# Metal Structures

# Design Project II

# Floor girders

## PROJECT OBJECTIVE’S

Difference between erection and exploitation stage;

Difference between II$^{nd}$ and I$^{st}$ class of cross-section;

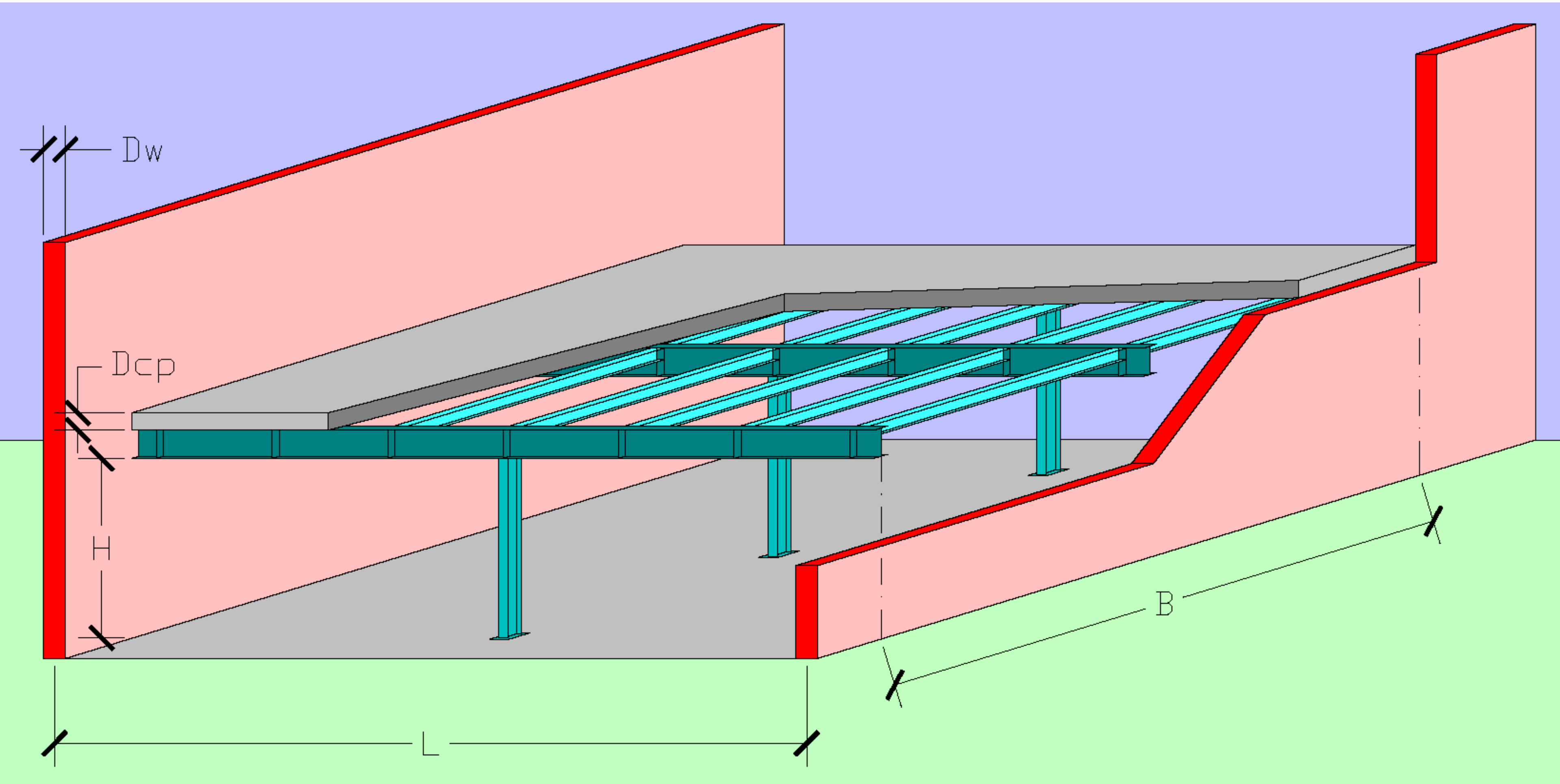
Bending and lateral buckling;

Plastic redistribution of bending moments;

Shear bolted joints: rigid and hinge;

Stiffeners;

Hinge supports of steel structure on steel column, masonry wall and concrete base;

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# DESIGN EXERCISES # 2

Student.........................................................................................................................

**Topic:**

Design of floor girders in masonry building:
B..........................................................
L..........................................................
H..........................................................

Data

- L the same as for truss (I[st] project; L ≈ 30,0 m);
- B = L / 3 (round to whole decimeters, +/- 5 cm);
- H = H for truss / 2 (round to whole decimeters, +/- 5 cm);
- Steel the same as for truss;

The same for everybody:

- $D_{cp}$ = 10 cm (concrete plate);
- $D_w$ = 40 cm (masonry wall);
- Load E1;
- Concrete base C 30/37;
- Masonry structure $f_d$ = 4 MPa;

**Algorithm:**

- Initial drawing
- Loads

Members:

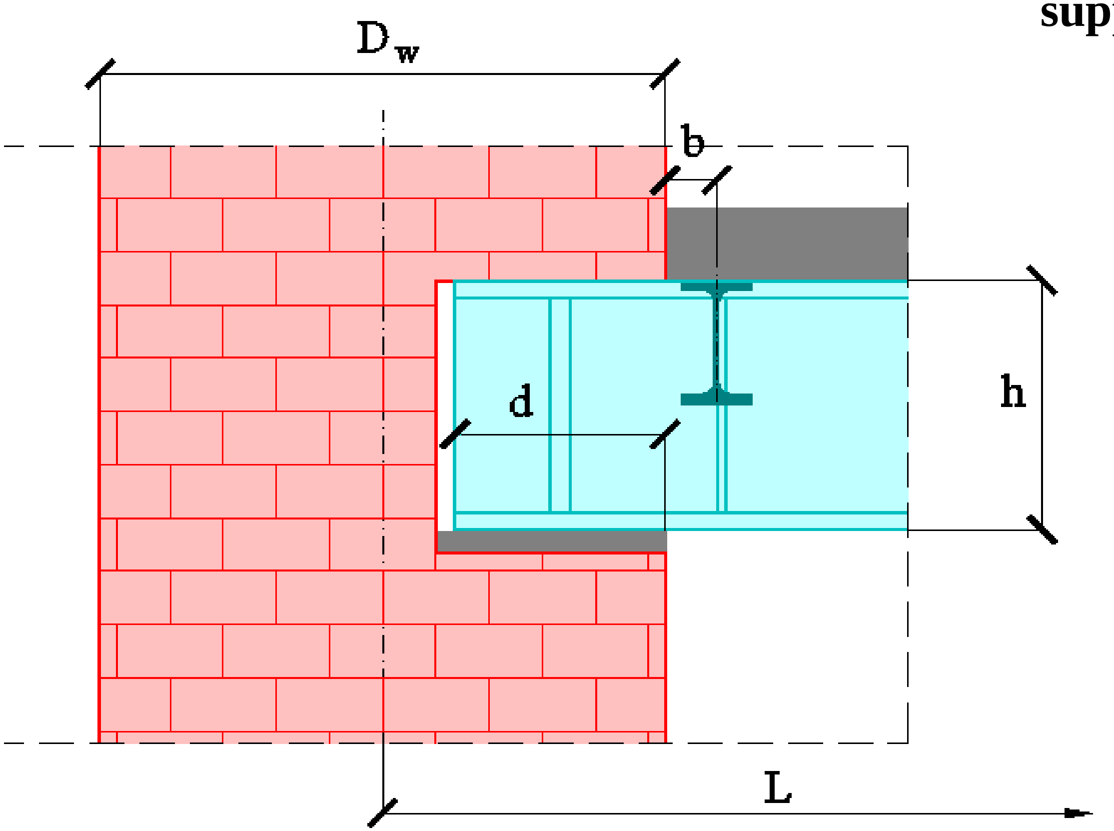
- Secondary beam
- Primary beam
- Column

Joints:

- Hinge joint, secondary beam - primary beam + stiffeners
- Rigid joint, two transport parts of primary beam
- Supports on wall and column head + stiffeners
- Column base (support on concrete base)

- Drawing, list of materials

## Initial assumptions about support of primary beam on wall

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$L = 2\ L_{span}$

$h = (1 / 20 \div 1 / 25)\ L_{span}$

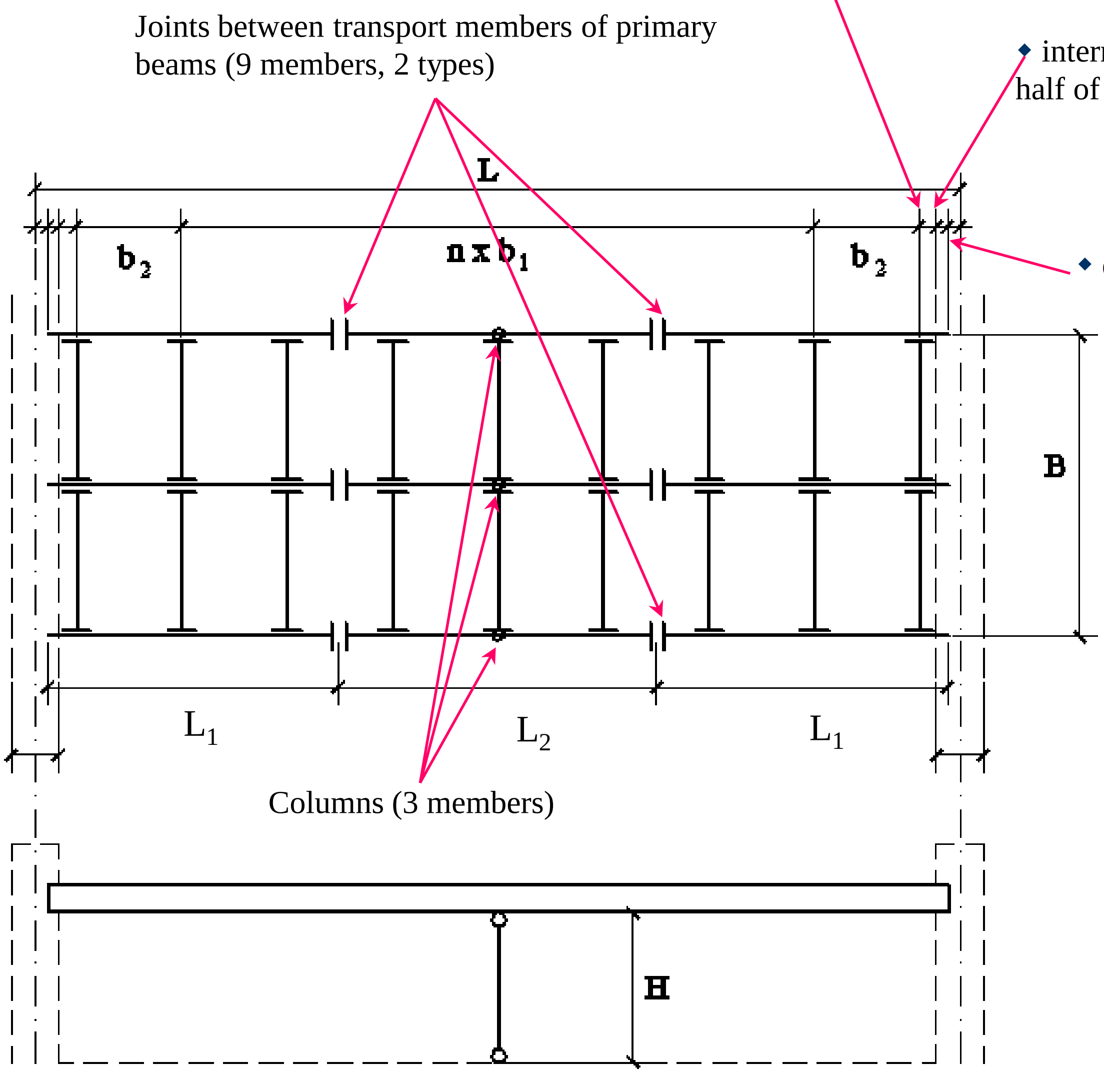
$d = \max\ (h / 10\ ;\ D_w / 2)$

$b = 150\ mm$

**<u>according to previous slide</u>** distances between:

# Initial drawing

- axis of last secondary beam and internal face of wall (b=150 mm);
- internal face of wall and end of primary beam (probably half of wall thickness, 200 mm);
- end of primary beam and axis of wall (probably 0);




$$2\,000 \le b_2 \le b_1 \le 2\,500$$

$$L_1 \quad ; \quad L_2 \le 12\,000$$

Photo: Author

**Loads**

- Live load EN 1991-1-1  6.3.2.1, 6.3.2.2   value E1

- Industrial floor ~ 5 - 15 mm
- Concrete plate 10 cm
- Plaster coating ~ 1 cm
- Dead weight of steel structures

I$^{st}$ Stage (erection):

- Concrete mix
- Framework
- Dead weight of steel structures
- Lateral buckling

II$^{nd}$ Stage (exploatation):

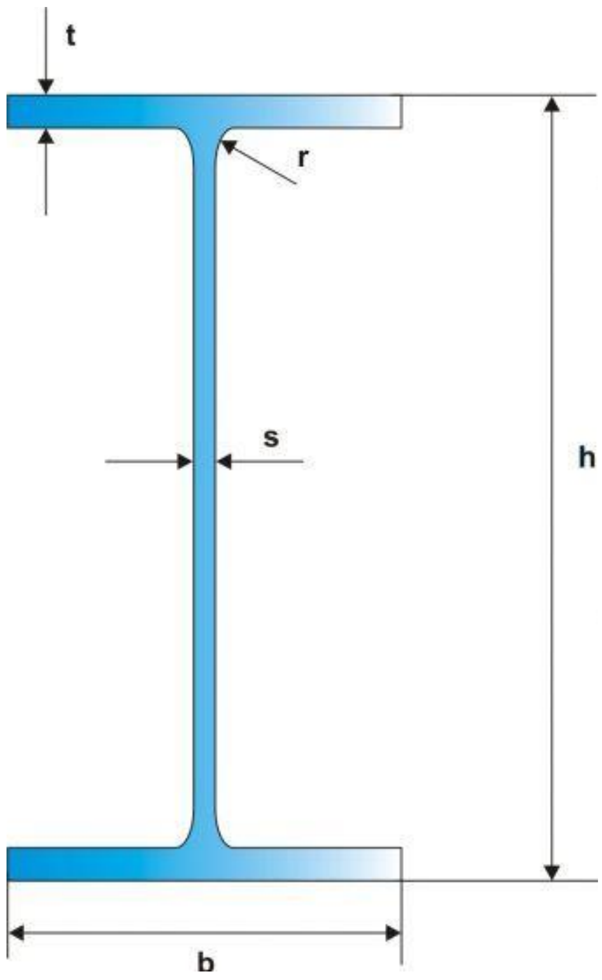
- Concrete
- No framework
- Floor, coating
- Dead weight of steel structures
- Live load
- No lateral buckling / restricted lateral buckling

Concrete mix + framework = 26 kN / m$^3$

Concrete = 25 kN / m$^3$

# Members

- Secondary beam
  - $I^{st}$ Stage – resistance
  - $I^{st}$ Stage – stability
  - $II^{nd}$ Stage – resistance
  - $II^{nd}$ Stage – deflection
- Primary beam
  - $I^{st}$ Stage – resistance
  - $I^{st}$ Stage – stability
  - $II^{nd}$ Stage – resistance
  - $II^{nd}$ Stage – stability
  - $II^{nd}$ Stage – deflection
- Column
  - $II^{nd}$ Stage – resistance
  - $II^{nd}$ Stage – stability

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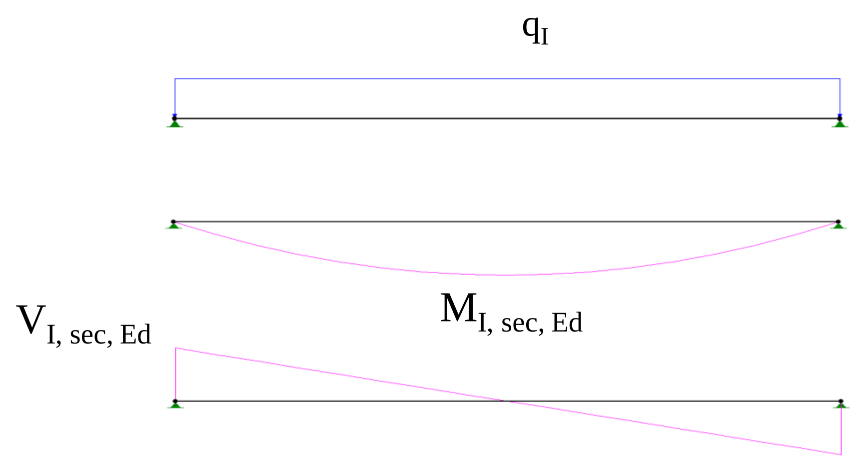
Secondary beam

IPE

$h \approx L_{sec\text{-}beam} / 20 \div L_{sec\text{-}beam} / 25$

## $I^{st}$ Stage:

- Class of cross-section
- Shear resistance
- Bending + lateral buckling ($l_{0w} = l_{beam}$)

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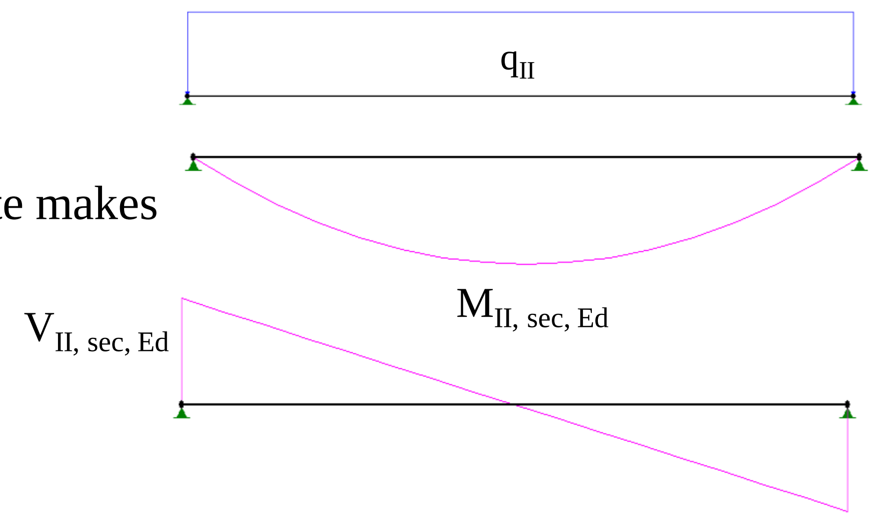
## $II^{nd}$ Stage:

(Class of cross-section – no change)

- Shear resistance
- Bending (no lateral buckling, concrete plate makes protection)
- Deflections



Class of the cross-section:

Lecture #4

(should be I[st] or II[nd] class)

Shear resistance (I[st] and II[nd] stage):

$$V_{sec,\,Ed} / V_{Rd} \leq 1{,}0$$

$$V_{Rd} = A_v\, f_y / (\gamma_{M0} \sqrt{3})$$

$$A_v \approx h\, t_w$$

Bending resistance (I[st] and II[nd] stage):

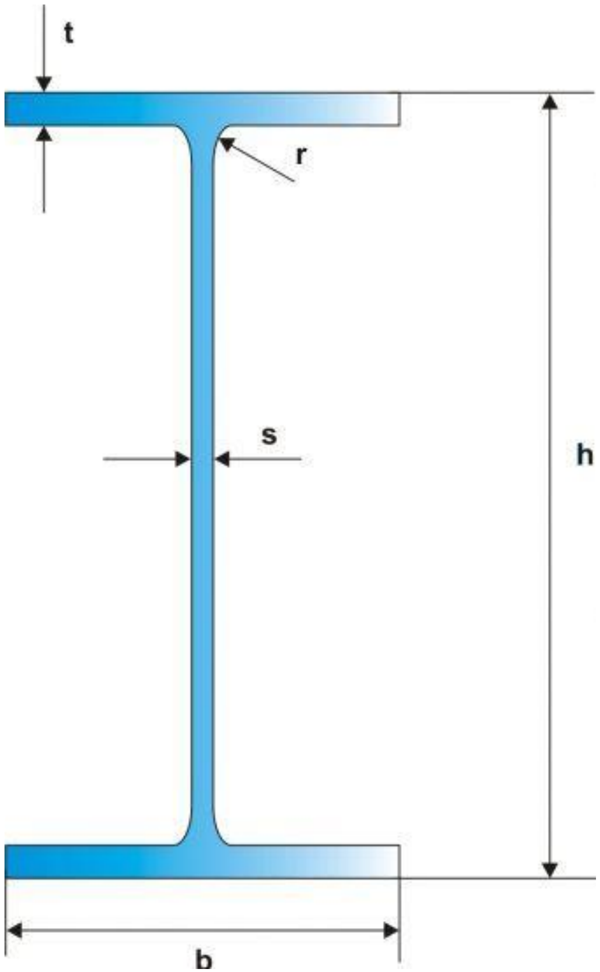
$$M_{sec,\,Ed} / M_{Rd} \leq 1{,}0$$

$$M_{Rd} = W_{pl}\, f_y / \gamma_{M0}$$

Lateral buckling (I[st] stage):

$$M_{sec,\,Ed} / \chi_{LT}\, M_{Rd} \leq 1{,}0$$

$\chi_{LT}$ Lecture #5

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# Primary beam

IPE, HEA, HEAA

$h \approx L_{pri\text{-}beam} / 20 \div L_{pri\text{-}beam} / 25$

Loads will be applicated as complex of vertical forces from secondary beams.

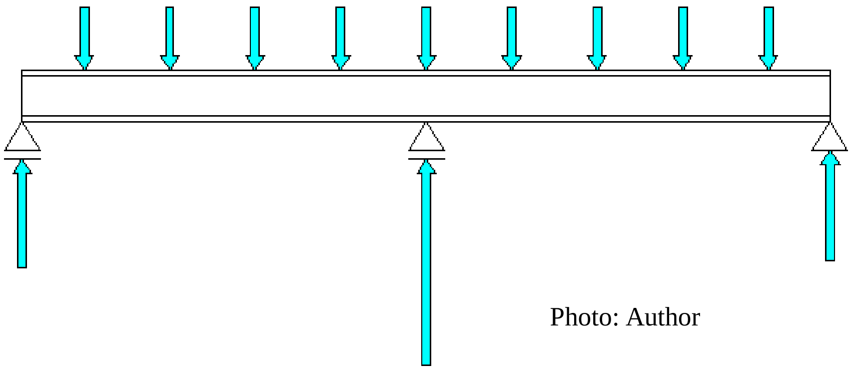


Photo: Author

Its values: pair of max reactions for secondary beam( pair: one force from left secondary beam and one force from righs secondary beam).

Dead-weight of primary beam could be recalculated to complex of vertical forces.

Photo: mscsteel.com

I$^{st}$ Stage:

- Class of cross-section
- Shear resistance
- Bending (as for II c.c.s.) + full lateral buckling

II$^{nd}$ Stage:

- (Class of cross-section – no change)
- Shear resistance
- Bending (as for I c.c.s. = plastic redistribution of bending moment) + limited lateral buckling
- Deflections

Primary beam - I[st] class of cross-section. For this type, using advantage of plastic redistribution of bending moments is possible (for multi-span contunous beam; as, for this case, two-span). Theoretical approach to problem is presented on Lectures #4 and #11.

| | |
|---|---|
| I[st] Stage | Partial value of external actions → average values of bending moments → bending moments too small to make plastic hinges → no plastic hinges → no redistribution of bending moments → beam of I[st] class of cross-section calculated as beam II[nd] class of cross-section. |
| II[nd] Stage | Final value of external actions → big values of bending moments → bending moments enough to make plastic hinges (and, additionally, there is multi-span beam) → plastic hinges → redistribution of bending moments → beam of I[st] class of cross-section calculated as beam I[st] class of cross-section. |

II[nd] class of cross-section: checking of resistance based on $W_{pl}$ and „normal" static calculation.

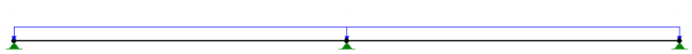
I[st] class of cross-section: checking of resistance based on $W_{pl}$ and plastic redistribution of bending moments.

# I[st] Stage, resistance:

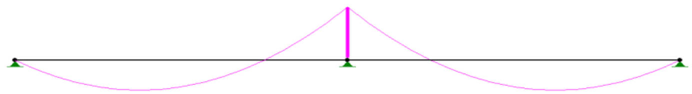
$M_{I,\ supp,\ Ed,\ max}$ for checking resistance and stability;

$V_{I,\ supp,\ Ed,\ max}$ for checking resistance;

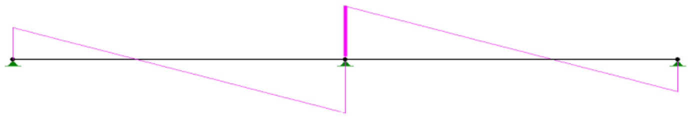
q = const



$M_{I,\ supp,\ Ed,\ max}$



$V_{I,\ supp,\ Ed,\ max}$



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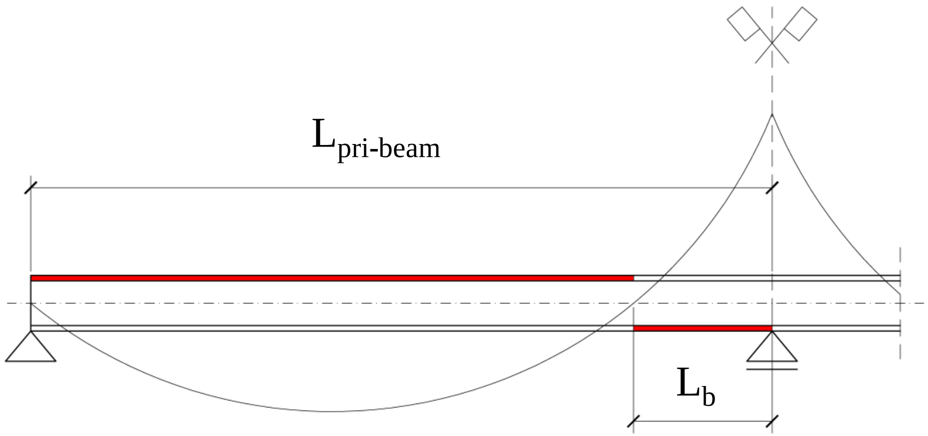
I^st Stage, stability:

Critical length = $L_{pri\text{-}beam}$ (no stiff members, which prevent primary beam from lateral buckling on total length)

Lateral buckling → Lecture #5

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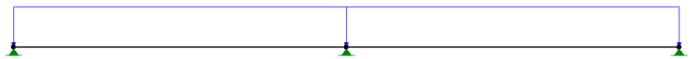
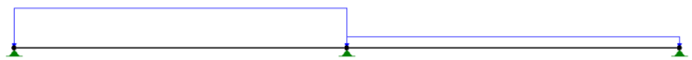
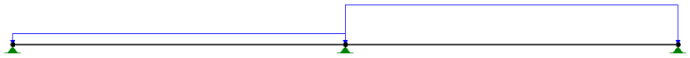
IInd Stage, combinations of loads:

Deadweight on both spans, live load on both spans:



Deadweight on both spans, live load on one span (left or right); combinations are mirror images:





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II$^{nd}$ Stage, resistance:

There are few values of cross-sectional forces, important for calculation:

- For resistance of cross-section of primary beam: $M_{II, Ed, max}$ ; $V_{II, supp, Ed, max}$ (#t / 24)
- For resistance of joint between two parts of primary beam: $M_{II, joint, Ed}$ ; $V_{II, joint, Ed}$ (#t / 25)
- Resistance of vertical stiffener over end support and resistance of wall: $R_{end, Ed, max}$ (#t / 26)
- Resistance of column (main part, head, base) and resistance of vertical stiffener over central support: $R_{top, Ed}$ ; $R_{bottom, Ed}$ (#t / 27)
- Resistance of joint between secondary and primary beam and resistance of vertical stiffner in this joint: vertical forces from pair of secondary beam (2 x $V_{sec, Ed}$ ; #t / 15)

## II[nd] Stage, resistance of primary beam; bending moments:

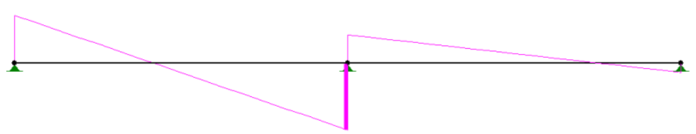
$\mathbf{M_{II,\ Ed,\ max}}$ **comes from redistribution of bending moments**. Results from „normal" static calculation will be used for checking results from redistribution only.

## II[nd] Stage, resistance of primary beam; shear forces:

$$V_{II,\ supp,\ Ed,\ max} = \max \left(V_{II,\ u\text{-}sym,\ sup,\ Ed,\ max} \quad ; \quad V_{II,\ sym,\ sup,\ Ed,\ max}\right)$$

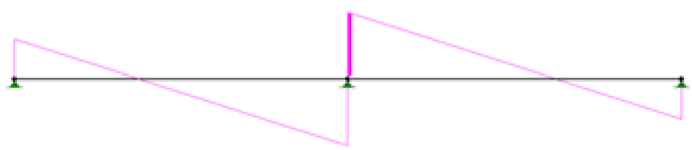
For shear forces, for simplification, colud be used results from „normal" statis calculation

Unsymmetrical loads



$V_{II,\ u\text{-}sym,\ sup,\ Ed,\ max}$

Symmetrical loads



$V_{II,\ sym,\ sup,\ Ed,\ max}$

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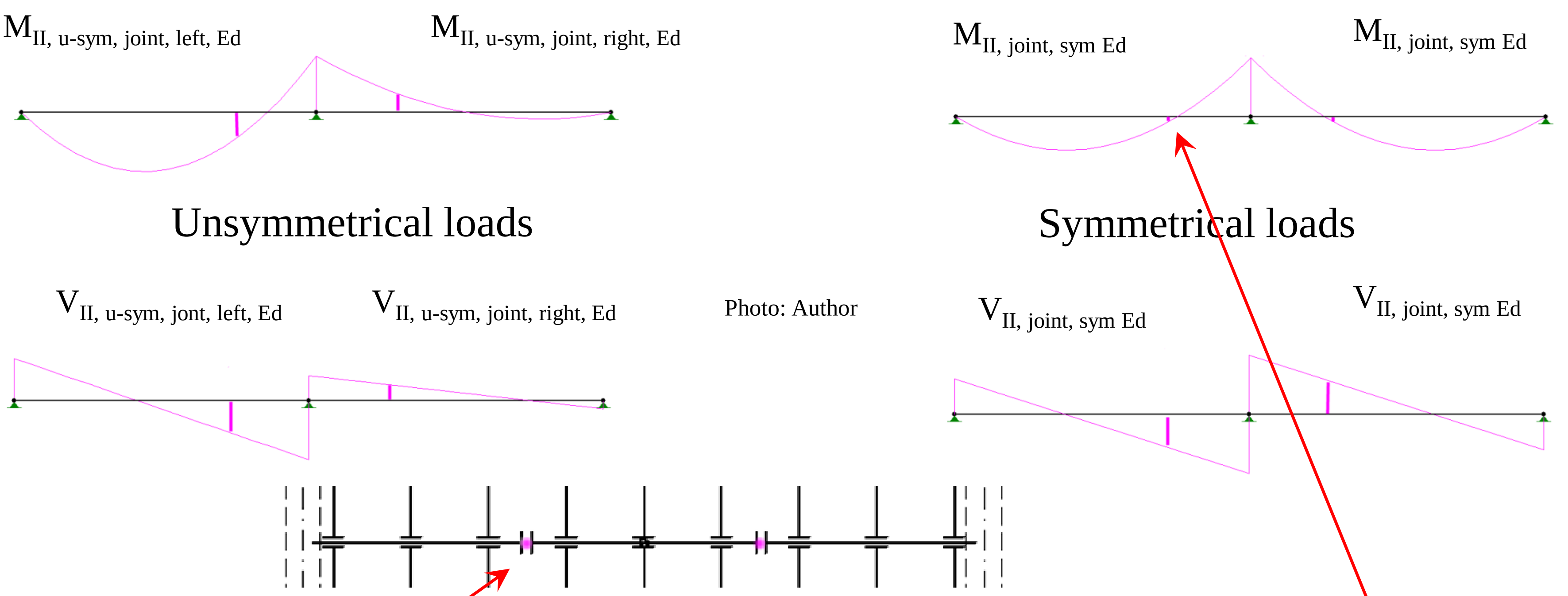
## II[nd] Stage, resistance of joints betweet two parts of primary beam:

For joint, for simplification, colud be used results from „normal” statis calculation

$$M_{II,\ joint,\ Ed} = \max\left(M_{II,\ u\text{-}sym,\ joint,\ left,\ Ed}\ ;\ M_{II,\ u\text{-}sym,\ joint,\ right,\ Ed}\ ;\ M_{II,\ joint,\ sym,\ Ed}\right)$$

$$V_{II,\ joint,\ Ed} = \max\left(V_{II,\ u\text{-}sym,\ joint,\ left,\ Ed}\ ;\ V_{II,\ u\text{-}sym,\ joint,\ right,\ Ed}\ ;\ V_{II,\ joint,\ sym,\ Ed}\right)$$




+/- halfway between the beams…

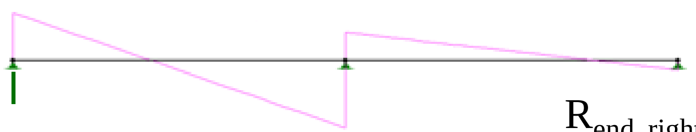
…and, at the same time, as close as possible to zero moment value for a symmetrical system

II^nd Stage, resistance, vertical stiffener over end support, support on wall:

For side reactions, for simplification, colud be used results from „normal" statis calculation enlarged by 10%.

$$R_{end,\, Ed,\, max} = 1{,}1 \max \left(R_{end,\, left,\, u\text{-}sym,\, Ed} \;\; ; \;\; R_{end,\, right,\, u\text{-}sym,\, Ed} \;\; ; \;\; R_{end,\, sym,\, Ed}\right)$$

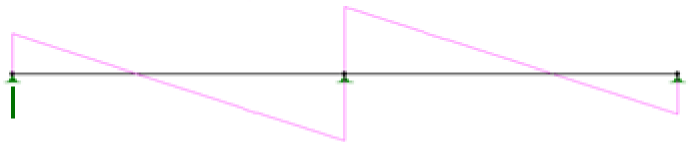
$R_{end,\, left,\, u\text{-}sym,\, Ed}$



$R_{end,\, right,\, u\text{-}sym,\, Ed}$

Unsymmetrical loads

$R_{end,\, sym,\, Ed}$ $R_{end,\, sym,\, Ed}$



Symmetrical loads

Photo: Author

II[nd] Stage, resistance, central stiffener, column, head of column, base of column:

For central reaction, for simplification, colud be used results from „normal” statis calculation

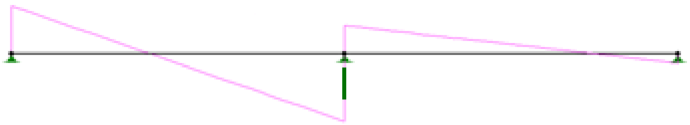
$R_{top,\ Ed} = \max\ (R_{supp,\ u\text{-}sym,\ Ed,\ max}\ ;\quad R_{supp,\ sym,\ Ed,\ max})$

$R_{bottom,\ Ed} = R_{top,\ Ed}$ + dead weight of column

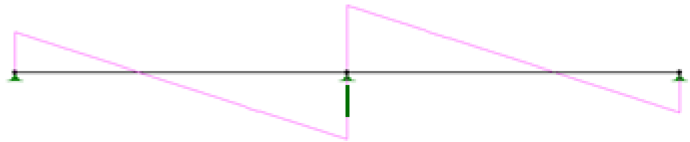
$R_{supp,\ u\text{-}sym,\ Ed,\ max}$

Photo: Author

$R_{supp,\ sym,\ Ed,\ max}$



Unsymmetrical loads



Symmetrical loads

Stiffener, head of column: $R_{top,\ Ed}$

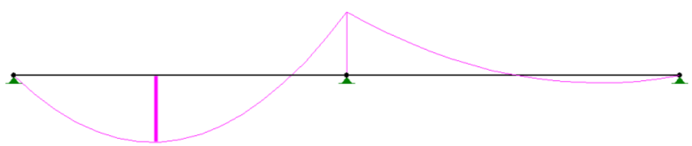
Main part of column, base of column: $R_{bottom,\ Ed}$

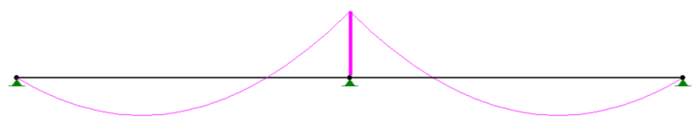
## II[nd] Stage, resistance of primary beam, verification of results (moments and reactions):

- „Normal" static analysis vs plastic redistribution:

$$M_{II,\ „normal",\ u\text{-}sym,\ span,\ Ed,\ span} < \mathbf{M_{span\ ,\ redistribution}} = \mathbf{M_{support,\ redistribution}} < M_{II,\ „normal",sym,\ supp,\ Ed,\ support}$$

$M_{II,\ „normal",\ sym,\ Ed,\ support}$





$M_{II,\ „normal",\ u\text{-}sym,\ Ed,\ span}$

Unsymmetrical loads

Photo: Author

Symmetrical loads

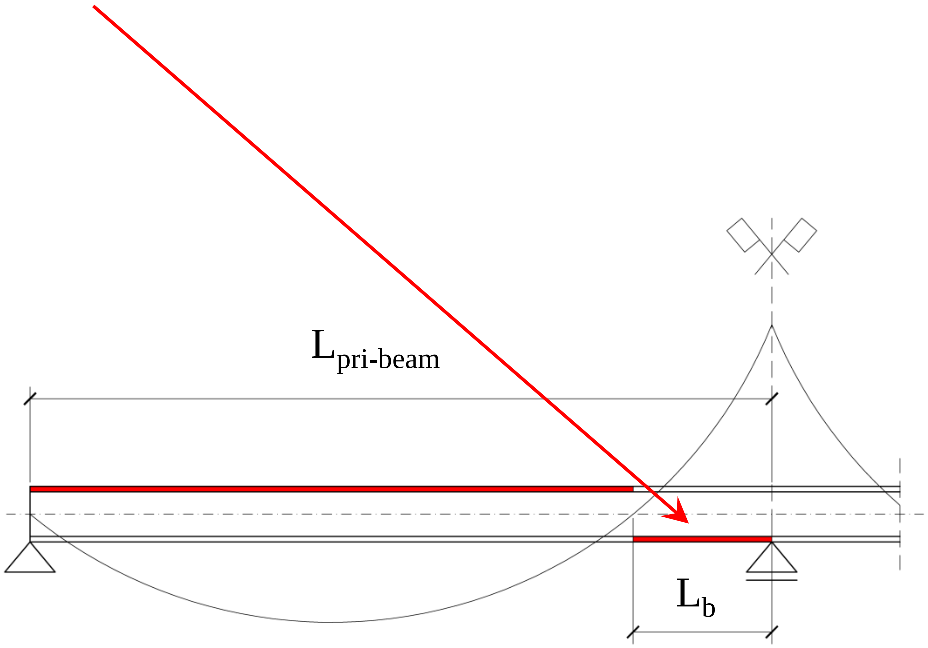
- $R_{top,\ Ed}$ (#t / 27) ≈ 2 $V_{II,\ supp,\ Ed,\ max}$ (#t / 24) + forces directly over column

- Reactions at end and central support:

$R_{end,\ Ed,\ max}$ (#t / 26) ≈ 0,30 ÷ 0,40 $R_{top,\ Ed}$ (#t / 27)

II^nd Stage, stability:

Critical length = $L_b$ (concrete plate prevents top part of cross-section from lateral buckling)

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I[st] Stage, effort:

$$M^{I}_{Ed} / \chi^{I}_{LT} M_{Rd} = eff\ I \leq 1{,}0$$

II[nd] Stage, effort:

$$M^{II}_{Ed} / \chi^{II}_{LT} M_{Rd} = eff\ II \leq 1{,}0$$

Recommendation:

$\underline{eff\ I \leq eff\ II}$

Opposite situation means, that cross-section of primary beam is designed as for a short-term assembly period (I[st] Stage), not as for a long-term period of expliotation (II[nd] Stage). It is uneconomical. If the assembly period becomes more important (bigger effort), the static scheme should be changed for this stage by adding temporary supports.

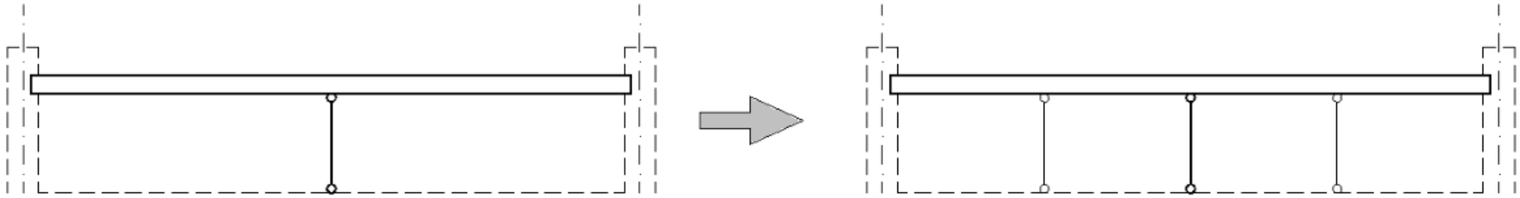


Photo: Author

Deflections:

Value of deflections can be approximated by one of two ways:

- Values from „normal" static calculations;
- Values from formula:

$$\Delta = 0{,}50\ [5\ g\ L^4 / (384\ E\ J_y)] + 0{,}75\ [5\ q\ L^4 / (384\ E\ J_y)]$$

where

$\Delta$ - deflection; g – dead weight; q – live load; L – length of one span

Primary beam is $I^{st}$ example of calculations in Example Part

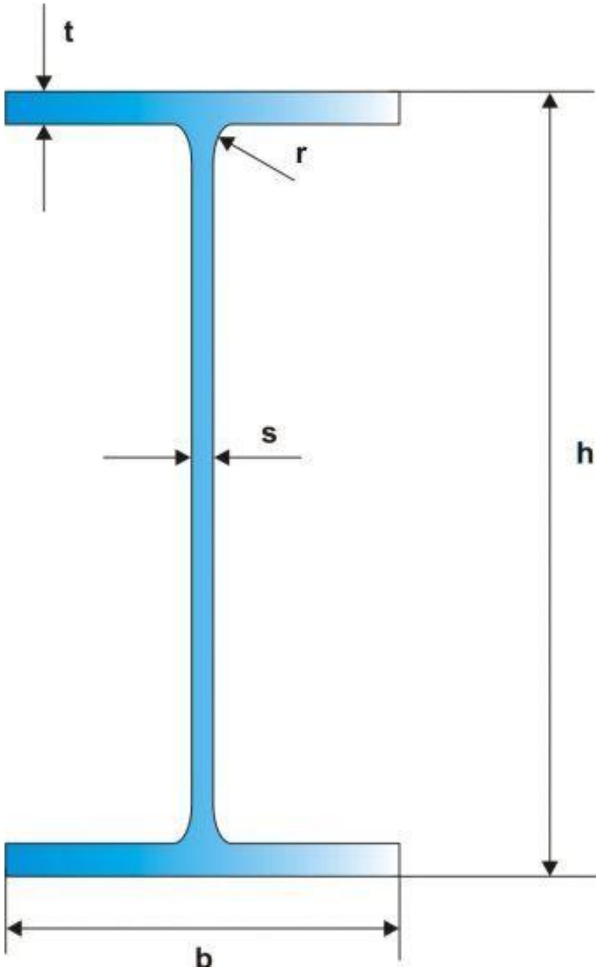



Photo: hmsteel.pl

<u>Column</u>

HEB

h ≤ width of primary beam's flange (probably 300 mm)

I$^{st}$ Stage:

- Nothing (too small loads to get important effects)

II$^{nd}$ Stage:

- Class of cross-section
- Axial compression + flexural buckling (y, z); calculation the same as in I$^{st}$ design project, stability of bracing bars ($\mu_y = \mu_z = 1{,}0$)

Critical length for both directions is equal height of column

# Joints

- Secondary-primary beams
  - $II^{nd}$ Stage – stiffness
  - $II^{nd}$ Stage – resistance (bolts, plates)
- Primary-primary beam
  - $II^{nd}$ Stage – stiffness
  - $II^{nd}$ Stage – resistance (bolts, plates, welds)
- Beam suport (on wall, on column's head)
  - $II^{nd}$ Stage – stiffness
  - $II^{nd}$ Stage – resistance (wall / head, plates, welds)
- Column support
  - $II^{nd}$ Stage – stiffness
  - $II^{nd}$ Stage – resistance (concrete, plate, welds)

Stiffeners must be applicated for

- joint secondary-primary beam;
- over column's head;
- over wall.

<u>Algorithm of calculation is the same for each stiffener, so total stiffeners will be presented as separated point of calculation</u>.

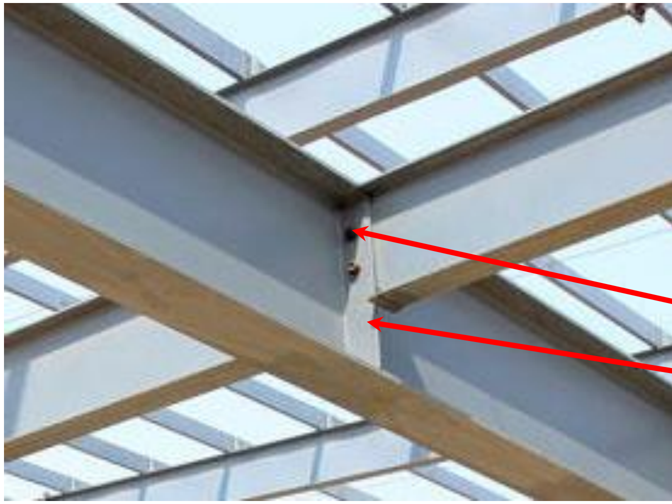


Photo: mscsteel.com

<u>Hinge joint</u>, secondary beam - primary beam

Calculation of secondary beam – primary beam joint consists of two parts. The first one concerns resistances of bolts, the second one concerns resistance of vertical stiffener.

Different values of forces act on primary beam can cause different thickness of stiffeners

A – max reaction over central support;
B – reaction over end support;
C – pair of reactions from secondary beams

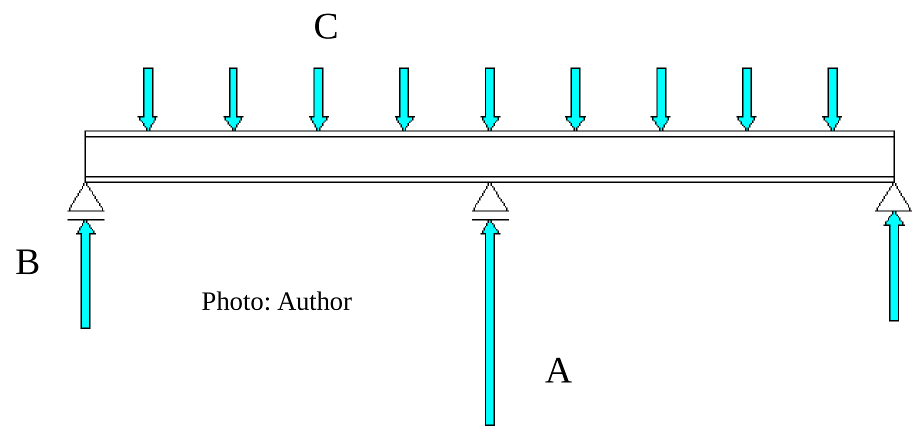
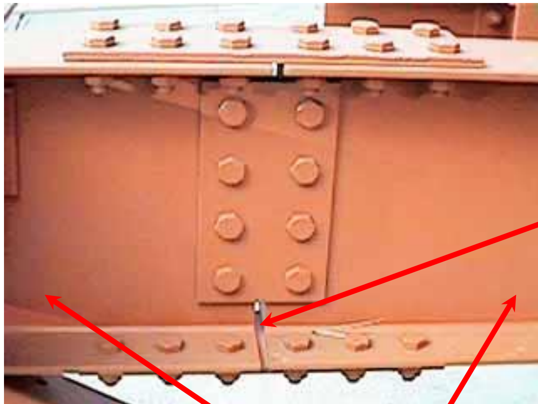



Photo: Author

Bolts: force as in case C
Stiffeners: cases A, B, C

It is II$^{nd}$ example of calculations in Example Part

Photo: amsd.co.uk



# Rigid joint, two part of primary beam

Small gap (≈ 20 mm) between transpor members for compensation of support's imperfections.

Joint between two parts of transport members

Joint consists on two pairs of special plates:

Web plates

Flange plates

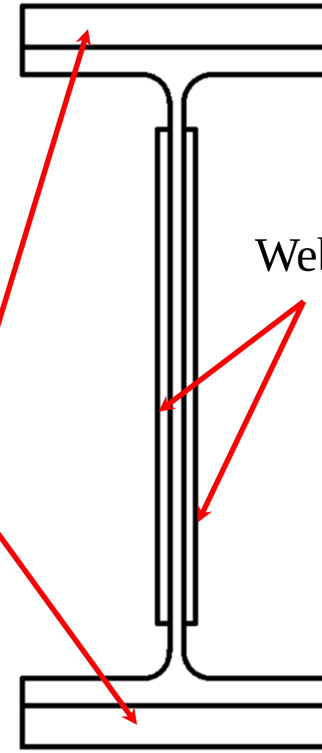


Photo: Author

Calculation concerns resistances of shank of bolts, plates in contact with bolts and effect of presence of bolts.

It is III[rd] example of calculations in Example Part

# Supports of primary beam

Photo: homeownercosts.co.uk

Photo: Author

- Resistance of rocker's sub-parts – common procedure for both cases of support;
- Resistance of masonry wall;
- Resistance of column's top part;

It is IV$^{th}$ example of calculations in Example Part

# Stiffeners

A – reaction over central support;

B – max reaction over end support;

C – pair of reactions from secondary beams

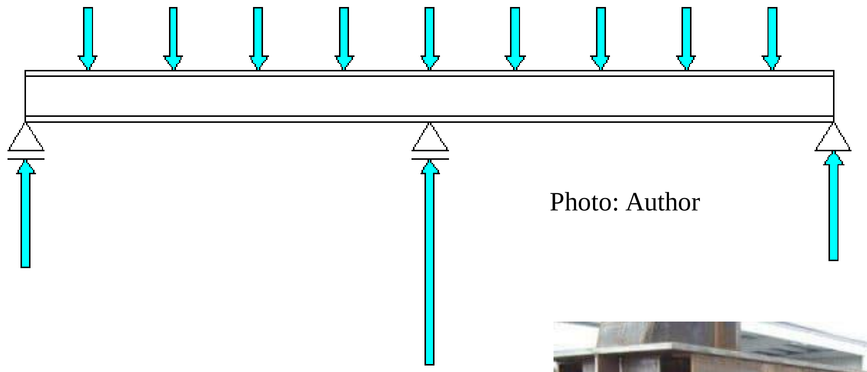


Photo: Author

Photo: theconstructor.org

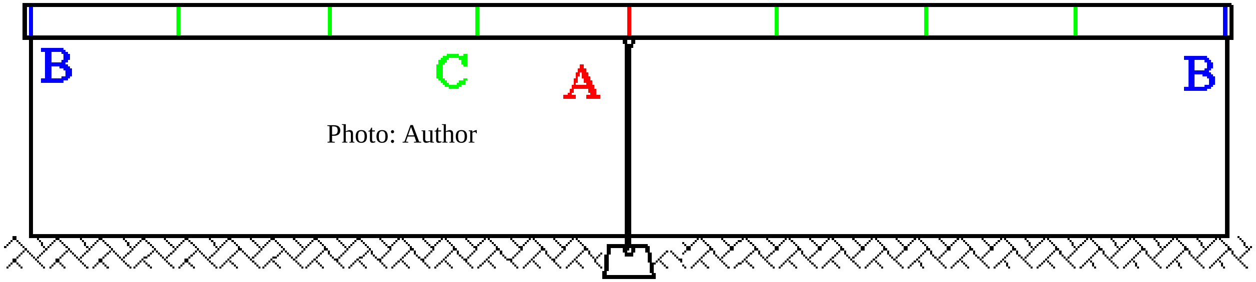
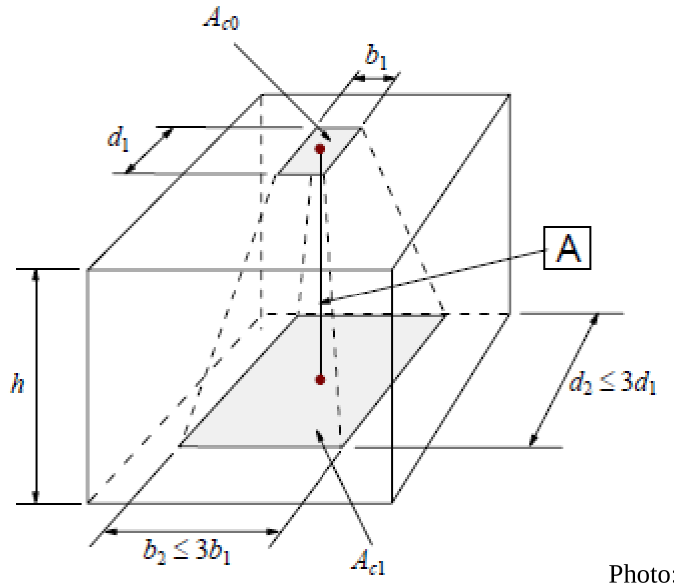



Photo: Author

Different values of forces act on primary beam can cause different thickness of stiffeners A, B, C ($t_A > t_B > t_C$)

It is V$^{th}$ example of calculations in Example Part

# Column base




$h \geq (b_2 - b_1)$ i $h \geq (d_2 - d_1)$

Photo: EN 1992-1-1 fig 6.29

Photo: j-p.com.ua

Resistance of concrete in contact with steel structure

It is VI$^{th}$ example of calculations in Example Part

# Drawing

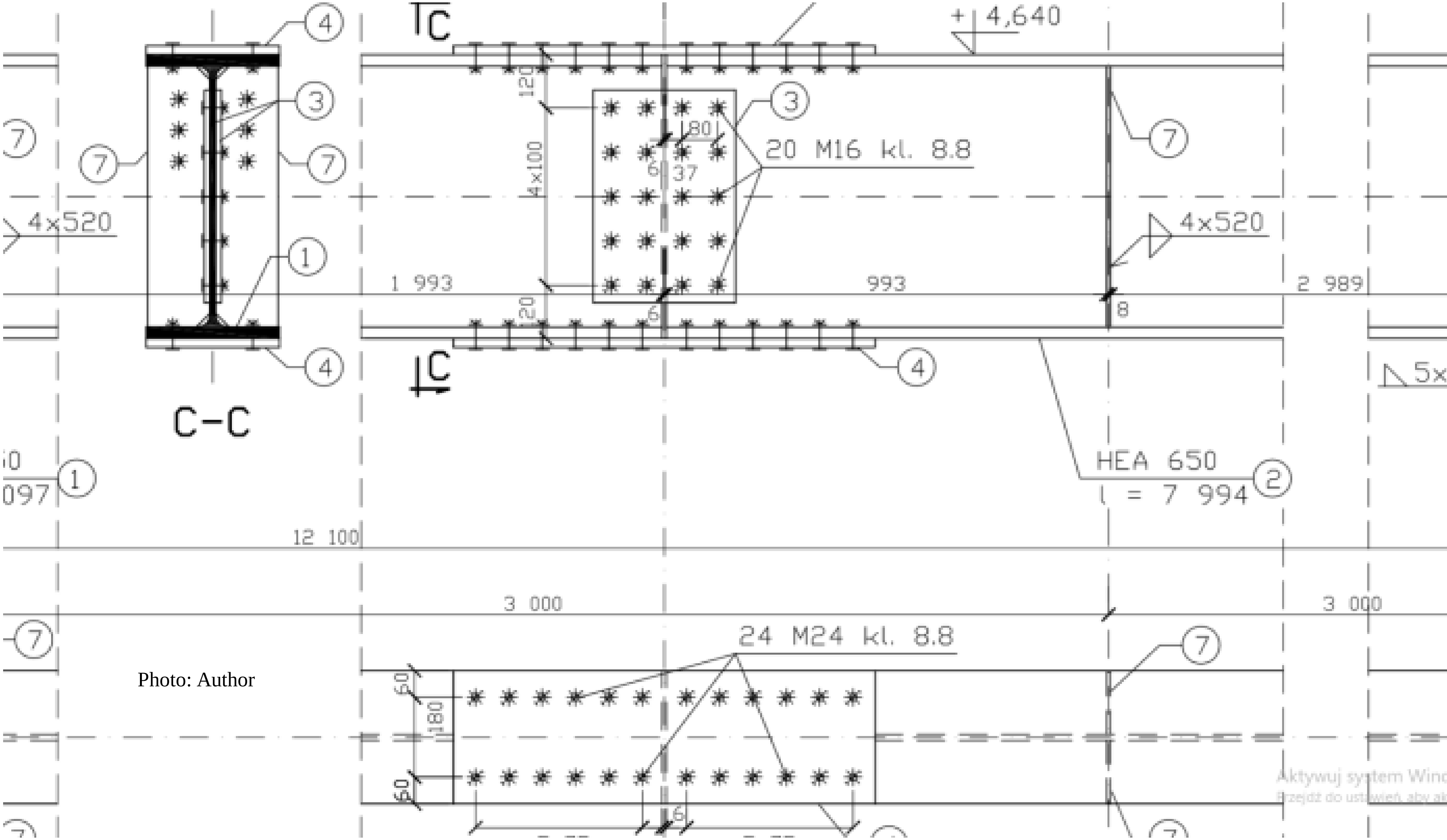



Photo: Author

# List of materials

Photo: Author

| MODULUS | SYMBOL OF ELEMENT | NAME OF ELEMENT | DIMENSIONS [mm] | UNIT MASS [kg / m2], [kg / m], [kg / 1000 pieces] | MASS OF ELEMENT [kg] | NUMBER OF ELEMENTS | MASS OF ELEMENTS [kg] | UNIT MASS [kg] | NUMBER OF UNITS [kg] | TOTAL MASS [kg] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pa** | 1 | HEA 650 | 8 097 | 190,00 | 1538,43 | 1 | 1538,43 | 1 697,69 | 6 | 10 186 |
| | 3 | pl 8 | 320x480 | 64,00 | 9,83 | 2 | 19,66 | | | |
| | 4 | pl 20 | 300x950 | 160,00 | 45,60 | 2 | 91,20 | | | |
| | 6 | pl 8 | 140x588 | 64,00 | 5,27 | 2 | 10,54 | | | |
| | 7 | pl 10 | 140x588 | 80,00 | 6,59 | 4 | 26,34 | | | |
| | 11 | pl 40 | 120x300 | 320,00 | 11,52 | 1 | 11,52 | | | |
| | M16 | M16 cl 8.8 | 50 | - | - | 10 | - | | | |
| | M24 | M24 cl 8.8 | 70 | - | - | 12 | - | | | |
| **Pb** | 2 | HEA 650 | 7 994 | 190,00 | 1518,86 | 1 | 1518,86 | 1 577,08 | 3 | 4 731 |
| | 5 | pl 14 | 140x588 | 112,00 | 9,22 | 2 | 18,44 | | | |
| | 7 | pl 10 | 140x588 | 80,00 | 6,59 | 4 | 26,34 | | | |
| | 8 | pl 20 | 20x300 | 160,00 | 0,96 | 2 | 1,92 | | | |
| | 11 | pl 40 | 120x300 | 320,00 | 11,52 | 1 | 11,52 | | | |
| | M16 | M16 cl 8.8 | 50 | - | - | 20 | - | | | |
| | M24 | M24 cl 8.8 | 70 | - | - | 24 | - | | | |
| **S** | 10 | HEA 240 | 4 110 | 60,30 | 247,83 | 1 | 247,83 | 286,81 | 3 | 860 |
| | 12 | pl 20 | 300x300 | 160,00 | 14,40 | 1 | 14,40 | | | |
| | 13 | pl 30 | 320x320 | 240,00 | 24,58 | 1 | 24,58 | | | |
| | M16 | M16 cl 4.8 | 50 | - | - | 4 | - | | | |
| | M20 | M20 cl 4.8 | 420 | - | - | 2 | - | | | |
| **B** | 15 | IPE 300 | 4 406 | 42,20 | 185,93 | 1 | 185,93 | 185,93 | 14 | 2 603 |
| | M16 | M16 cl 4.8 | 50 | - | - | 6 | - | | | |

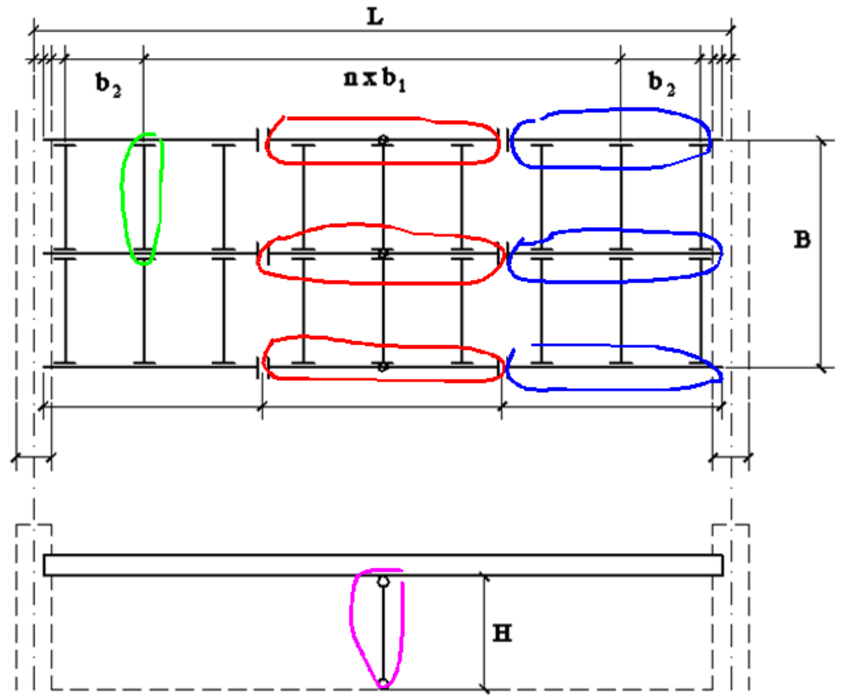
| | | | | |
|---|---|---|---|---|
| | | | Sum | 18 381 |
| | | | 2% for welds | 368 |
| **Bolts** | M16 cl 4.8 | 50 mm | 107 kg / 1000 szt | 96 pieces | 10 |
| | M16 cl 8.8 | 50 mm | 107 kg / 1000 szt | 120 pieces | 13 |
| | M20 cl 4.8 | 420 mm | 1,06 kg / 1 szt | 6 pieces | 6 |
| | M24 cl 8.8 | 70 mm | 347 kg / 1000 szt | 144 pieces | 50 |
| | | | | **TOTAL** | **18 828** |

| MODULUS | SYMBOL OF ELEMENT | NAME OF ELEMENT | DIMENSIONS [mm] |
|---|---|---|---|
| Pa | 1 | HEA 650 | 8 |
| | 3 | pl 8 | 320 |
| | 4 | pl 20 | 300 |
| | 6 | pl 8 | 140 |
| | 7 | pl 10 | 140 |
| | 11 | pl 40 | 120 |
| | M16 | M16 cl 8.8 | 5 |
| | M24 | M24 cl 8.8 | 7 |
| Pb | 2 | HEA 650 | 7 |
| | 5 | pl 14 | 140 |
| | 7 | pl 10 | 140 |
| | 8 | pl 20 | 20x |
| | 11 | pl 40 | 120 |
| | M16 | M16 cl 8.8 | 5 |
| | M24 | M24 cl 8.8 | 7 |
| S | 10 | HEA 240 | 4 |
| | 12 | pl 20 | 300 |
| | 13 | pl 30 | 320 |
| | M16 | M16 cl 4.8 | 5 |
| | M20 | M20 cl 4.8 | 4 |
| B | 15 | IPE 300 | 4 |
| | M16 | M16 cl 4.8 | 5 |

Photo: Author

First column – modulus. This is information about transport members of structure. For example, structure can be divided into:

- central part of primary beam;
- side part of primary beam;
- secondary beam;
- column.



Floor girder, floor system - ruszt stropowy

Secondary beam - belka poprzeczna

Primary beam - podciąg

Envelope (of bending moments, shear forces) – obwiednia

Thank you for attention



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