Metal Structures

Design Project III

Steel hall

PROJECT OBJECTIVE'S

Cold-formed mutispan purlins with hangers – simplified analysis;

Complex form of column's lost of stability: flexutral buckling + lateral buckling;

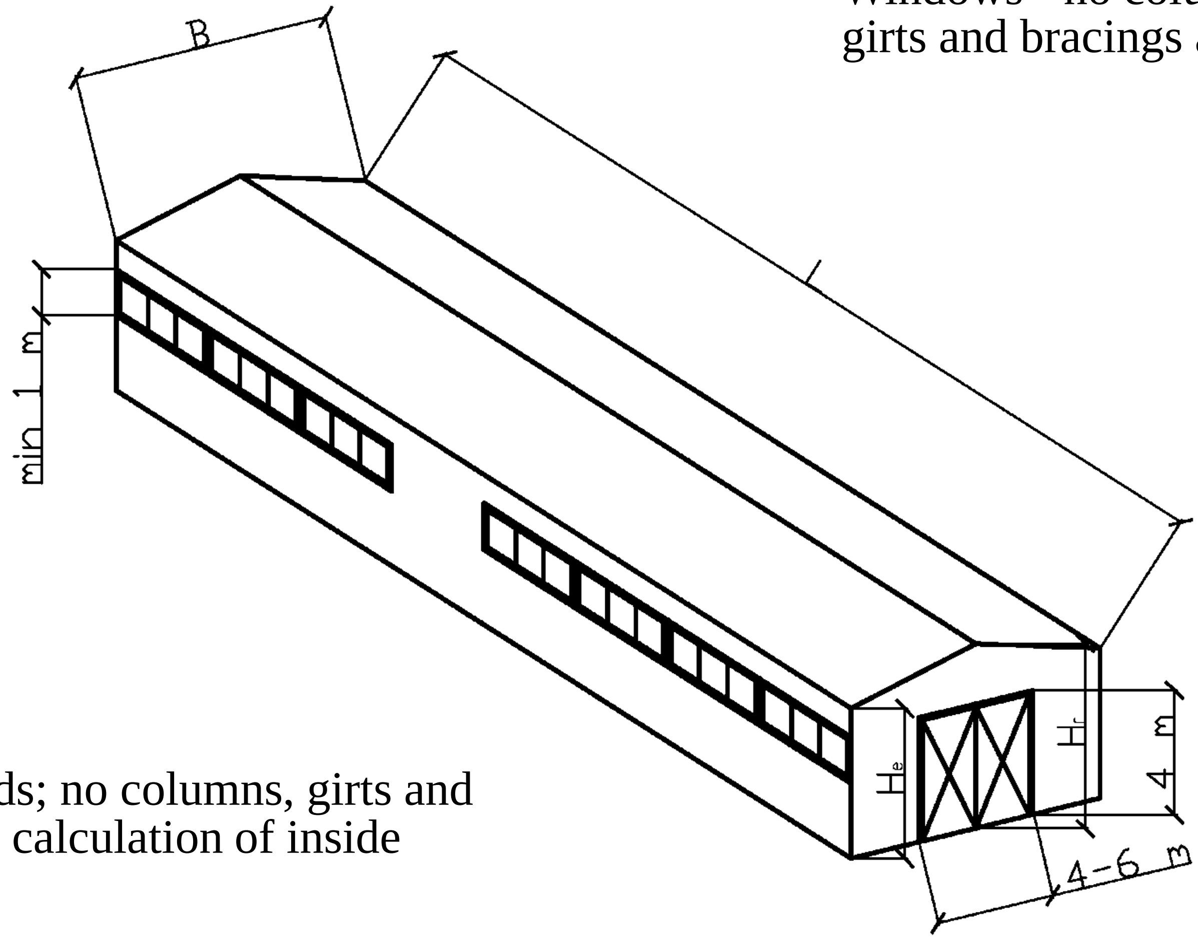
Rigid tension bolted joint girder-column: stifness and resistance;

Topic:

Design of steel hall:
B…………………………………………………………
L…………………………………………………………
H_e………………………………………………………
H_r………………………………………………………
Steel:……………………………………………………
Location:…………………………………………………
Stored material:…………………………………………
Mass of stored material:………………………………

View

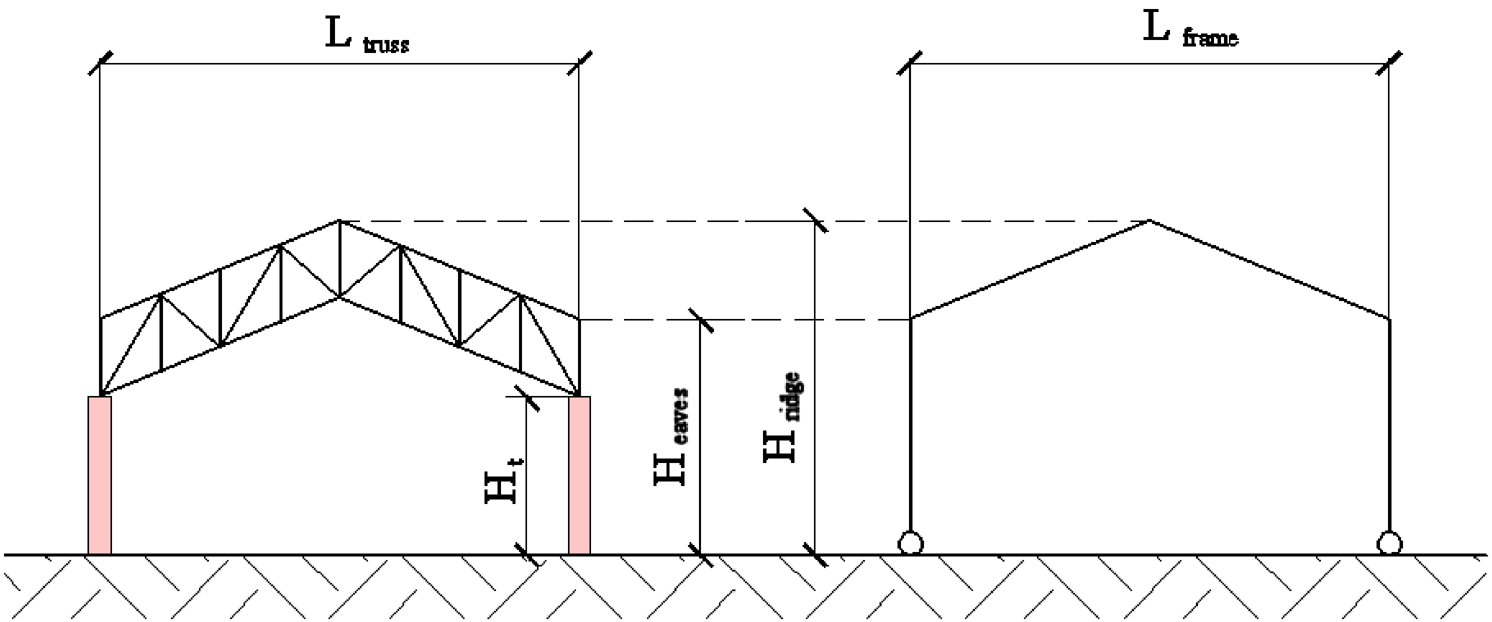
Windows - no columns, girts and bracings across.



Doors - both ends; no columns, girts and bracings across; calculation of inside pressure.

Photo: Author

Location the same as for truss



Geometry the same as for truss

Photo: Author

$B_{truss} = B_{frame}$

$L_{truss} = L_{frame}$

Grade of steel the same as for truss

Structure

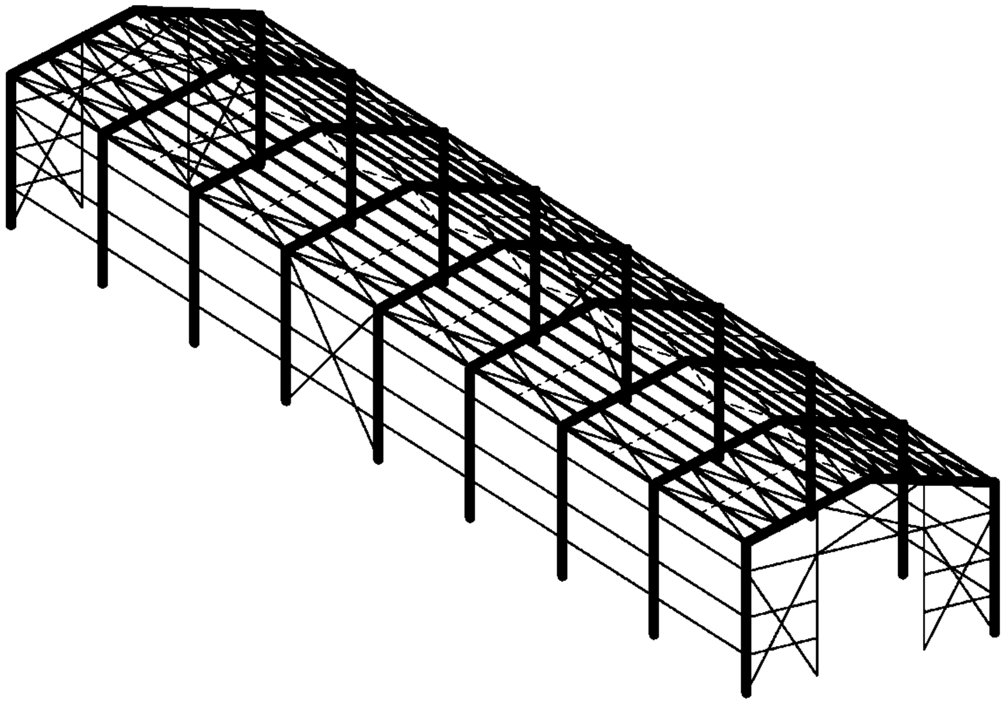
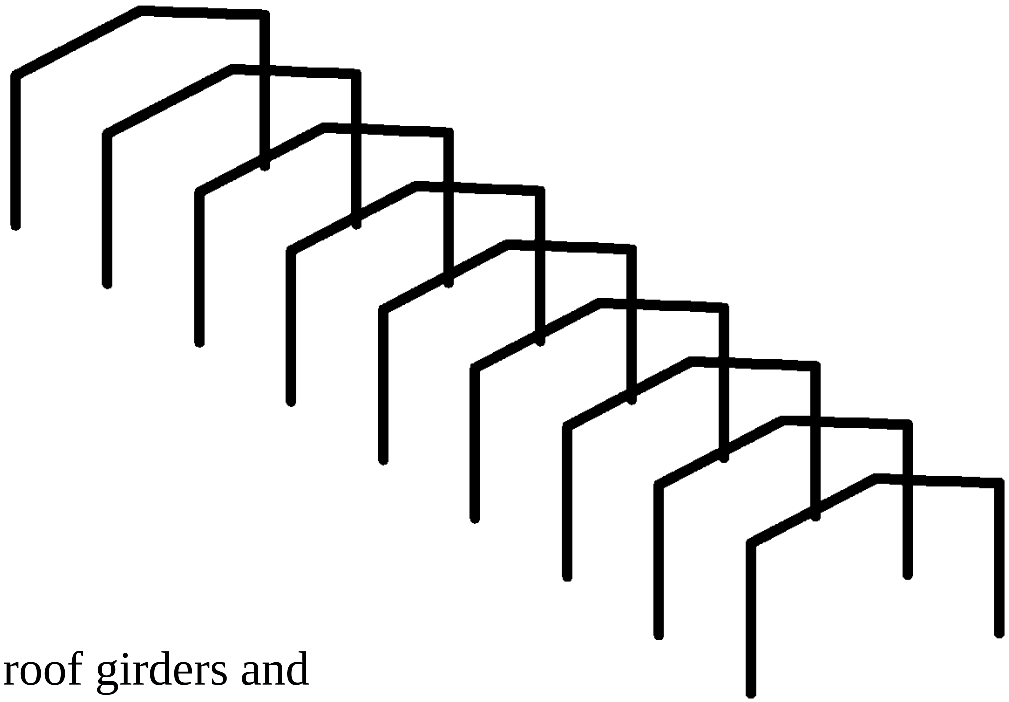
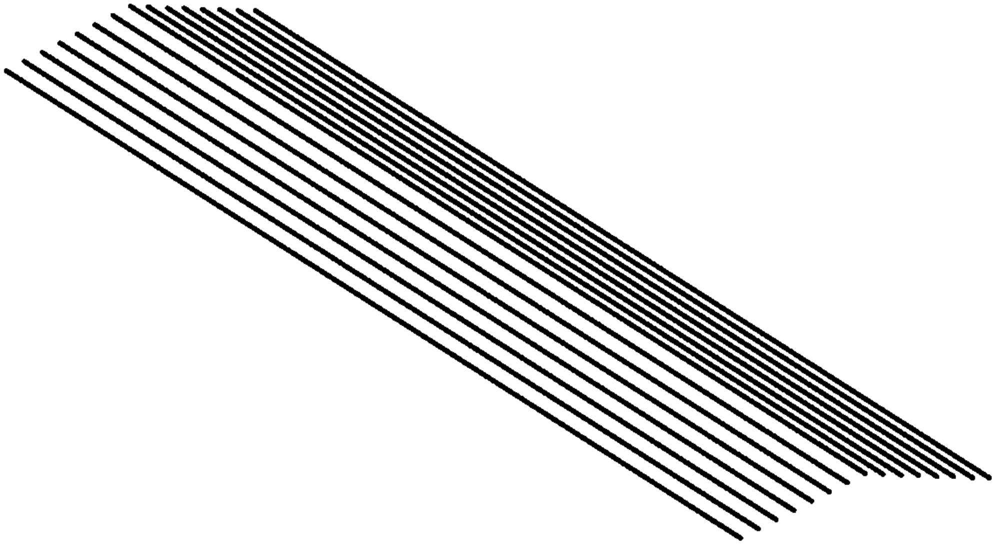


Photo: Author



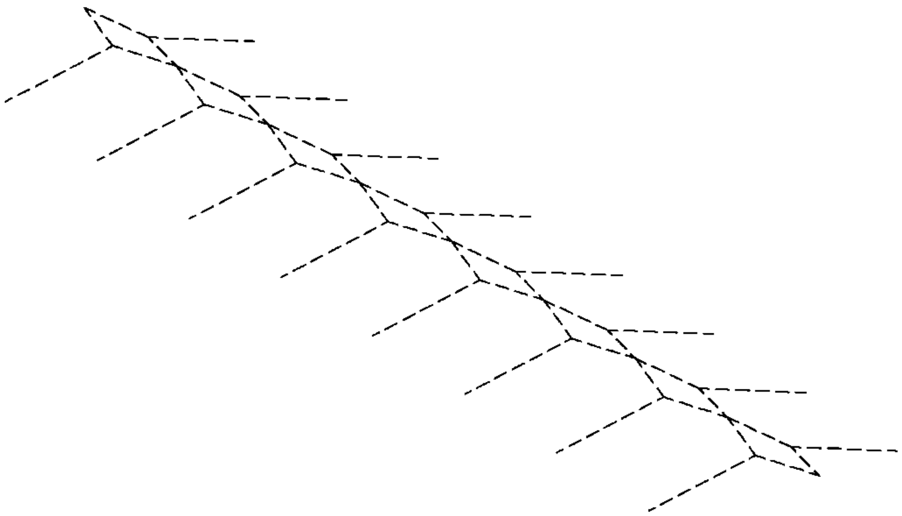
Main frames - roof girders and main columns

Photo: Author



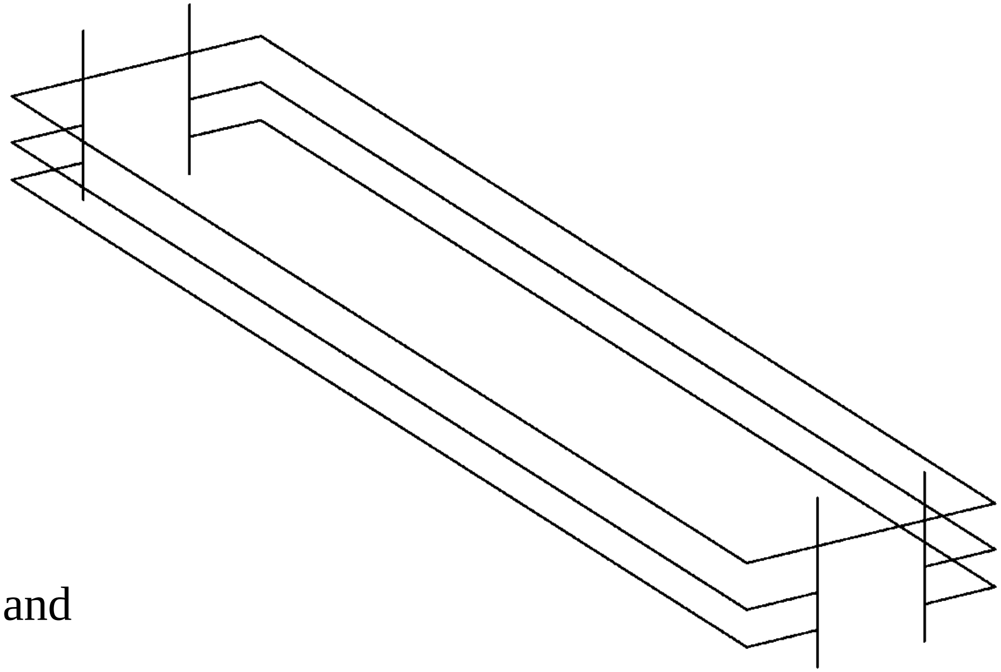
Continous purlins

Photo: Author



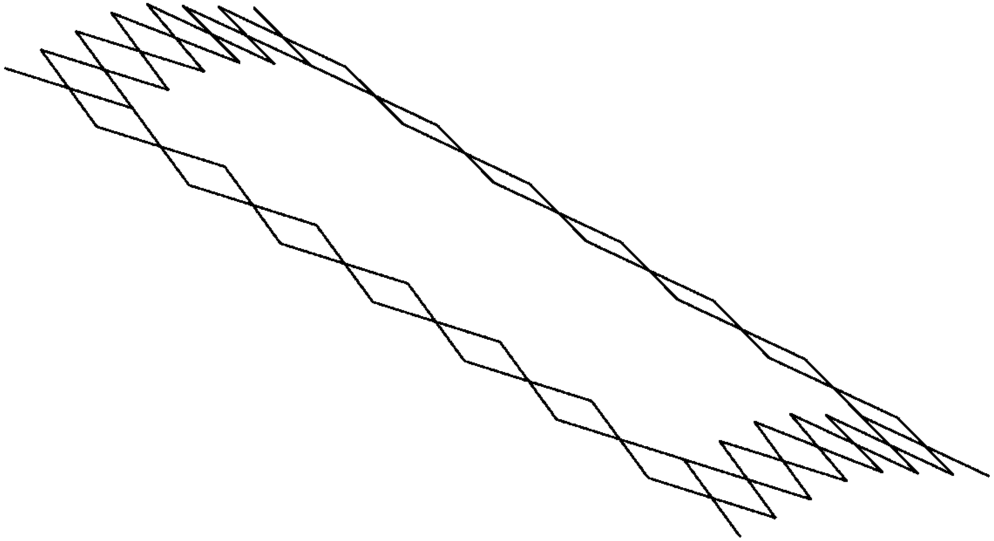
Suspension for purlins

Photo: Author



Housing - girts and columns

Photo: Author



Roof bracing

Photo: Author

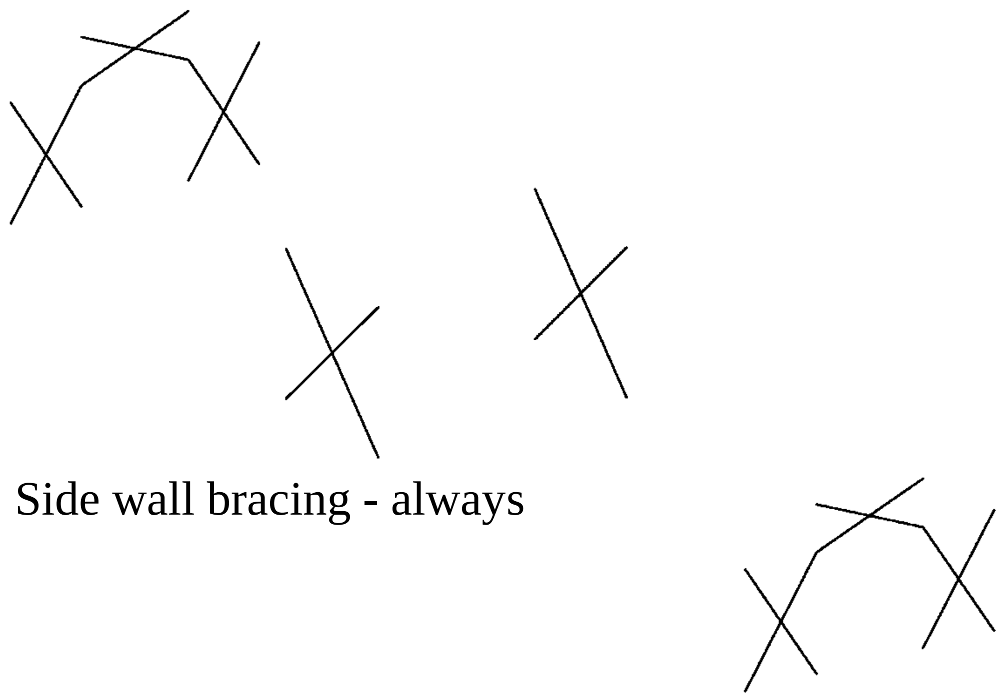
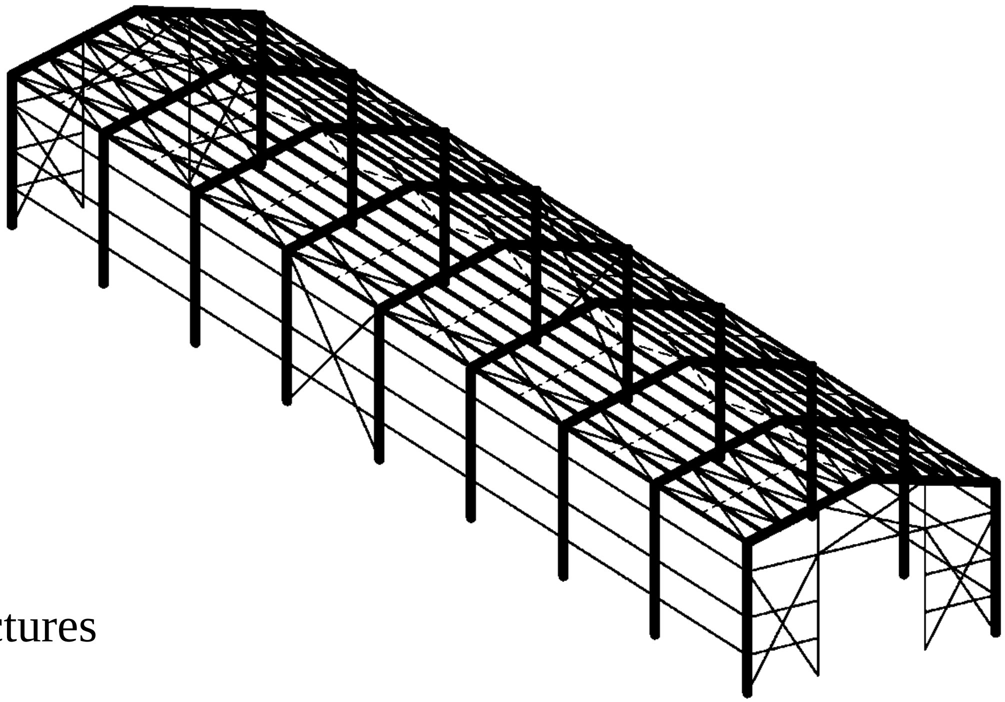


Photo: Author



Sum of sub-structures

Photo: Author

Algorithm

- Initial drawing
- Loads
- Purlins
- Suspension for purlins
- Housing
- Roof girder
- Main column
- Roof bracing
- Wall bracing
- Joints
- Drawing, list of materials, card of structure

Initial drawing

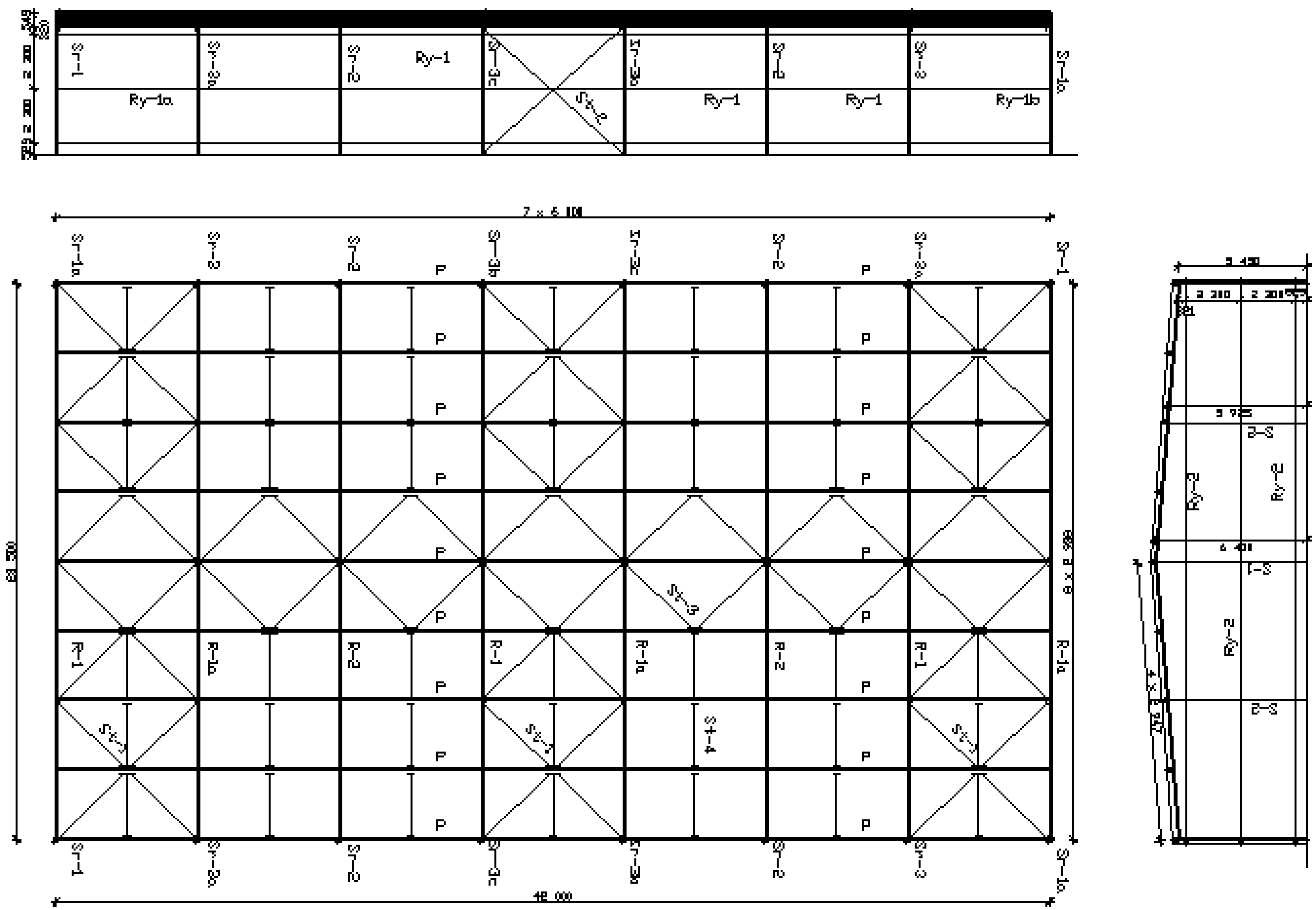


Photo: Author

Photo: steelconstruction.info

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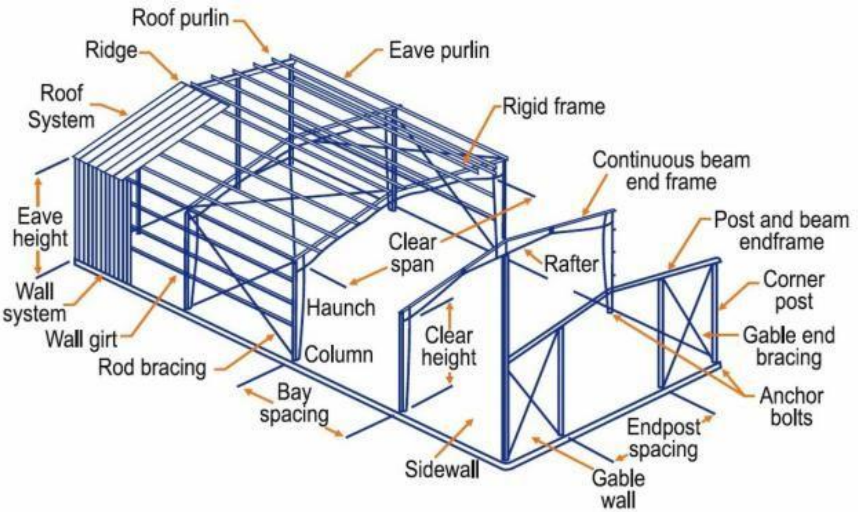


Photo: greenterrahomes.com

Wall girts, purlins, roof bracings and side wall bracings make specific system for wind action. Front wall housing columns must be connected with purlins and roof bracings at one point. The same, girts on front and side walls.

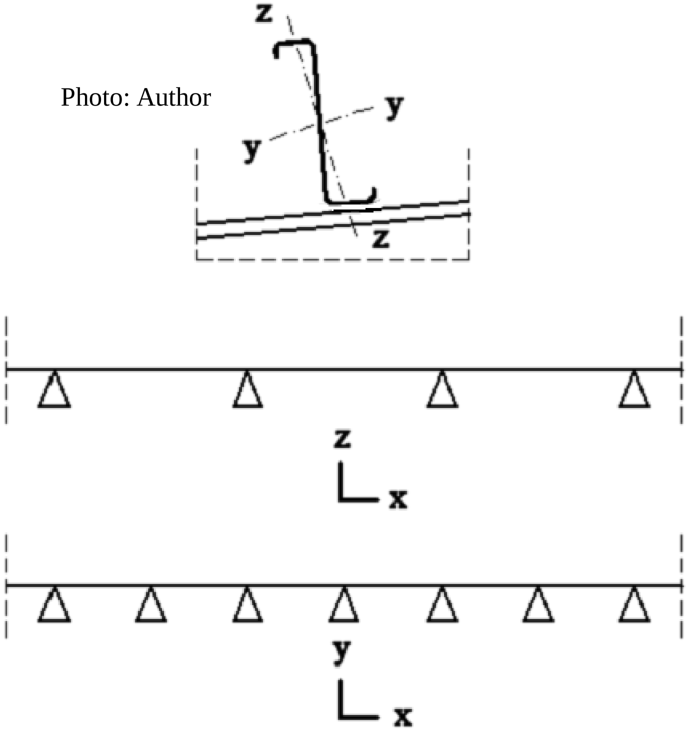
Loads

The same geometry and location as for II project → the same loads for roofing, snow and wind on roof

- Dead weight of roofing
- Dead weight of purlin
- Snow
- Wind on roof
- Wind on wall
- Inside pressure
- Dead weight of housing
- Dead weight of steel structure
- Equivalent loads for columns

- Imposed loads
- Thermal actions
- Exposed to fire
- Accidental actions
- Actions durin execution

Purlins



Cold-formed cross-section, continous beam with suspension.

Exact calculations: EN 1993-1-3

Aproximation for I, II or III clas of cross-section, non-symmetrical cross-section:

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

Main axes are not horizontal, not vertical, not parallel and not perpendicular to surface of roof

Components of loads in main axes of purlin:

$$q_{\xi} = S\,(\alpha + \beta) + Dw\,(\alpha + \beta) +/- W\,(\beta)$$

$$q_{\eta} = S\,(\alpha + \beta) + Dw\,(\alpha + \beta) +/- W\,(\beta)$$

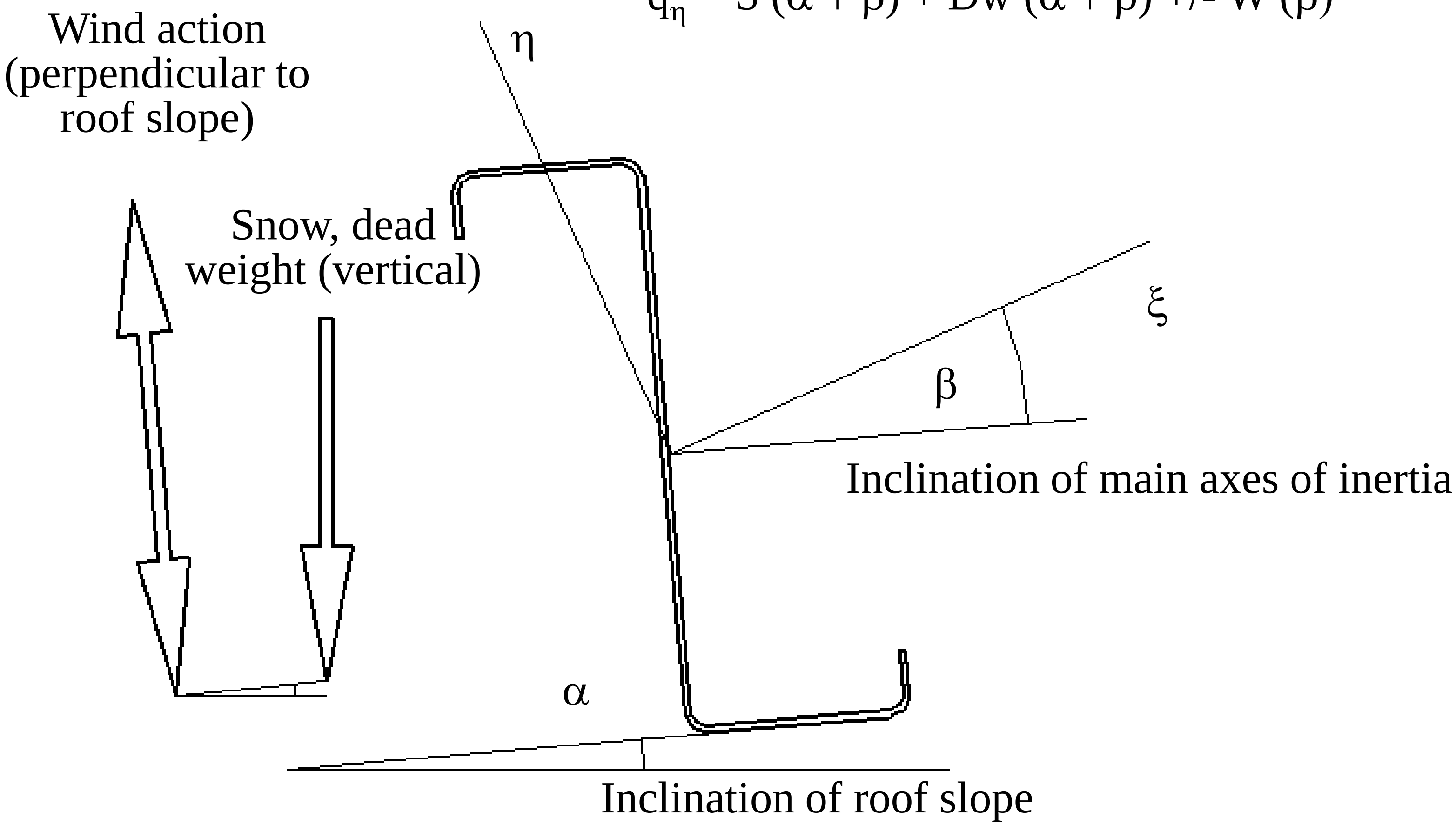


Photo: Author

First stage: full cooperation between purlin and sandwich panel. Orientation of purlin axis forced by cooperation of panels. Moments of inertia and sectional moduluses according to tables (mani axes parallel and perpendicular to surface of roof). Protection against lateral buckling.

Second stage: no cooperation between purlin and sandwich panel after about 10-15 years. Main axes are not horizontal, not vertical, not parallel and not perpendicular to surface of roof. No protection against lateral buckling.

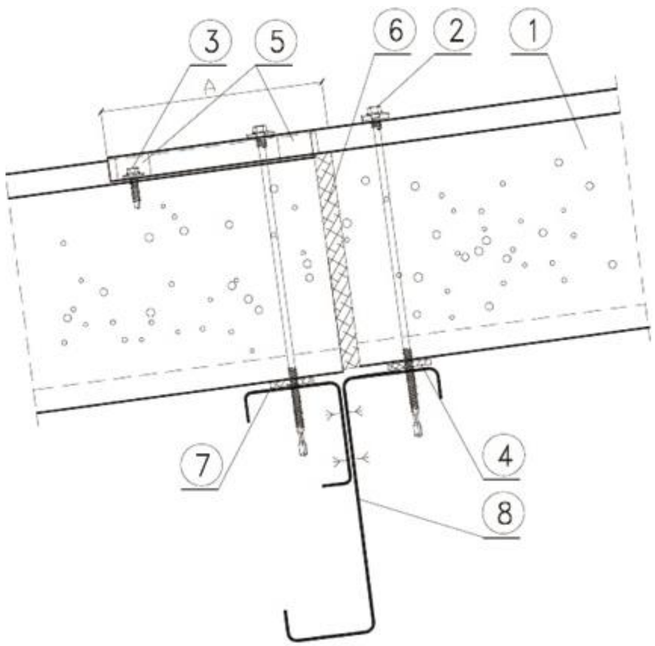


Photo: dachyplaskie.info.pl

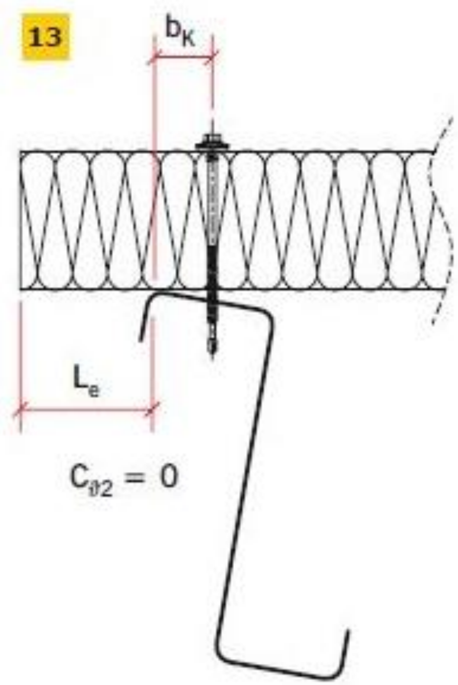


Photo: izolacje.com.pl

Resistance of cross-section of purlin – second stage

There is non-symmetrical cross-section. There should be taken into consideration four points:

- Top (B_1);
- Bottom (A_1);
- Left (B_2);
- Right (A_2).

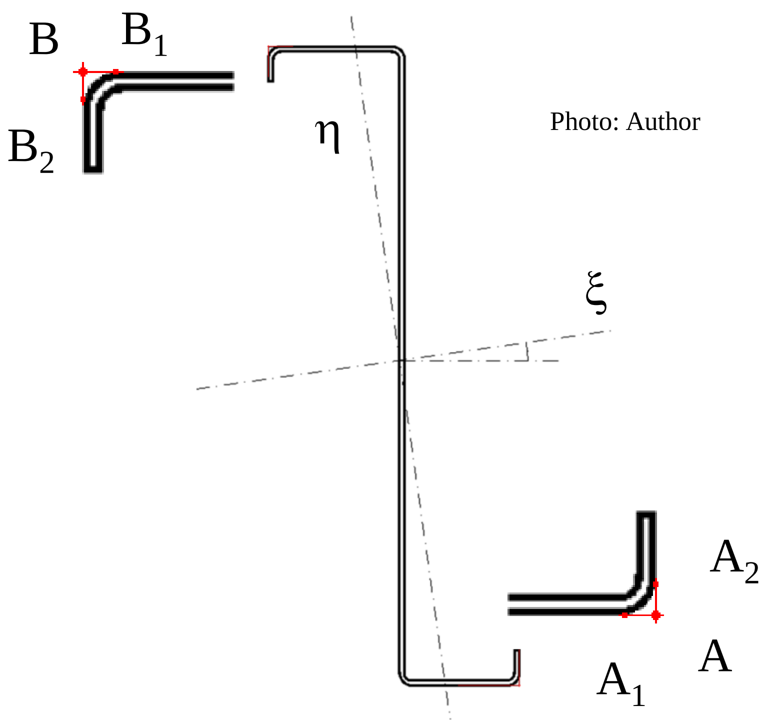


Photo: Author

Points B_1 and B_2 are close to each other; the same A_1 and A_2. It is possible to make approximation for calculation and take into consideration „average" points A and B.

$$W_{A,\xi} = J_\xi / \eta_A$$

$$W_{B,\xi} = J_\xi / \eta_B$$

$$W_{A,\eta} = J_\eta / \xi_A$$

$$W_{B,\eta} = J_\eta / \xi_B$$

Bi-axian bending of purlin must be checked for both points, A and B.

"Normal" multispan purlin - in both direction the same length ($l_y = l_z = l$)

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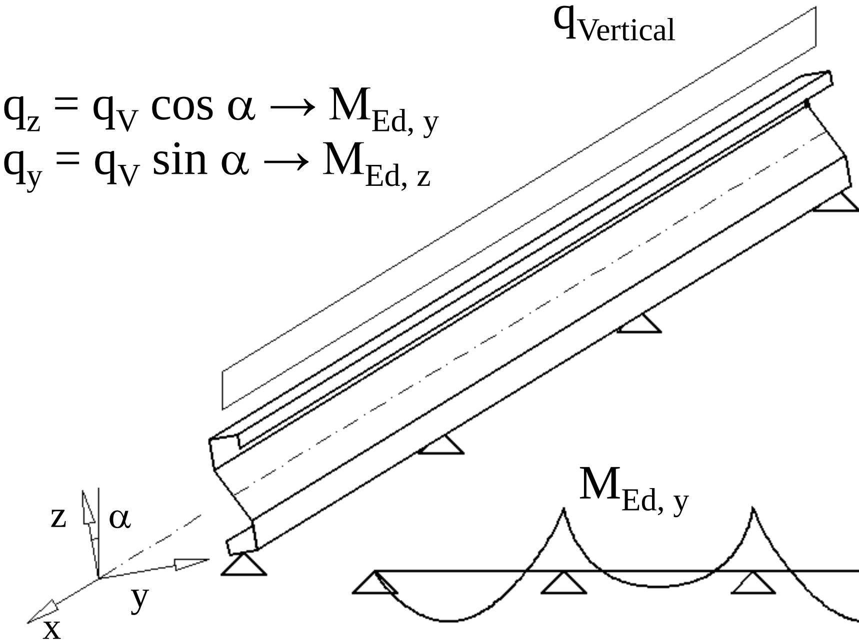
$q_z = q_V \cos\alpha \rightarrow M_{Ed,y}$

$q_y = q_V \sin\alpha \rightarrow M_{Ed,z}$



$M_{Ed,y} \approx q_z\, l^2 \qquad M_{Ed,z} \approx q_y\, l^2$

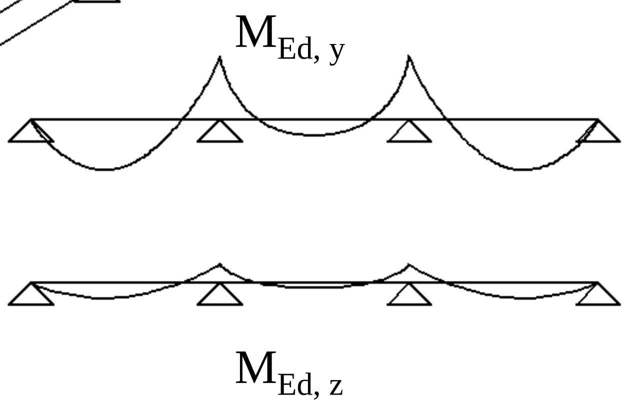
$q_z < q_y \rightarrow M_{Ed,z} < M_{Ed,y}$ but

$J_z << J_y \rightarrow W_z << W_y \rightarrow M_{Rd,z} << M_{Rd,y}$

there is possible, that $M_{Ed,z} / M_{Rd,z} > M_{Ed,y} / M_{Rd,y}$

$f_y \approx q_y\, l^4 / EJ_z \approx f_z \approx q_z\, l^4 / EJ_y$

Big efforts in both directions, big deflections in both directions. Is possible, that cross-section must be very massive because of problems with weak axis.



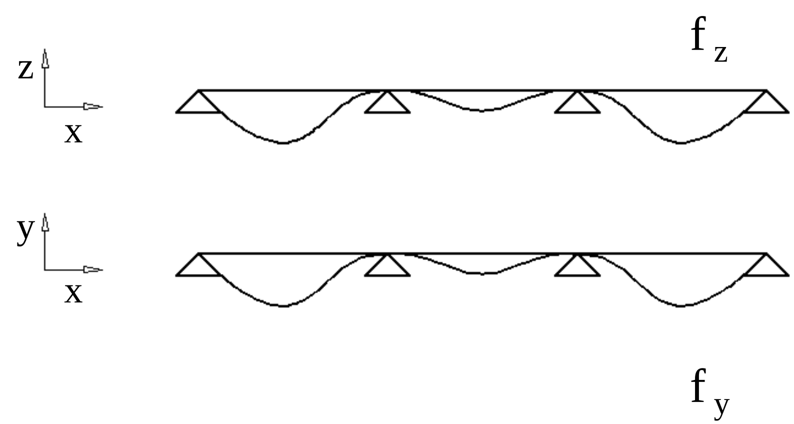


Photo: Author

Suspended purlin: hangers = additional support on y-direction (weak axis is supported).

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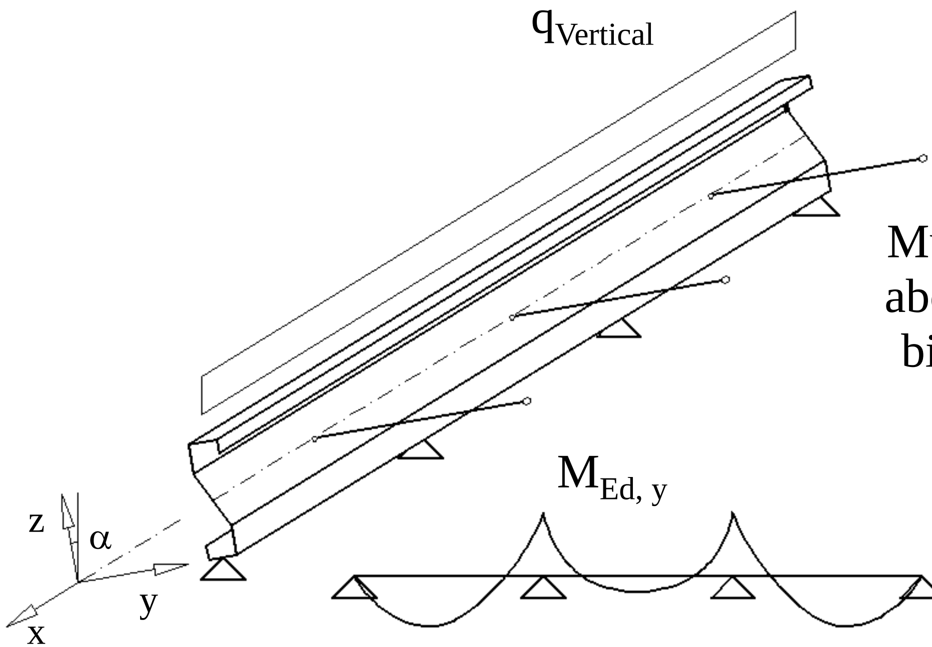


At now, for weak axis $l_1 = l / 2$

$$M_{Ed,\,y1} \approx q_z\, l_1^2 = q_z\, l^2 / 4 = M_{Ed,\,y} / 4$$

$$f_{y1} \approx q_y\, l_1^4 / EJ_z = q_y\, l^4 / EJ_z / 16 = f_y / 16$$

Much smaller bending moments and deflections about weal axis. Very economical design projec: big effort for strong axis, small effort for weak axis.

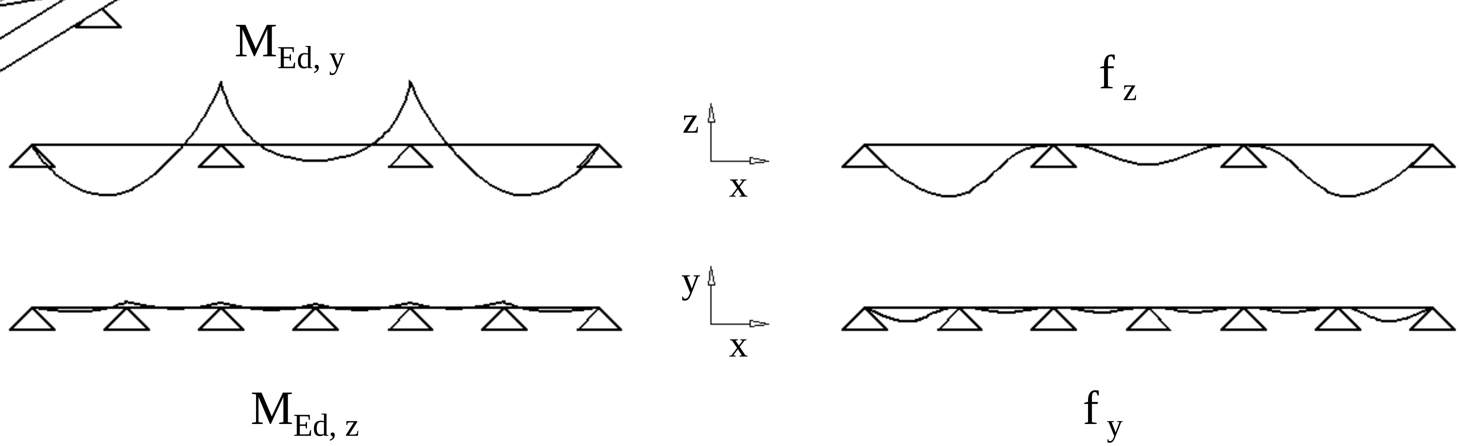
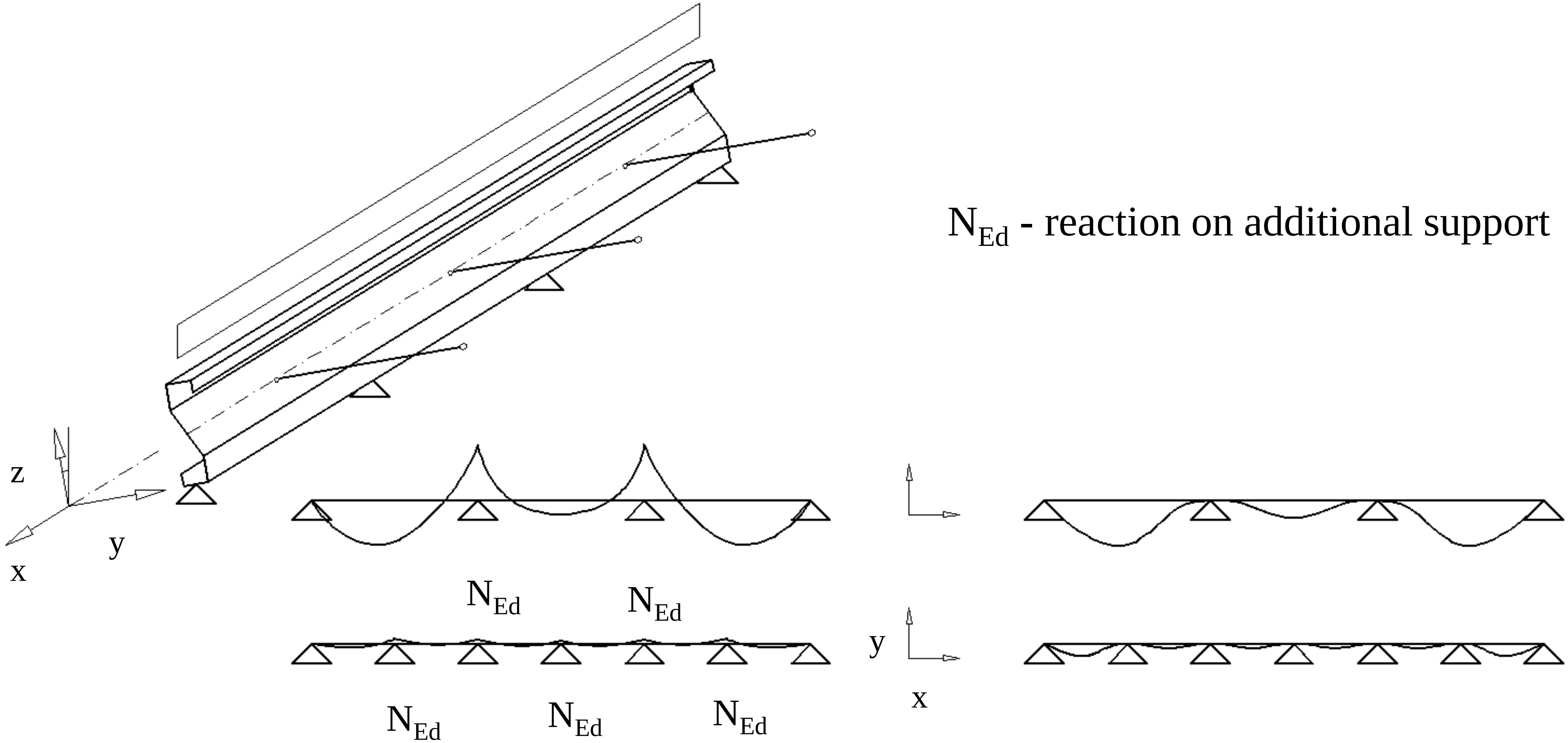


Photo: Author

Hanger, cross-section: round bar

$$N_{Ed} / (A\ f_y) \leq 1{,}0$$



N_{Ed} - reaction on additional support

Photo: Author

It is I[st] example of calculations in Example Part

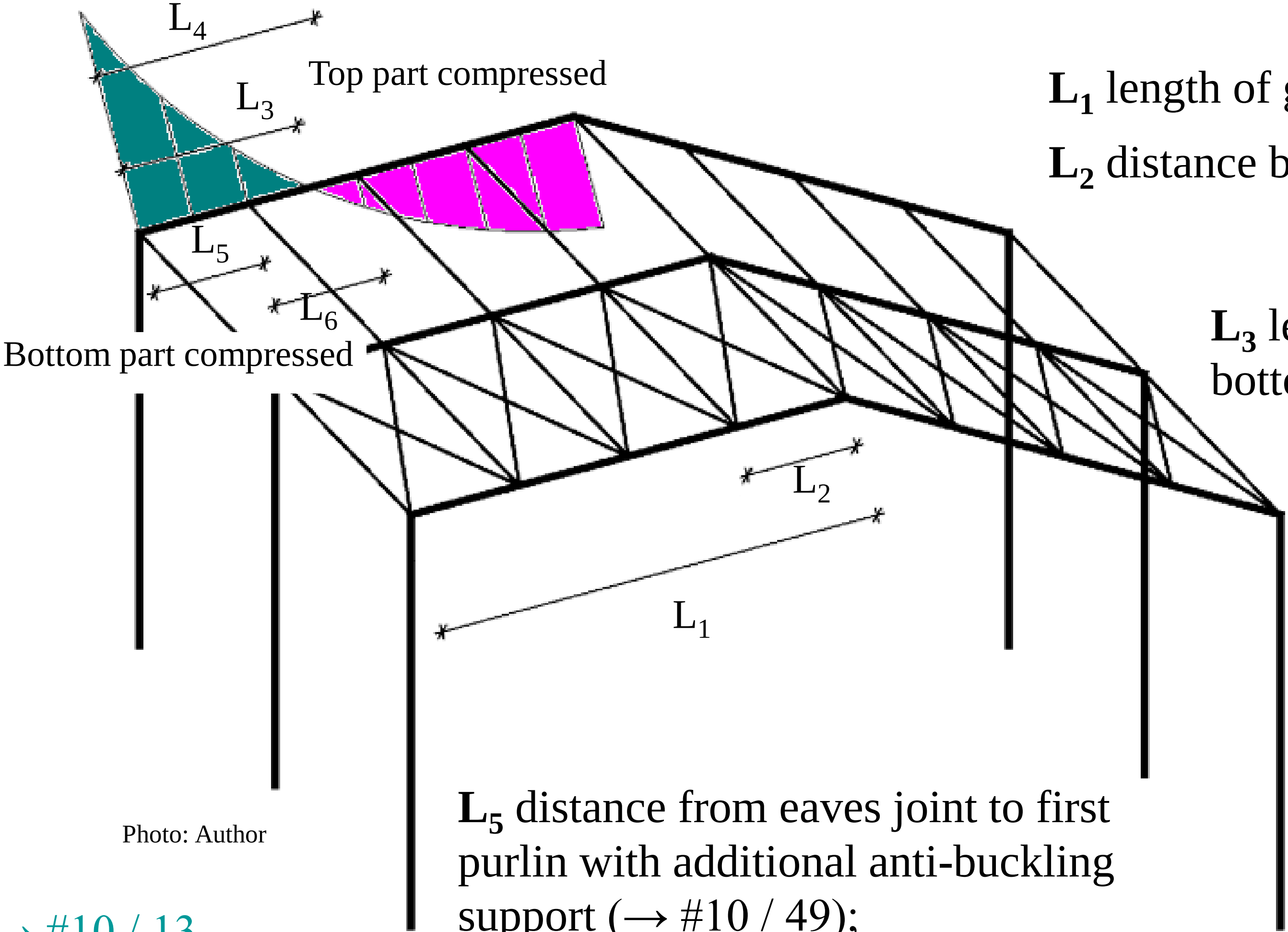
Roof girder

IPE, HEA, HEAA, $h = 1/20 - 1/25\ L_{frame}$

- Class of cross-section
- Shear resistance
- Bending and axial force
- Interaction flexural buckling - lateral buckling
- Deflection

Critical lengths for flexural nad lateral buckling depend on analysed direction.

I-beam roof girder



L_1 length of girder;

L_2 distance between bracings

L_3 length of girder where bottom part is compressed;

L_4 distance from eaves joint to first purlin in top part compressed;

L_5 distance from eaves joint to first purlin with additional anti-buckling support (→ #10 / 49);

Photo: Author

→ #10 / 13

L_6 distance between the closest purlins with additional anti-buckling supports (→ #10 / 49);

Resistance for bending and axial force - M_{Ed} i N_{Ed} for analysed cross-section.

Interaction flexural buckling - lateral buckling - M_{Ed} i N_{Ed} max for analysed member, even if they are in different cross-sections.

Main columns

IPE, HEA, HEAA

- Class of cross-section
- Shear resistance
- Bending and axial force
- Interaction flexural buckling - lateral buckling
- Deflection

$\mu_y \rightarrow$ two methods: W. Bogucki, M. Żyburtowicz and numerical analysis.

$\mu_z = \mu_{LT} = 1{,}0$

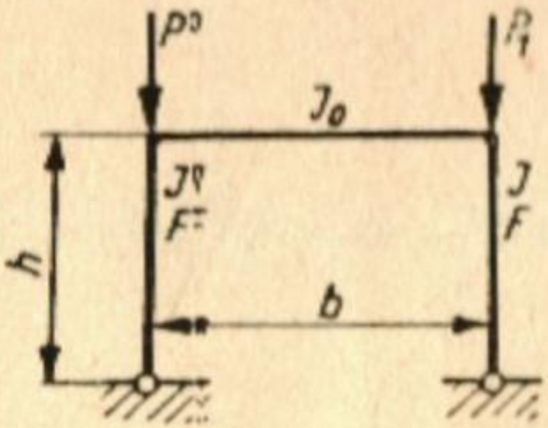
$L_{cr,\,y} = L_{cr,\,z} = L_{cr,\,LT} = H$

y - in plane; z - out of plane

It is IInd example of calculations in Example Part

Buckling length factor in-plane of frame

"Tablice do projektowania konstrukcji metalowych", W. Bogucki, M. Żyburtowicz, Arkady, Warszawa 1984

Rodzaj ramy	Oznaczenia	Współczynnik
	$n = \frac{P_1}{P}$ $c = \frac{Jb}{J_0 h}$ $s = \frac{4J}{b^2 F}$	$\sqrt{0{,}5(1+n)} \times$ $\times \sqrt{4 + 1{,}4(c+6s) + 0{,}02(c+6s)^2}$

Calculation according to table and comparison with computer calculation of α_{cr}

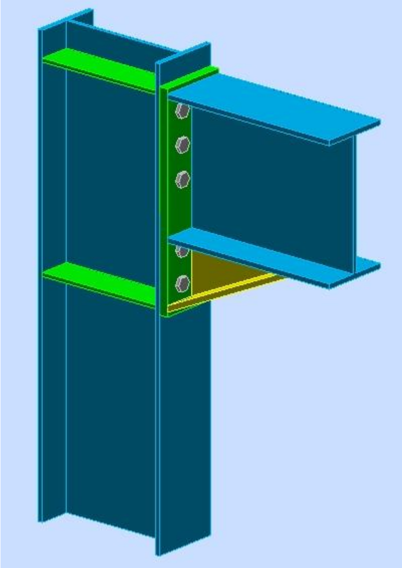
$$N_{cr} = \pi^2 E J / (h \mu)^2$$

$$N_{cr} = N_{Ed} \alpha_{cr}$$

Joints

- purlin-purlin: rigid, bolted
- purlin-girder: hinge, bolted and welded
- girt - column: hinge, bolted
- girt - housing column: hinge, bolted
- housing column - girder: hinge, bolted
- base plate of housing column: hinge, bolted and welded
- roof bracing - girder: hinge, bolted and welded
- wall bracing - column: hinge, bolted and welded
- base plate of column: hinge, bolted and welded
- column - column (for very high halls): rigid, bolted (and welded)
- girder - girder (for very wide halls): rigid, bolted (and welded)
- girder - girder (ridge): rigid, bolted and welded
- column - girder: rigid, bolted and welded

Photo: kilonewton.prv.pl



Joint column-girder

- Stiffness of the joint
- Welds between roof girder and end plate
- Bolted joint girder - column; bedning moment
- Bolted joint girder - column; shear force

It is III^rd example of calculations in Example Part

Photo: tatasteelconstruction.com

Photo: promerol.com.pl

Stresses in bolted tensile joint

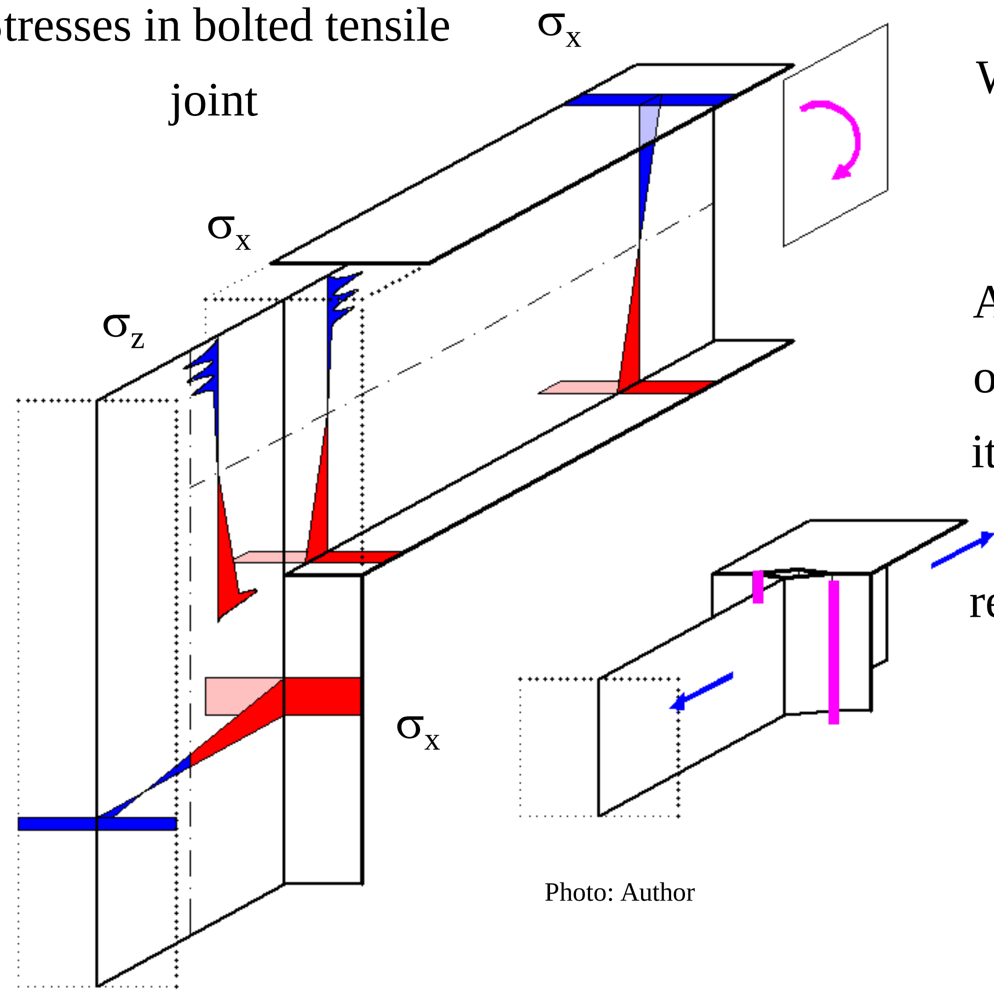
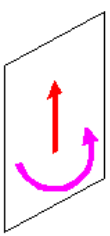


Photo: Author



We have a full set of cross-sectional forces in beam: M_{Ed} , N_{Ed} , V_{Ed} .

Axial force is taken into account only in form of stipulation in EN 1993-1-8 6.2.7.1 (2) that it must not exceed 5% of beam’s resistance; it is then neglected in calculations. This requirement is another condition to be met for beam.

Shear force is traditionally applied by calculation to compressed zone only.

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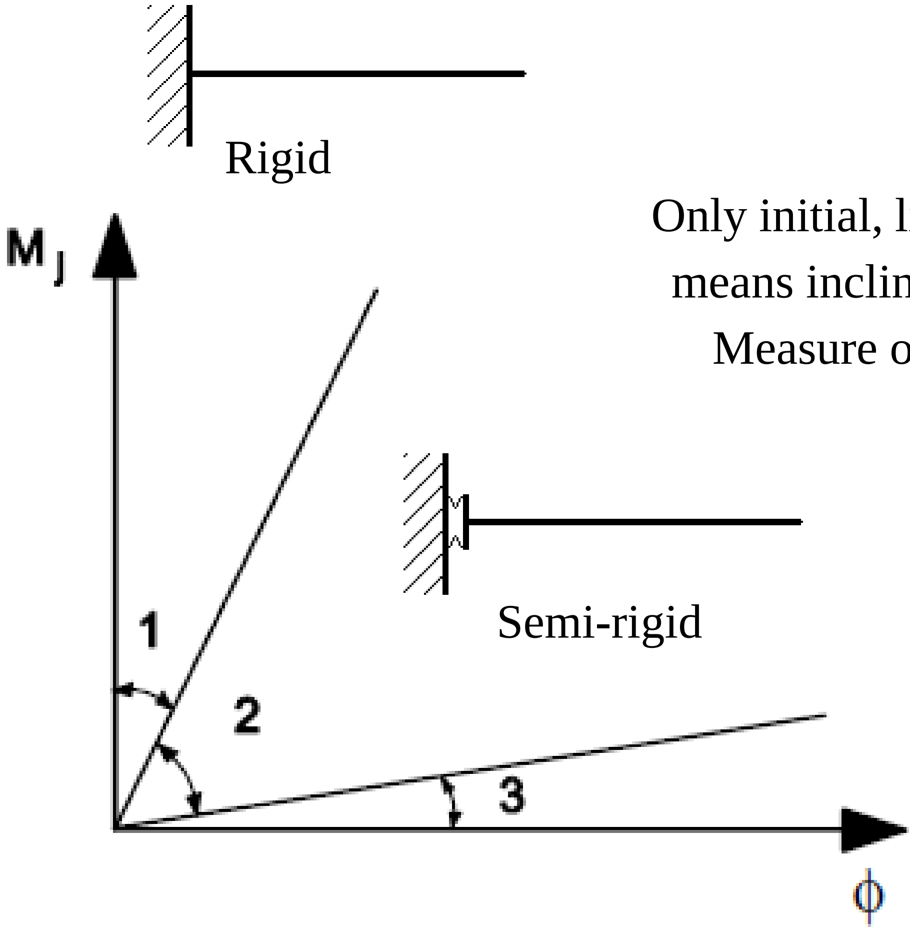
Shear force in column don’t affected on joint.

Calculations according to elastic analysis



Only initial, linear part is taken into consideration, this means inclination of limist 1-2 and 2-3 is calculated. Measure of stiffness is angle between axis ϕ and characteristis of joint.

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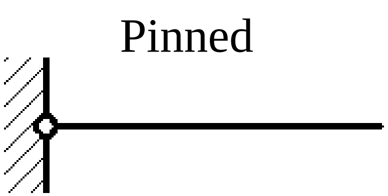


Photo: Author

Dimensions

Arms of actions:

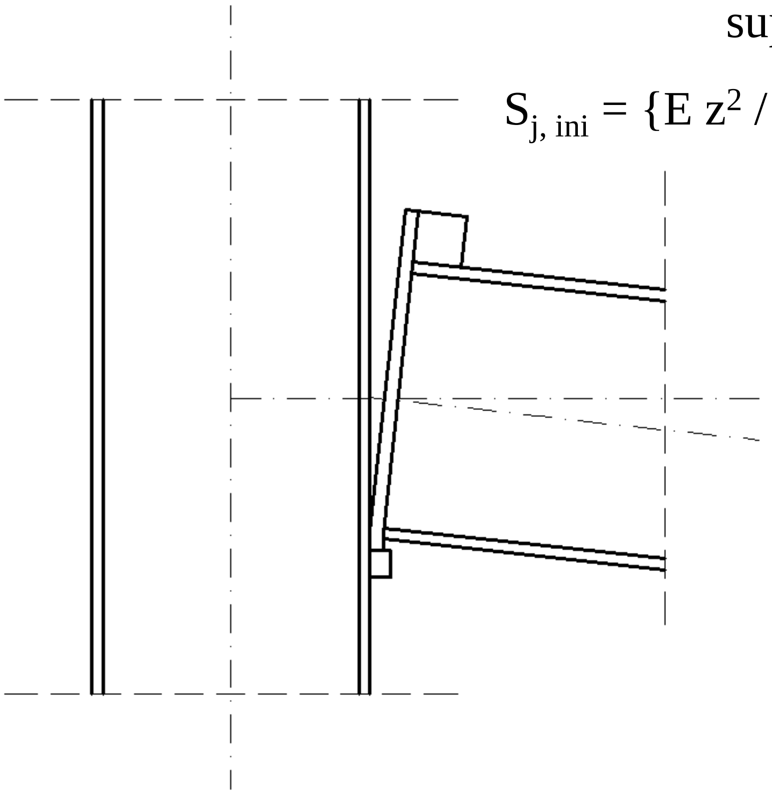
"frame" joints:

$$S_{j, ini} = E z^2 / [S (1 / k_i)]$$

support joints:

$$S_{j, ini} = \{E z^2 / [S (1 / k_i)]\} e / (e + e_k)$$

Photo: Author



Theoretical situation: no bolts in joint – rotation of beam around bottom part of compressed zone. Theoretical axis of rotation: centre of gravity (CoG) of compressed beam’s flange.

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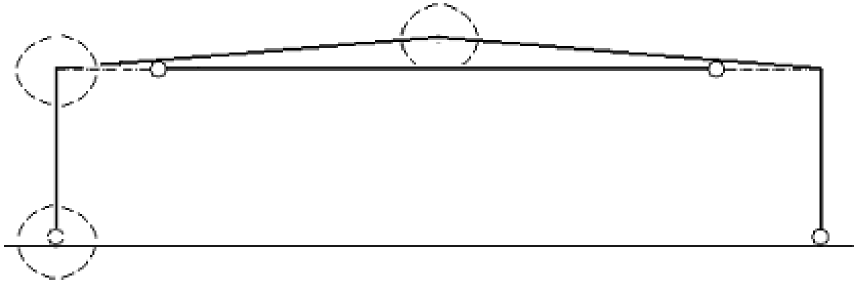
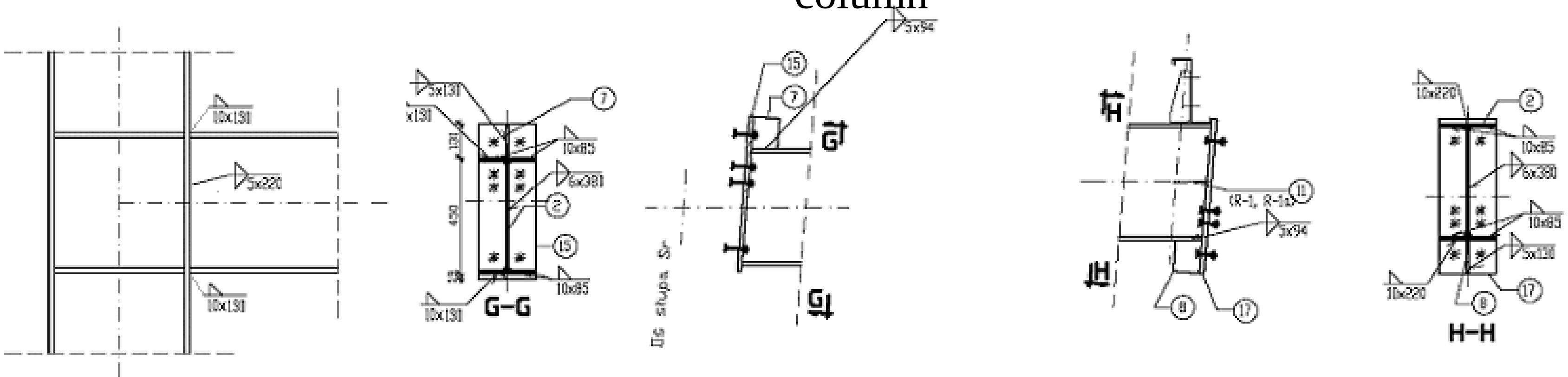


Example 3

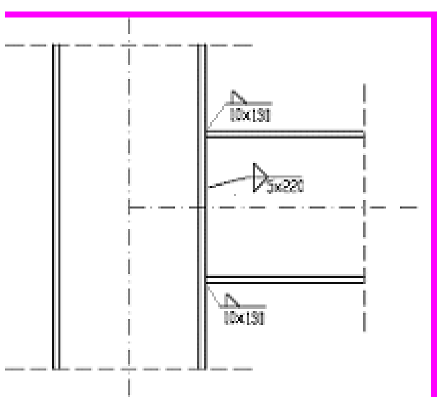
Filled welds

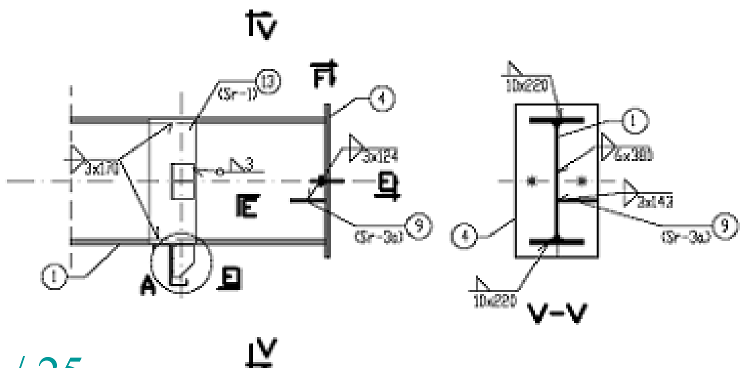
Welds between end-plate and girder or between base plate and column or between girder and column



3a, 3b

Photo: Author





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3c, 3d

Photo: scielo.br

Drawing, list of materials, card of structure

Card of structure

Storage hall for clothing wholesaler; Rybnik, mass of stored material 50 kg / m^2

Card of Structure (page 1 / 6)

Structure	Steel hall for storage of clothing
Designer	Author's data

Reliability of structure				
Consequence Class (EN 1990, EN 1993-4-1, EN 1993-4-2)		CC1	CC2	CC3
Reliability Class (EN 1990, EN 1993-3-2)		RC1	RC2	RC3
Design Supervision Level (EN 1990)		DSL1	DSL2	DSL3
Supervisor (DSL2, DSL3)		Tomasz Michałowski, PhD		
Inspection Level (EN 1990)		IL1	IL2	IL3
Action Assessment Class (EN 1991-4)	Not applicable	AAC1	AAC2	AAC3

According to Lec #3 / 32, 37

Important for silos only

Working life					
Design working life category (EN 1990)	1	2	3	4	5
Design working life of structure in years for main structure (EN 1990)	≤ 10	10 - 25	15 - 30	50	100

The most often case

Photo: Author

Category of use				
Category of use of floor areas (EN 1991-1-1)	A	B	C	D
Additional information	No loads form people congregation			
Category of storage and industrial use (EN 1991-1-1)	E	FL	F	G
Additional information	Clothing, 50 kg / m^2; loads from stored material and forklifts doesn't act on structure			
Category of use of roof (EN 1991-1-1)		H	I	K
Additional information	Repairs carried out only in snow-free periods or after removing snow (in accordance with separate instructions) from the roof			

The same for everybody

According to information in data

According to information in data for truss on I[st] project

Photo: Author

Snow on the roof precludes renovation

Photo: Author

According to information in data

According to information in data for truss on I[st] project

Loads and Actions	
Imposed load on floor $q_{k,\ floor}$ [kN / m^2] (EN 1991-1-1)	0,5 + forklifts
Imposed load on roof $q_{k,\ roof}$ [kN / m^2] (EN 1991-1-1)	0,4
Additional notices about imposed load	Loads from stored material and forklifts doesn't act on structure Paraseismic loads from mining damage and traffic can be neglected

The same for everybody

(paraseismic – only if strucute on mining activity)

Photo: Author

Loads and Actions				
Location	Rybnik			
Zone of				
Snow load (EN 1991-1-3)	Wind action (EN 1991-1-4)	Maximum shade air temperature $T_{min}(H)$ [°C] (EN 1991-1-5)	Minimum shade air temperature $T_{max}(H)$ [°C] (EN 1991-1-5)	Icing PN-EN 50 341-2-22: 2016
2 0,9 kN / m²	1 22 m / s 0,3 kN / m²	36	+34	Blank field
Terrain				
Topography – snow (EN 1991-1-3)		Category - wind (EN 1991-1-4)		
Normal		3		
Recommendations on snow removal	If the load exceeds 1,08 kN / m², remove snow in accordance with separated instruction			
Technological temperature T_t [°C]	Internal temperature +20 [°C]			
Additional notices about temperature	Air conditioning installed to prevent moisture condensation in storage material			

According to information in data

For location

Important for rope structures, mast, towers, chimneys, electro-energetic lines

Value over s_d

According to information in data for truss on I[st] project

The same for everybody

For full version of calculation, differences between internal temperature and max / min temperature will be taken into consideration

Photo: Author

Loads and Actions	
Type of liquid	
Stored	Transported
Blank field	Blank field
Negative and positive pressure	
Blank field	Blank field
Stored bulk material	Blank field
Transmitted gas	Blank field
Notices about risk of explosion (dust, gases)	Blank field
Notices about para / seismic actions	Paraseismic loads from mining damage and traffic can be neglected
Notices about other loads and actions	Blank field

Important for silos

Important for tanks

Important for pipelines

The same for everybody

(paraseismic – only if strucute on mining activity)

Photo: Author

Imperfections	
Production Category (EN 1090-2)	PC1
Service Category (EN 1090-2)	SC1
Consequence Class (EN 1090-2)	CC2
Execution Class (EN 1090-2)	EXC2
Functional Imperfection Class (EN 1090-2)	1

According to Lec #6 and Lab #6

According to #t / 37

Photo: Author

Elements	
Main structure	Roof girders: IPE 450 S 235 Main columns: IPE 450 S 235
Secondary elements	Purlins: cold-formed Z 250 / 2,5 S 235 Wall girts: cold-formed Z 150 / 1,5 S 235 Purlin's hangers: round bars Φ 8 S 235 Front wall columns: hot-rolled RHS 120x120x5 S 235 Roof bracings: round bars Φ 20 S 235 Wall bracings: round bars Φ 20 S 235
Roofing	One-span panels PWD-PIR 120
External walls	One-span panels PWD-PIR 120
Internal walls	They don't exist
Floors	Industrial floor; adapted to the passage of forklifts, according to separate specification
Foundations	Concrete C 30 / 37
Additional notices about elements	During technical inspections, special attention should be paid to the cooperation of the purlins with the roofing, especially when the time of exploitation had exceeded 10 years.

According to result of calculation

If no calculation- the same for everybody

Effect of calculation in Ist project*

The same as roofing

The same for everybody

* It may turn out that roofing adopted in Ist project doesn't now meet fire protection requirements according to #t / 48

Photo: Author

Joints	
Quality level for welded joints (EN 1090-2)	C (generally); D (undercut, overlap, stray arc, end crater pipe)
Categories of bolted joints (EN 1993-1-8)	E for rigid joint girder-column, A for rest bolted joints
Class of bolts (EN 1993-1-8)	8.8 M24 l = 130 mm for rigid joints girder-column 4.8 M20 l = 600 mm for anchor bolts 4.8 M12 l = 80 mm for rest bolted joints
Grade of bolts	A for rigid joints girder-column B for rest bolted joints

According to Lec #6 and Lab #6 for EXC presendet on #t / 42

If no calculation- the same for everybody

According to Lec #18 / 94

Photo: Author

Corrosion protection	
Corrosivity category (EN ISO 12 944-2)	C1
Durability of corrosion protection (EN ISO 12 944-1)	L
Notices about corrosion protection	Painting with anticorrosion paint in accordance to EN ISO 12 944-5

According to Lec #7

The most often case

Photo: Author

According to data

Fire protection
(Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location, 12.04.2002)

Height	5,45 at the eaves 6,40 at the ridge
Use of	Storage of clothing 50 kg / m^2 19 MJ / kg
Maximum fire load density in the building Q [MJ / m^2]	95 MJ / m^2
Fire resistance class of structure	D

Fire resistance class for

Main structure	Roof girders	Ceilings	External wall	Internal wall	Roofing
R30	R30	Blank field	EI30	Blank field	EI30

Notices about fire protection	Sprinkler system, fire monitoring, painting with intumescent paint

According to analysis, #t / 47-48

According to Lec #7 / 66

The most often case

Didn't existed

Heat of combustion of various materials (extract from PN-70 / B-02852):

Material	**Q_c [MJ / kg]**
Asphalt	40
Butter, margarine	31
Cellulose	18
Flour	15
Gum	40
Lubricants	41
Paper	16
Polyethylene, polypropylene (PP, PE)	43
Textiles	19
Tobacco	15
Wood	18

Storage hall for clothing: data as for textiles: 19 MJ / kg

Mass of stored material (from initial data): 50 kg / m^2

Maximum fire load density in the building: $19 \cdot 50 = 950$ MJ / m^2

According to Lec #7 / 61: for single storey halls, when fire load density is between 500 MJ / m^2 and 1000 MJ / m^2 , fire resistance class of the building (OP) is D.

Thank you for attention

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