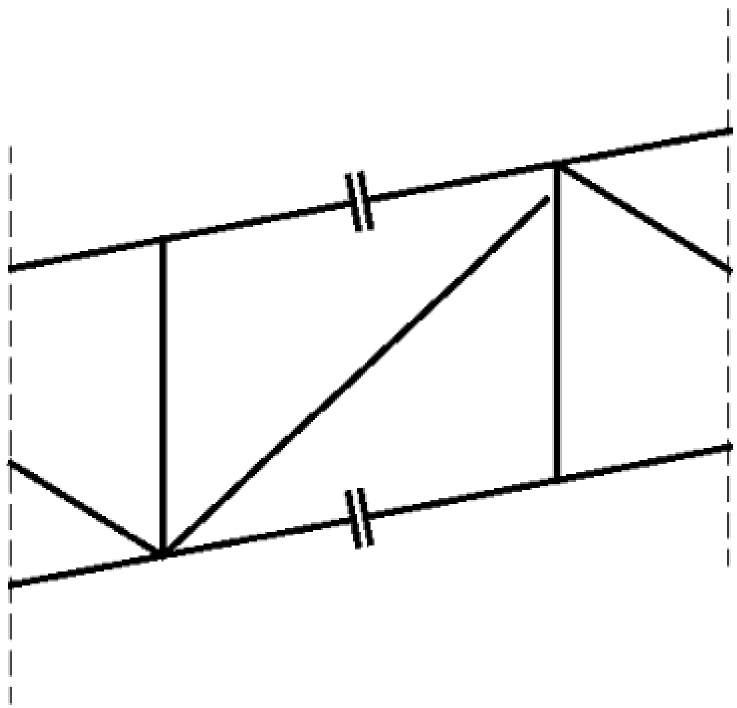


Photo: Author

→ Des #1/ 82

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° - 2°) may make impossible to connect the truss.

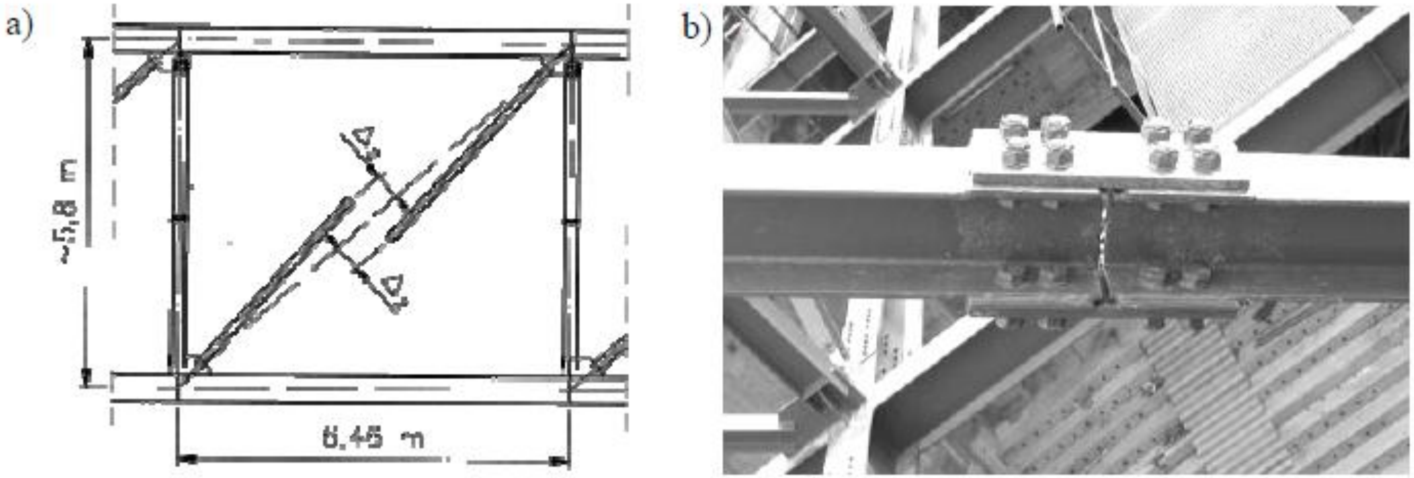




→ Des #1/ 83

Photo: Author

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



Additional secondary effect of splice joint in half of web member: deformaion after welding (→ #6 / 27). Both parts of member can have various position of axes ant there will be problem with connection.

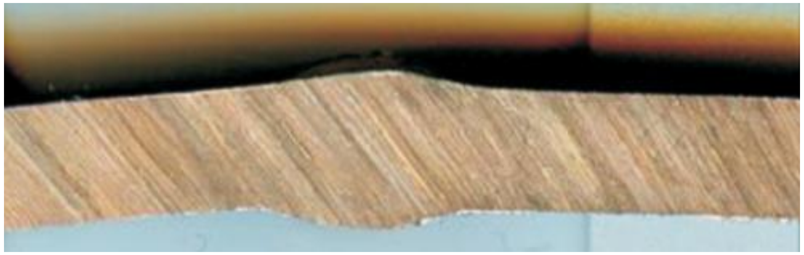


Photo: Analiza numeryczna odkształcenia i naprężenia w strefie złącza spawanego rurociągu przemysłowego, Gliha V Śniezek L Zimmerman J, Biuletyn WAT Vol. LVIII, No. 2, 2009

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.

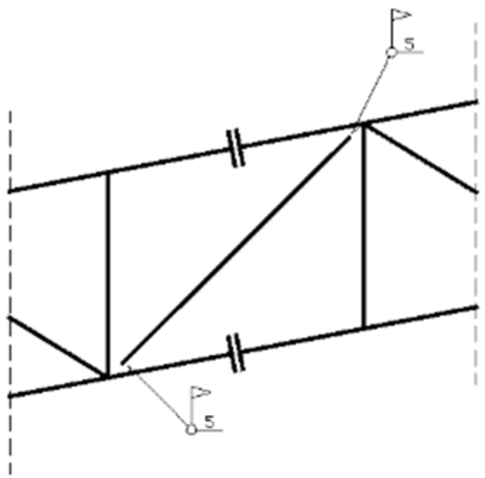


Photo: Author

→ Des #1/ 84

Photo: tboake.com

Photo: tboake.com

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

Recommendations from old Polish Standard:

$$\lambda = \max\left(L_{cr,\,y} / i_y \;\; ; \;\; L_{cr,\,z} / i_z\right)$$

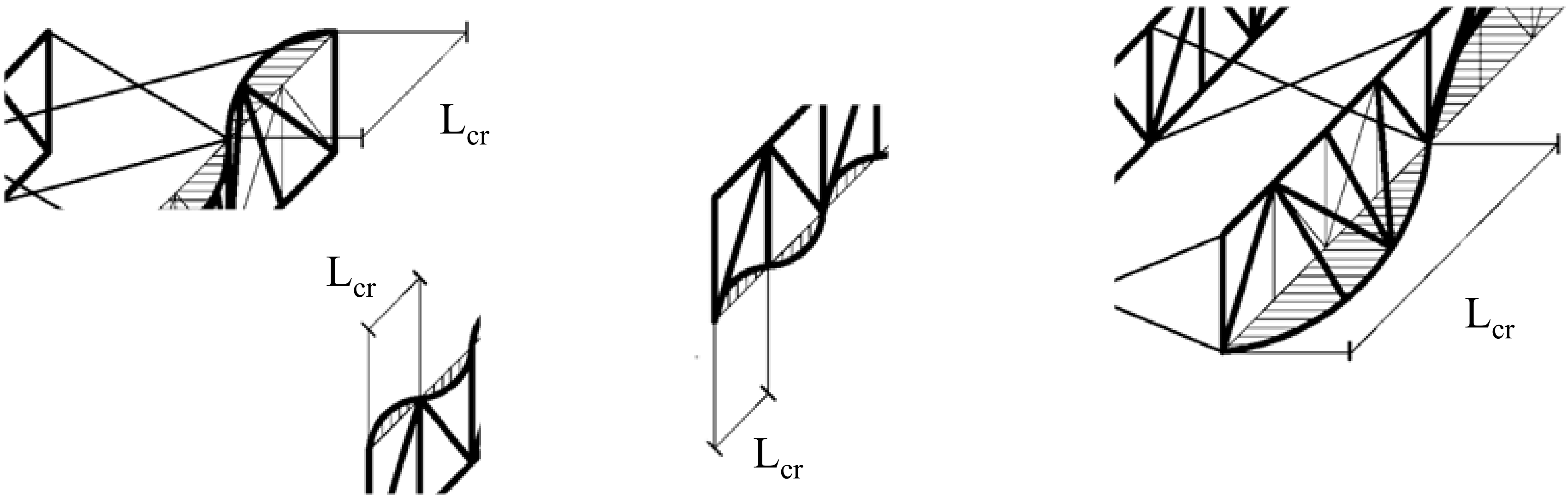
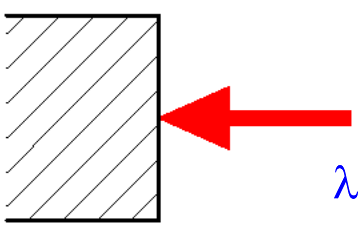
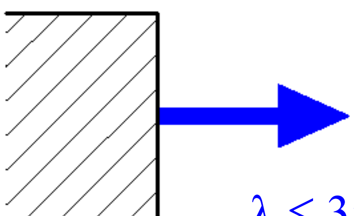


Photo: Author



$\lambda \leq 250$

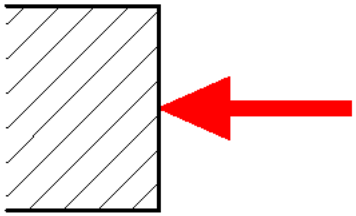


$\lambda \leq 350$

Slenderness is important for a compressed member (it determines the buckling factor χ). It seems to be completely irrelevant for case of axial tension. Why did the old Standard impose restrictions? Why small χ with large λ cannot be ballanced by the large value of A? Why should you consider slenderness at axial tension at all?

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

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



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

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

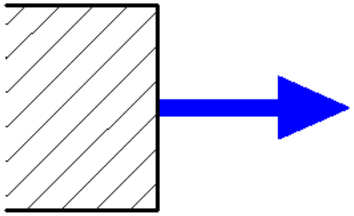


Photo: Author

In real world no ideal members. Not existed ideally straigth members, without initial curvature.

Photo: prikol.ru

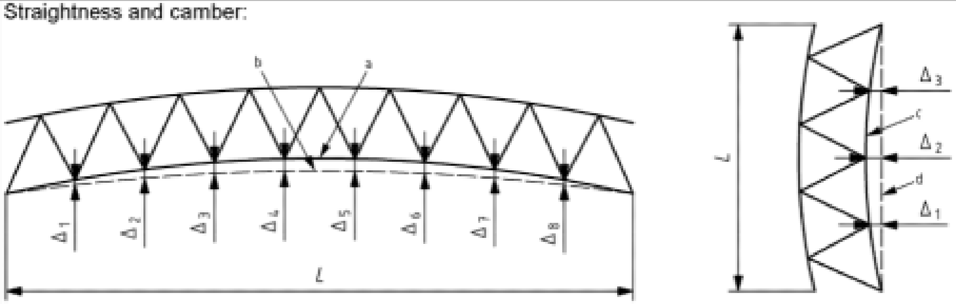
No	Criterion	Parameter	Permitted deviation Δ
1	Straightness and camber:  NOTE Deviations measured after welding, with the component lying flat on its side.		
	Key *a* actual camber; *b* intended camber; *c* actual line; *d* intended line	Deviation at each panel point, relative to a straight line - or to the intended camber or curvature.	$\Delta = \pm L/500$ But $\lvert\Delta\rvert \geq 12$ mm
2	Straightness of bracing components:	Deviation of bracing length L_1 from straightness:	$\Delta = \pm L_1/750$ but $\lvert\Delta\rvert \geq 6$ mm
NOTE Notations such as $\Delta = \pm L/500$ but $\lvert\Delta\rvert \geq 12$ mm mean that $\lvert\Delta\rvert$ is the *larger* of $L/500$ and 6 mm.			

Photo: PN 1090-2 tab. D1.10

Photo: hourdose.com

In theroy, on truss bar acts axial force only:

$$P / A \leq f_y$$

but, because of bow inperfection, bending moment on initiial eccenticity e must be taken into consideration:

$$P / A + P e / W \leq f_y$$

Sectional modulus W, moment of inertia J, depth of cross-section h for bi-symmetrical cross-section:

$$W = J / (h/2) = 2J / h$$

Moment of inertia J, area of cross-section A, radius of gyration:

$$i = \sqrt{(J / A)} \rightarrow J = A i^2$$

Finally sectional modulud can be presented as:

$$W = 2 A i^2 / h$$

This means:

$$P / A + P e / (2 A i^2 / h) \leq f_y \rightarrow (P / A) [1 + e h / (2 i^2)] \leq f_y$$

Part of formula $[1 + e\,h / (2\,i^2)\,]$ presents proportion between effect of axial force only (1) and effect of bow imperfection: secondary bending moment: $e\,h / (2\,i^2)$.

Slenderness: proportion between length of member and radius of gyration:

$$\lambda = L / i$$

According to EN 1090-2:

$$e / L \leq 1 / 750$$

According to old Polish Standard:

$$\lambda \leq 250$$

For example:

$$e / L = 1 / 1000 \rightarrow e = L / 1000$$

and

$$\lambda = 100 \rightarrow i = L / 100$$

Lets take into consideration proportion between depth of cross-section and length of truss bat the same as for I-beam (it’s not completey correct):

$$h = L / 25$$

Then:

$$(P / A) [1 + e h / (2 i^2)] = (P / A) \{1+ (L / 1000) (L / 25) / [2 (L / 100)^2]\} =$$

$$= (P / A) \{1 + [(L^2 / 25 000) / (L^2 / 5 000)]\} = (P / A) (1 + 0,2) = 1,2 P / A$$

Taking into account bending imperfection for a bar with moderate slenderness gives a bending contribution of 20% effort from the axial force. Total effort for characteristic value of forces is 1,20. According to Eurocode, axial force only is taken into consideration, but multiplied safety factors. Even for CC1 it will give about 1,35 P / A (for CC2 and CC3 even bigger value), so 1,20 P / A is in the safe range.

What about slenderness out of recommended range?

$$\lambda = 400 \rightarrow i = L / 400$$

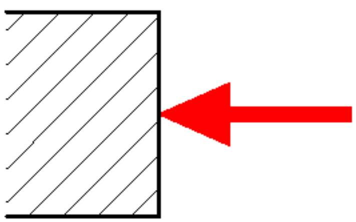
And rest parameters (e, h) the same as in previous case:

$$(P / A) [1 + e h / (2 i^2)] = (P / A) \{1+ (L / 1000) (L / 25) / [2 (L / 400)^2]\} =$$

$$= (P / A) \{1 + (L^2 / 25 000) / (L^2 / 80 000)]\} = (P / A) (1 + 3,2) = \mathbf{4,20\ P / A\ (!!!)}$$

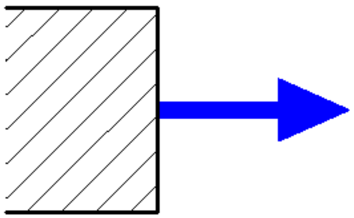
The effort from secondary bending from imperfection is now more than 4 times than the effort from axial force (for the same height of cross-sectional levels, the same surface areas and the same initial imperfection). We completely lose control over the behavior of the bar.

In analysed case stresses only were taken into consideration – this means, way of calculation is the same for compessive force and for tensile force. For too slender members secondary effects of imperfection can completely destruct cross-section, even if axial force is in safe range.



$\lambda \leq 250$

Photo: Author



$\lambda \leq 350$

More restrictive condition for compressive force are recommended (more compact elements are recommended) due to the possibility of loss of stability. Instability for more slender member is more possible.

Conclusion

Design according to	Limitations for imperfections	Slenderness of members	Impact of imperfections into calculations
PN / B 3200	PN 1090-2	Limitation	No impact
EN 1993-1-1		No limits	Schemes of equivalent actions

In formula

$$(P / A)\ [1 + e\ h / (2\ i^2)\ ]$$

part from secondary bending [$e\ h / (2\ i^2)$] can be limited in two ways:

- avoiding too big slenderness (too small i) as in old Polish Standard;
- analisis of effects of secondary bending moment from imperfection e (equivalent schemes of loads) as in Eurocodes. For too slender members (too small moment of inertia → too small sectional modulus → too small resistance for bending moment) secondary effects from imperfections make exceeding of resistance.

Numerical model

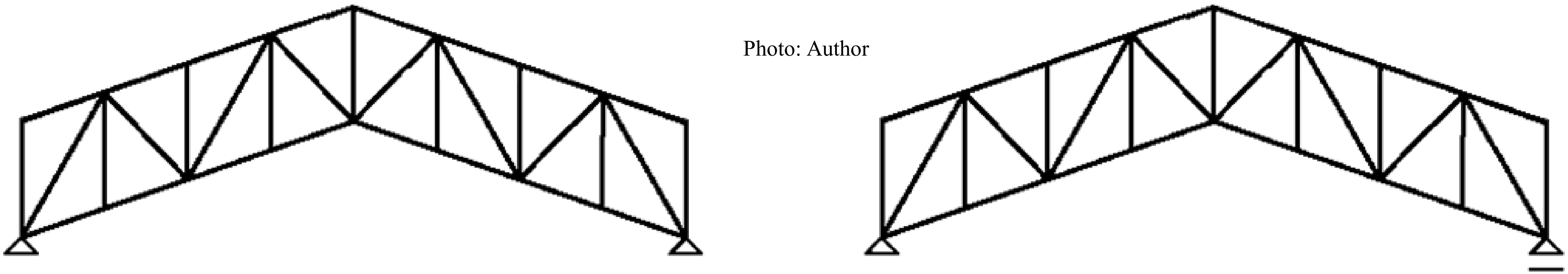


Photo: Author

Distribution of forces in top and bottom chords is completely different in case of symmetrical supports (pinned-pinned) and unsymmetrical (pinner-rolled). The most important question is, which one model is closer to real behaviour of truss.

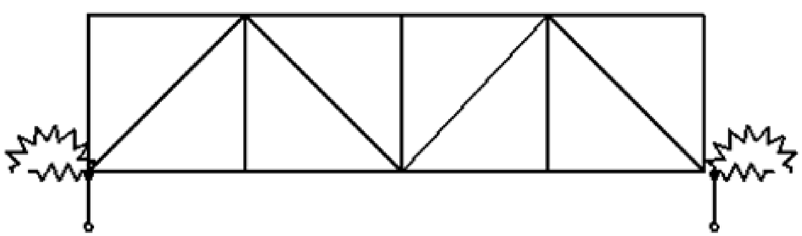


Photo: omniblock.com

Photo: aminds.com

Generally, support for truss is not completely rigid in each case.

Photo: structuralsteelcn.com

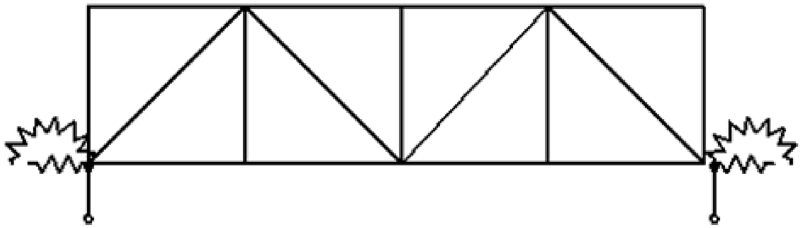


Photo: Author

The best static scheme is as above:

- vertical direction – very big stiffness of column / wall, so it could be presented as full support;
- horizontal direction – susceptibility of support (column / wall) for deformation make spring support of specific value of elasticity
- rotation - we purposely try to ensure rotation for support, but real behaviour is rather spring support because of problems with non-zero rigidity of rockers.

If rockers under truss are applicated in right way, It could be taken into consideration as ideal hinge. Technical solutions will be presented in Lec #20. The biggest problem is influence of horizontal spring supports

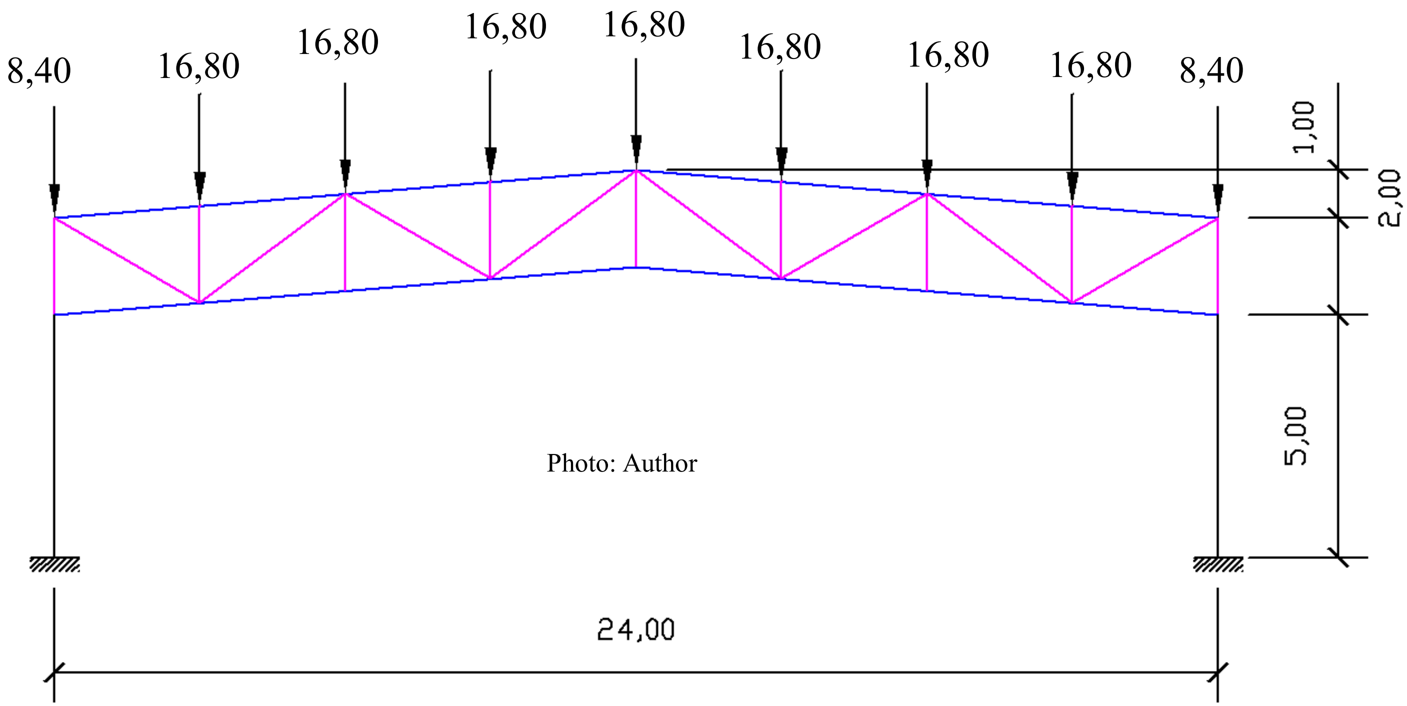


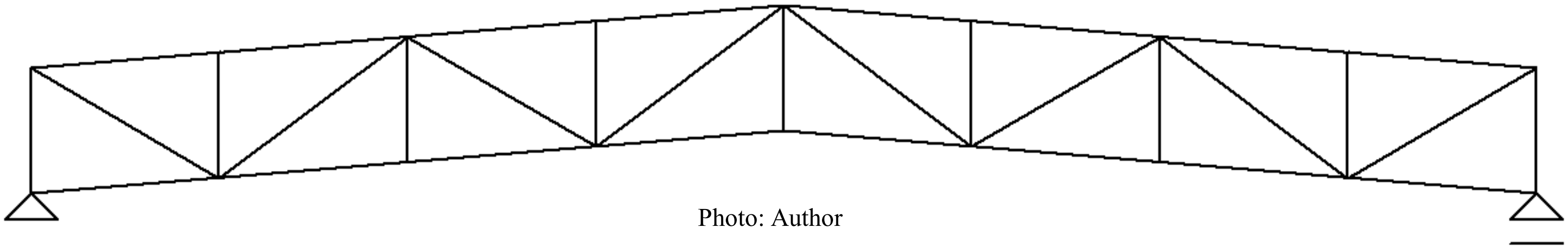
Photo: Author

We take into account truss as abowe:

CHS 139,0 / 5,0

CHS 76,1 / 5,0

Concrete column 30x30 cm C 30/37 or steel column HEB 300



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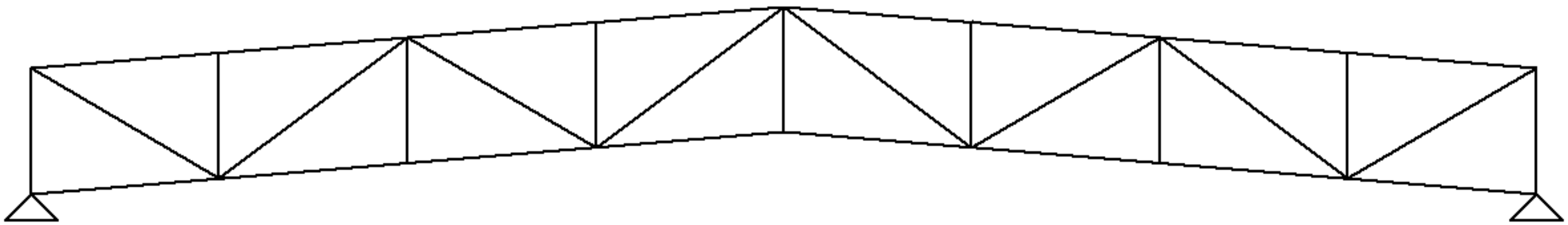


Two various models will taken for simplification:

1. Unsymmetrical supports (pinnd-rolled);
2. Symmetical supports (pinned-pinned).

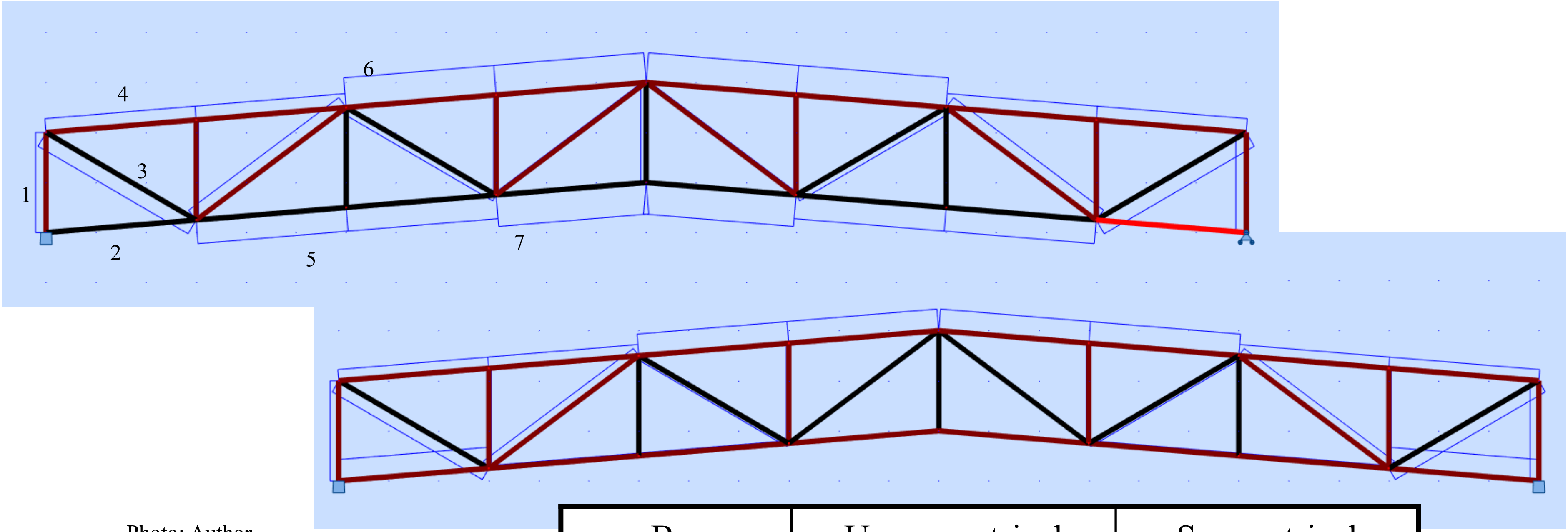


Photo: Author

Compression

Tension

Bar	Unsymmetrical	Symmetrical
1	72,82	60,59
2	0,00	147,30
3	111,04	89,79
4	96,24	77,83
5	164,99	19,14
6	206,24	151,00
7	220,00	0,95

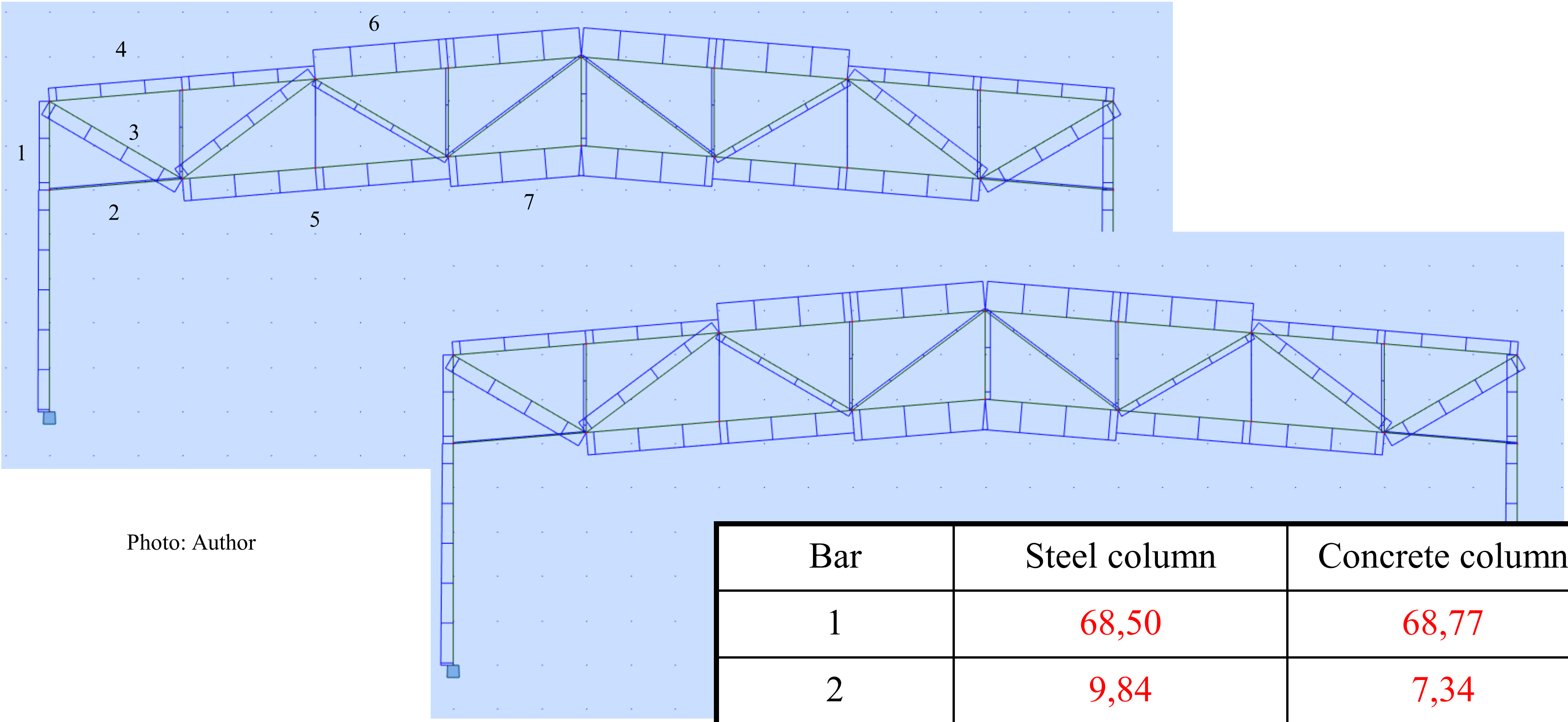


Photo: Author

Compression

Tension

Bar	Steel column	Concrete column
1	68,50	68,77
2	9,84	7,34
3	103,75	104,22
4	89,11	89,54
5	149,18	152,33
6	197,78	198,61
7	201,79	205,56

Bar	Steel column	Concrete column	Average	Unsymmetrical	Symmetrical
1	68,50	68,77	68,64	72,82	60,59 (-12%)
2	9,84	7,34	8,59	0,00	147,30 (+1 715 %)
3	103,75	104,22	103,99	111,04	89,79 (-14%)
4	89,11	89,54	89,33	96,24	77,83 (-13%)
5	149,18	152,33	150,76	164,99	19,14 (+113%)
6	197,78	198,61	198,20	206,24	151,00 (-24%)
7	201,79	205,56	203,68	220,00	0,95 (+100%)

Differences between unsymmetrical model of truss and full model (truss + column) are small; genrally cross-sectional forces are a little bigger for unsymmetrical model (safe side results).

Between full model and symmetrical model are big differenes, very big differences or even completely opposite direction of crosss-sectional forces.

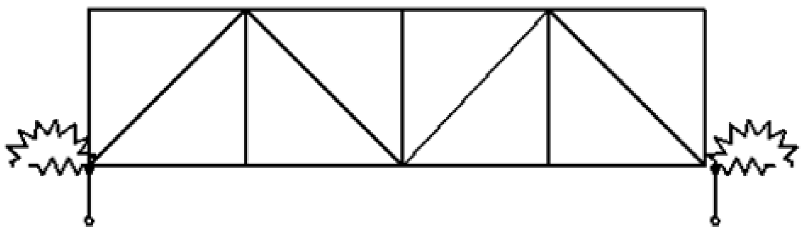
Bar	Steel column	Concrete column	Unsymmetrical	Symmetrical
Top chord	197,78	198,61	206,24	151,00
Bottom chord	201,79	205,56	220,00	147,30

Max values of axial forces in top and bottom chords show problems, which occurs after application wrong stati model: symmetrical supports.

Top chord – compression – will be designed for force about 75% only of real force: it means big probability of destruction of cord and truss.

Bottom chord – tension – will be designed for opposite (compressive, not tensile) force: it means big probability of oversizing for chord.

Conclusion: elastic supports in horizontal direction are simplified by pinned-rolled supports with very big accuracy.



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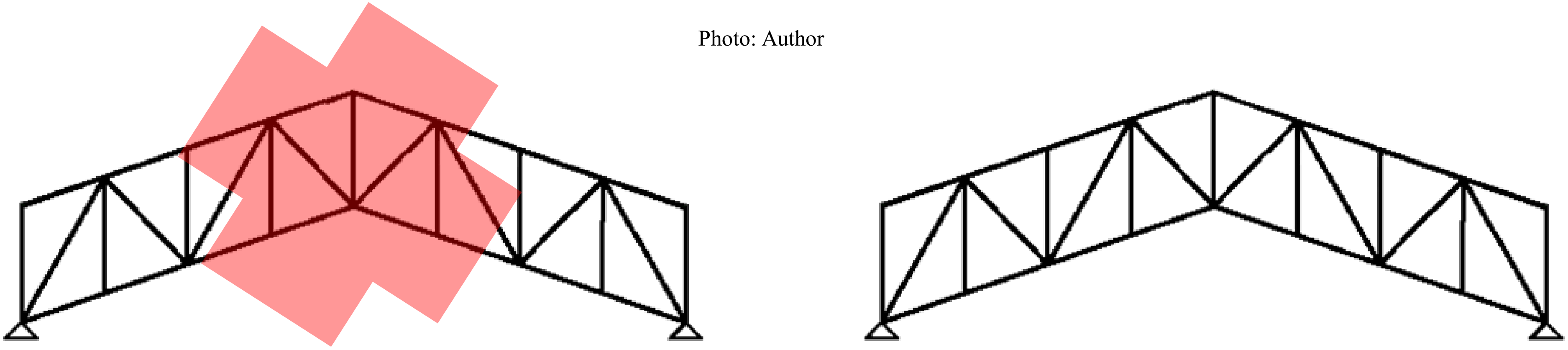
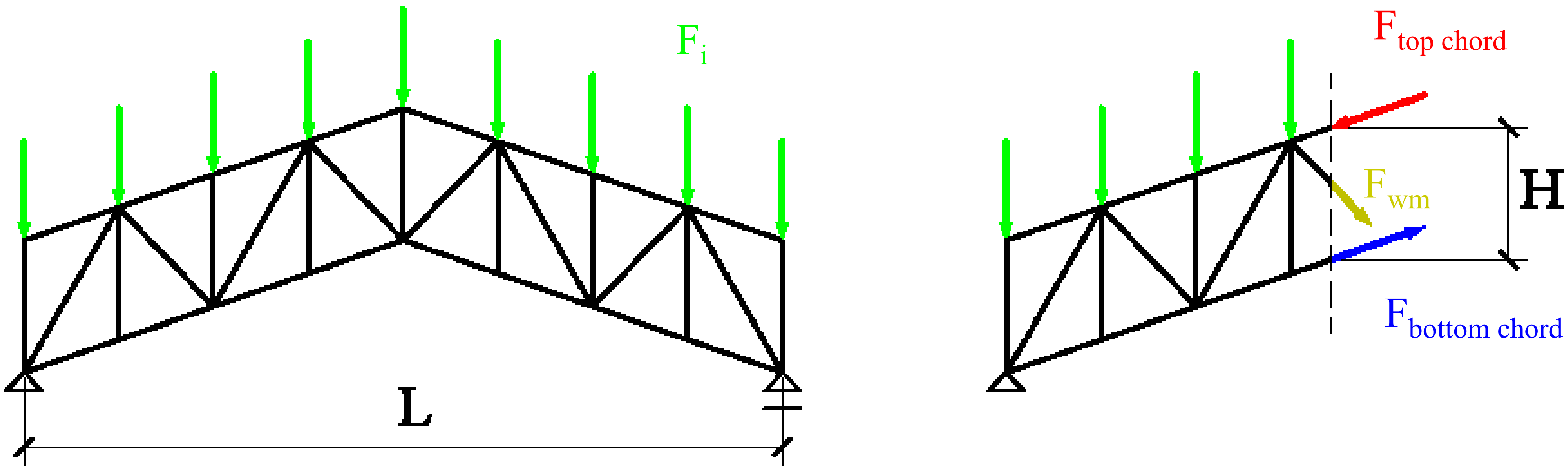


Results of calculations - verification

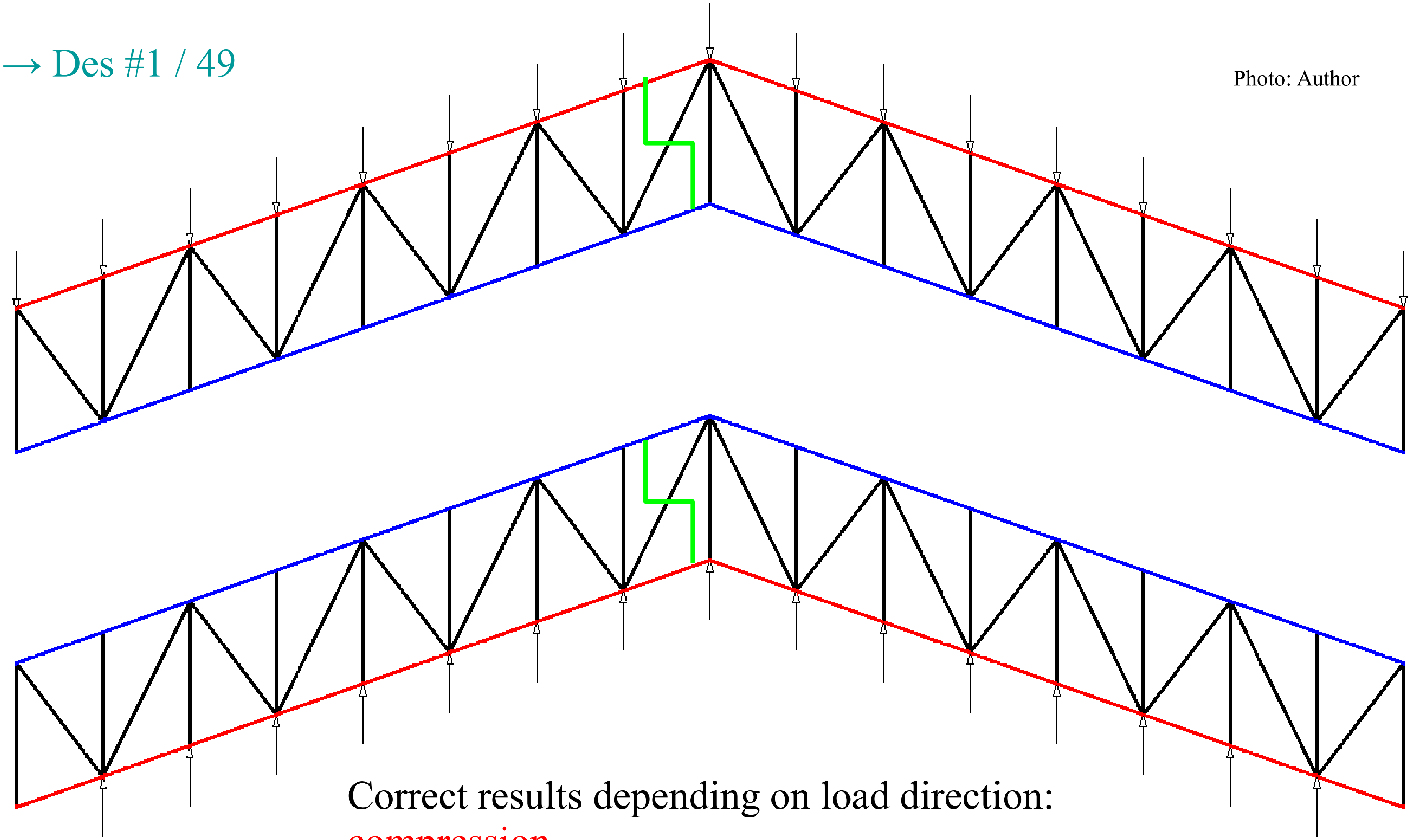


$\Sigma x = 0$; $F_{wm} / F_{bottom\ chord} \approx 0 \rightarrow$

$|F_{bottom\ chord}| \approx |F_{top\ chord}|$

Photo: Author

Photo: Author



Correct results depending on load direction:
compression
tension

Additionally:

|top tension| ≈ |bottom compression|

|top compression| ≈ |bottom tension|

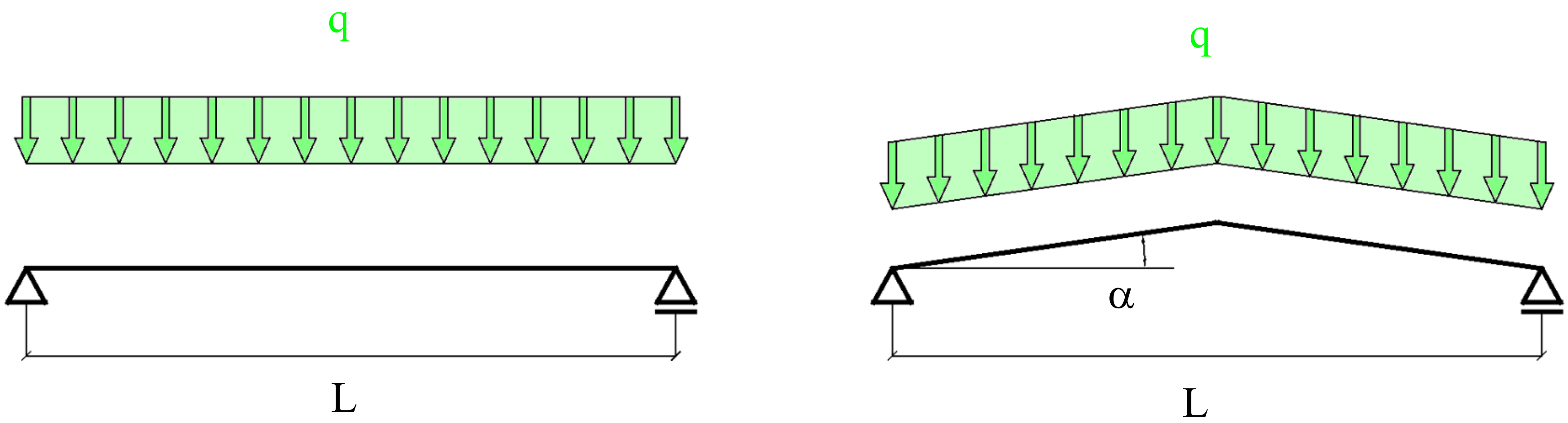


Photo: Author

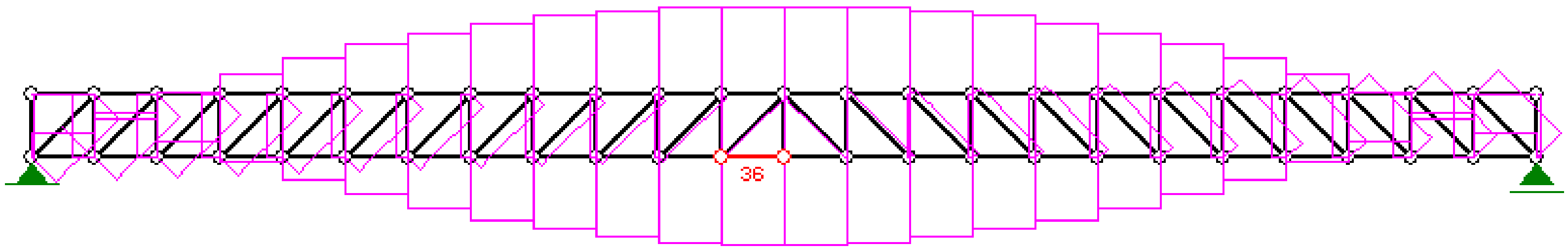
It is possible to estimate force in top and bottom chords; we use beam-analogy:

$$q = \Sigma F_i / L$$

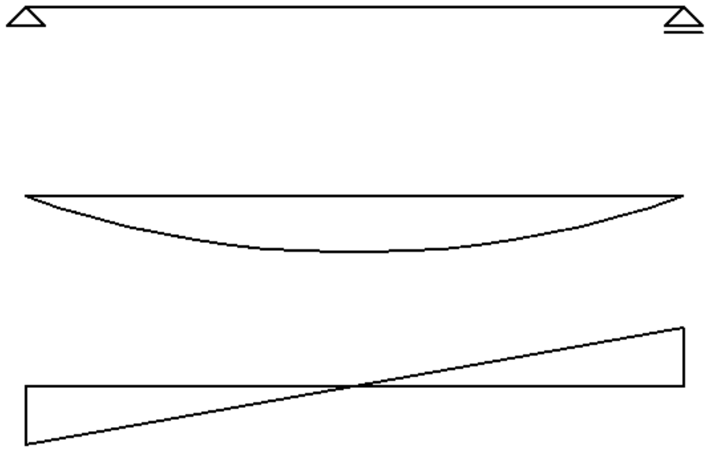
$$M_{max} = q L^2 / 8 \quad \text{or} \quad q L^2 / (8 \cos \alpha)$$

$$|F_{top\ chord}| \approx |F_{bottom\ chord}| \approx M_{max} / H$$

Photo: Author



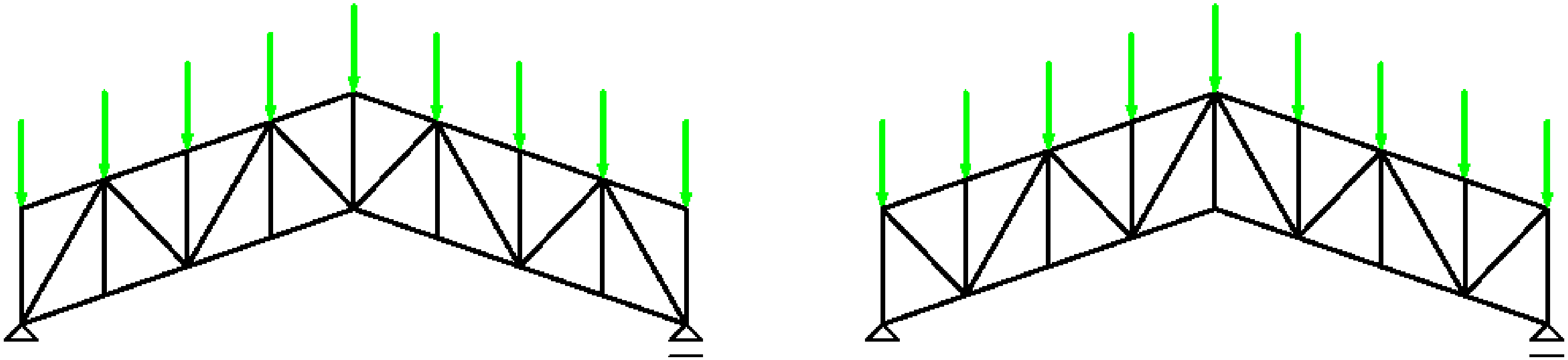
Similar shape of axial forces in chord and bending moment for single-span beam; the same for axial forces in web members and shear force in single-span beam.



Forces in chords

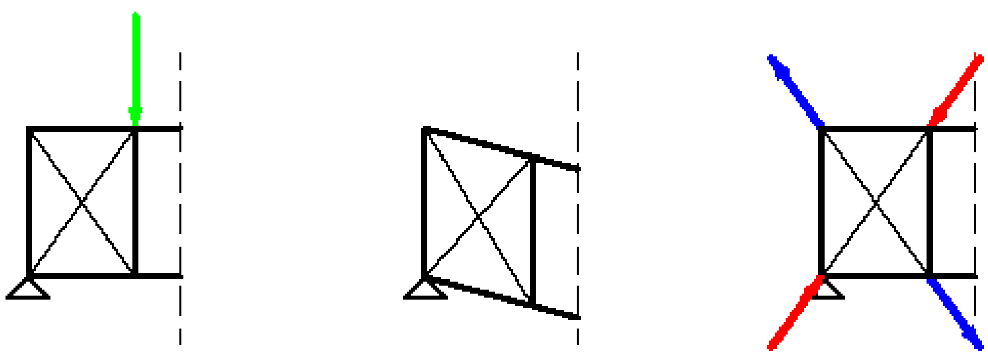
Forces in web members

Difference between two directions of web members

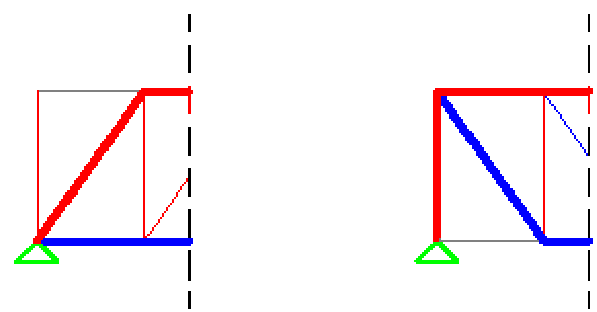


Deformations: elongation (tensile force) and abridgement (compressive force):

Photo: Author



Transmission of forces form chords to supports and zero force members:



Examination issues

Types of truss structures

Models of truss – algorithm of identification

Impact of slenderness and imperfections

Laced members - słup wielogałęziowy skratowany

Battened members - słup wielogałęziowy z przewiązkami

Closely spaced build-up members - pręt wielogałęziowy

Thank you for attention

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