Single-storey industrial buildings

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Lecture 10: 21/02/2014

European Erasmus Mundus Master Course

Sustainable Constructions under Natural Hazards and Catastrophic Events

520121-1-2011-1-CZ-ERA MUNDUS-EMMC

Universitatea Politehnica Timişoara

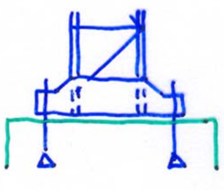
Part I – Industrial buildings

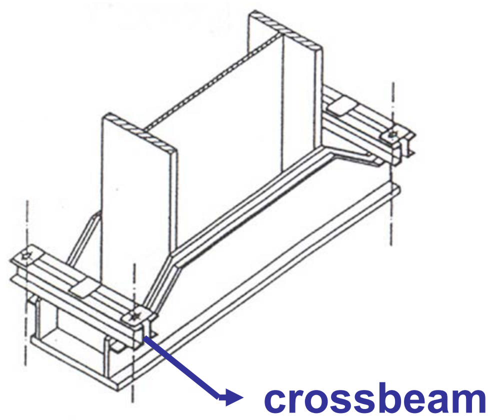
- Column base plates, vertical bracing of longitudinal walls and gables, wall elements (cladding, posts, columns, rails, cassettes, bracings).
- Classification (first and second order) of structures
- Frames, detailing, space behaviour of halls.
- Design of crane runway beams.

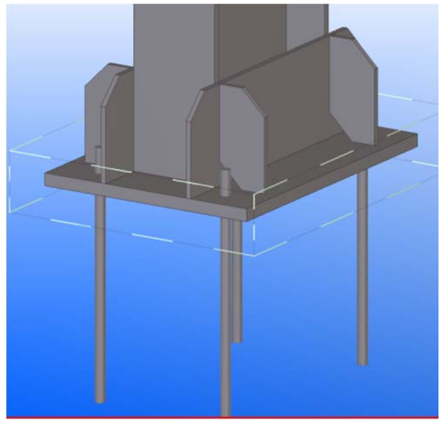
Fixed base

For large moments at the base, stiffened base plates are recommended.

a) 'Compact' base plates



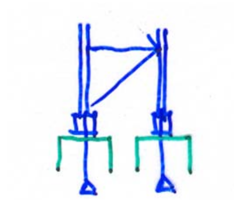


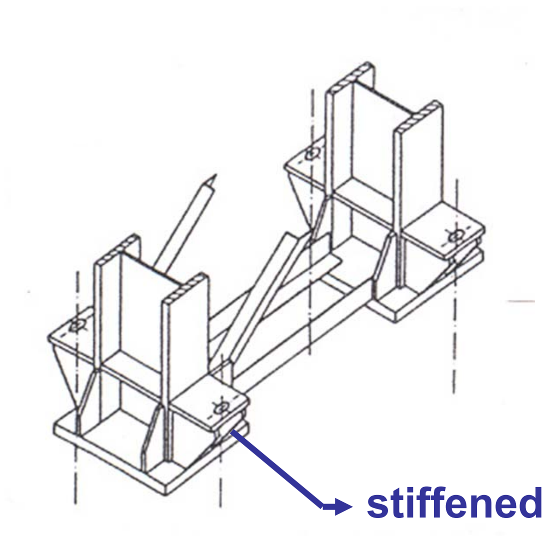


Principle:
- **Anchor bolts outside the base plate**
- **Bigger tolerances of the bolts**
- **Bending moment transferred through stiffeners**
- **Shear force may be transferred through embedment**

Column base plates

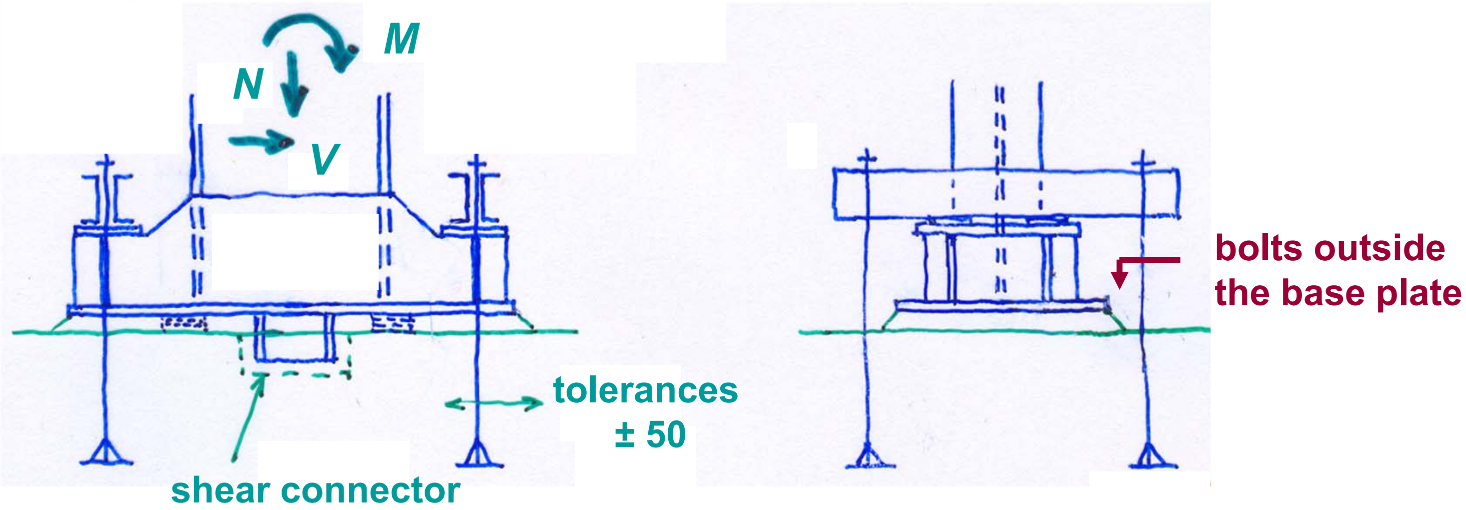
b) Latticed or battened column base



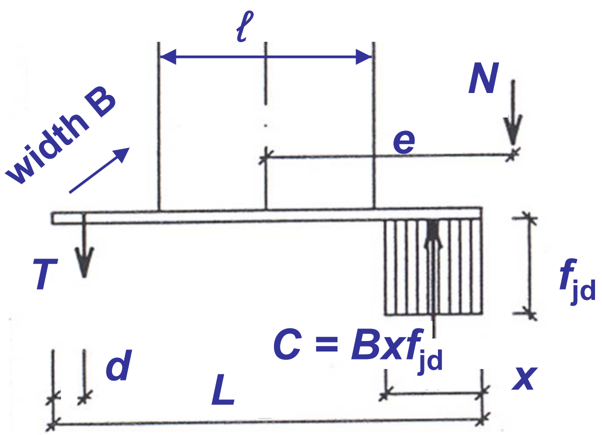


For smaller loads the base plate may be without stiffeners. In that case bending resistance of the plate is limited.

Design of stiffened moment column base



Plastic resistance:



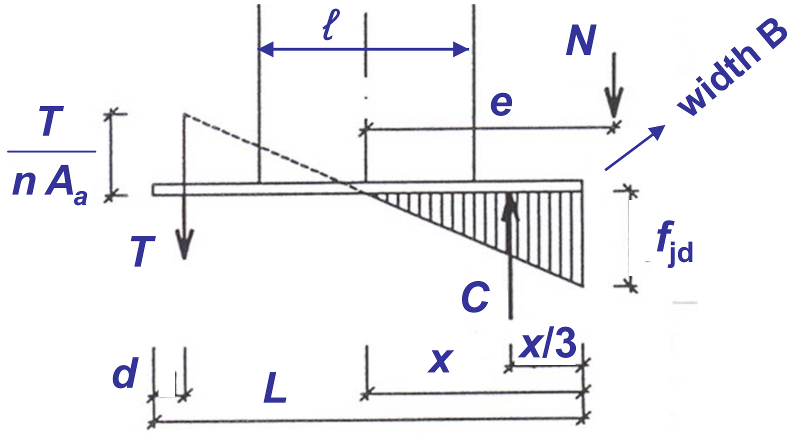
1. $e \leq 0{,}4\,L$ No tension.
   Check condition: $B(L - 2e)f_{jd} \geq N$

2. $e > 0{,}4\,L$ eg. $L \approx 2\ell$

$$\curvearrowleft_T \quad N\left(e + \frac{L}{2} - d\right) - C\left(L - d - \frac{x}{2}\right) = 0 \quad \Rightarrow x_{1,2}$$

$$\rightarrow \quad N + T - C = 0 \quad \Rightarrow T \text{ (used for ø of bolts)}$$

Elastic resistance



Elastic behaviour approach may be less conservative for design of the anchor bolts. Less common procedure.

Equilibrium conditions:

→ , ↷ } for elastic distribution σ

and ratio due to the elastic behaviour:

$$\frac{x}{f_{jd}} = \frac{L - d}{f_{jd} + \dfrac{T}{n\,A_a}}$$

Base plate

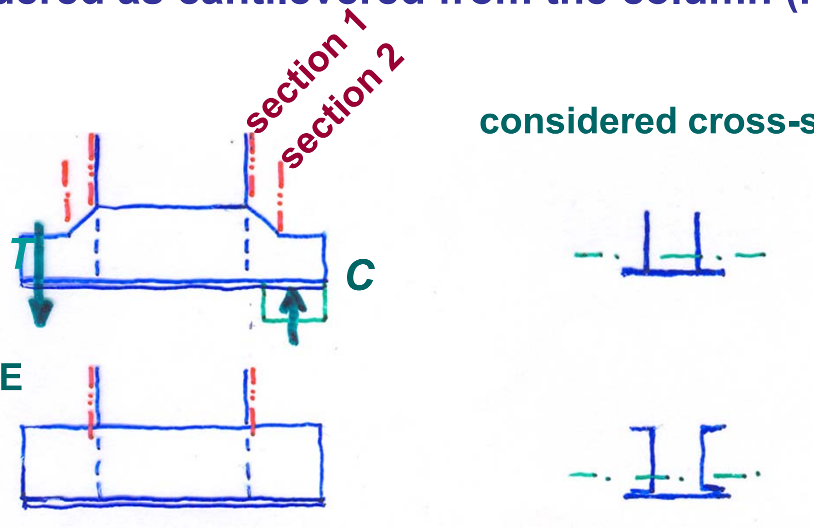
Choose thickness $t \Rightarrow$ effective width c

Calculated compressive reaction C (given by the effective area)

Base plate stiffeners

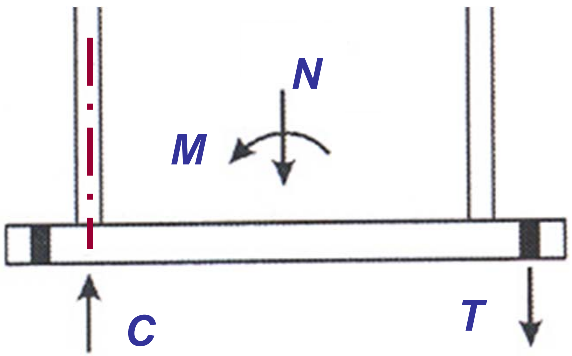
Verification of critical sections.
Stiffener considered as cantilevered from the column (its flange):

considered cross-section (*M*, *V*)



stiffeners may be plates or UPN/UPE

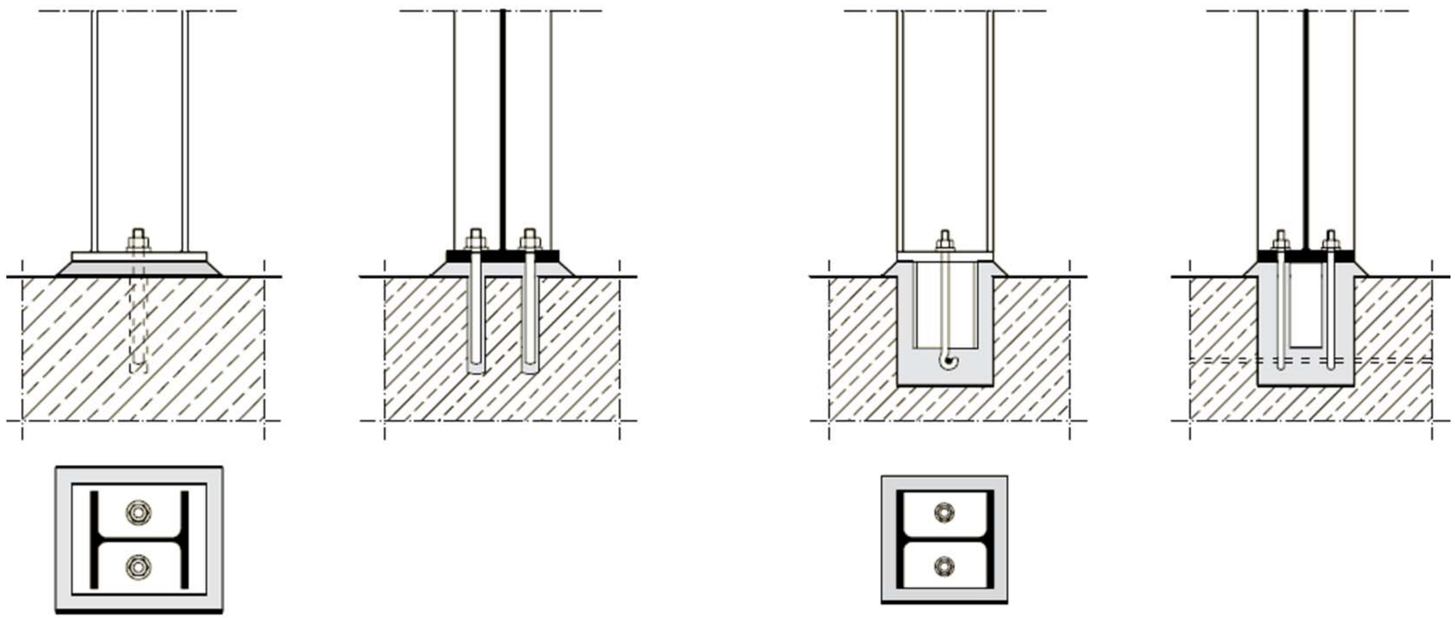
Smaller fixed base



Resistance of plain plate as for end-plate moment beam connection – equivalent T-stub connection.

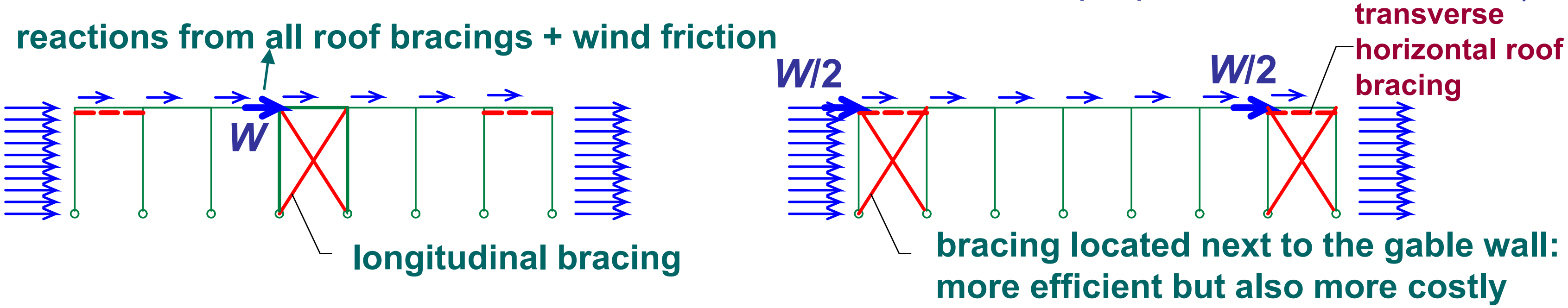
Prying forces may develop for relatively short bolts only.

Nominally pinned column bases in a portal frame



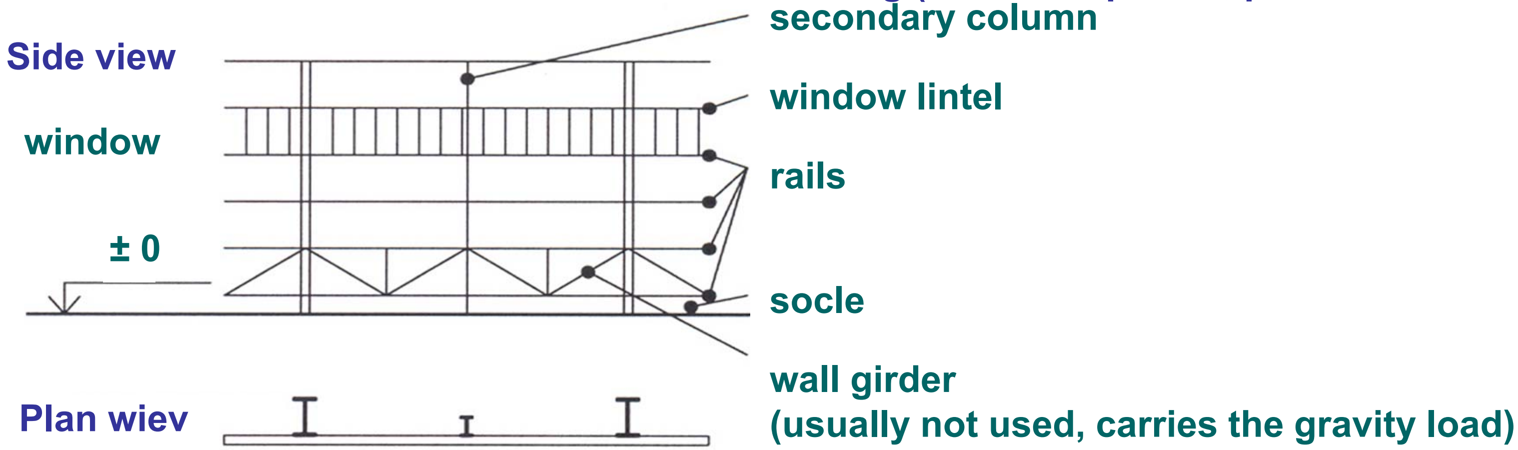
Vertical bracing, wall elements

Carry the wind pressure on gable wall and wind friction on the roof and parallel wall:
(Wind friction neglected when the total area of all surfaces parallel with the wind is equal to or less than 4 times the total area of all external surfaces perpendicular to the wind).

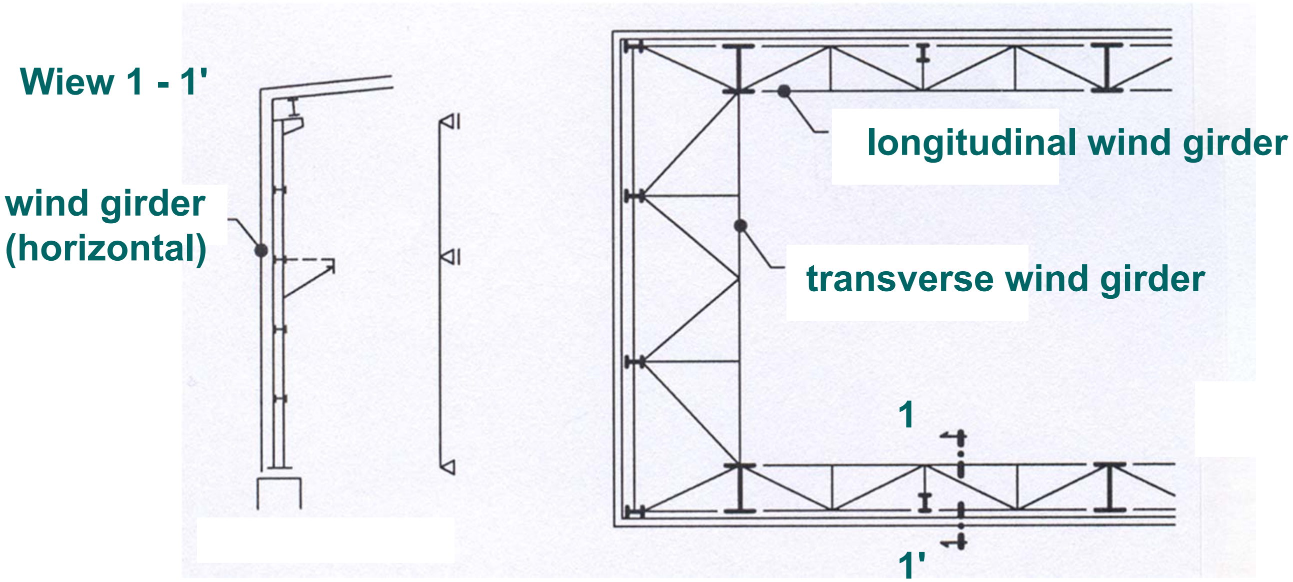


Wall supporting system

Steel substrate (rails, secondary columns) +
filling (masonry etc.),
cladding (sandwich panels, profiled sheeting…).



Tall wall



Rail design

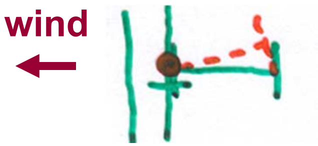
ULS: biaxial bending

example: hot-rolled I section (Class 1, 2), lateral torsional buckling restrained:

$$\left(\frac{M_{y,Ed}}{M_{y,Rd}}\right)^2 + \frac{M_{z,Ed}}{M_{z,Rd}} = \left(\frac{M_{y,Ed}}{W_{pl,y} f_y / \gamma_{M0}}\right)^2 + \frac{M_{z,Ed}}{W_{pl,z} f_y / \gamma_{M0}} \leq 1$$

if flange in compression not supported:

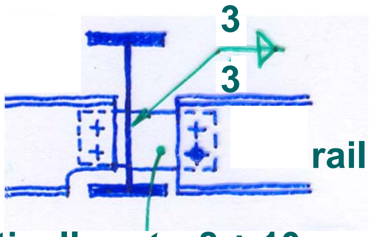
$$\frac{M_{y,Ed}}{\chi_{LT} W_{pl,y} f_y / \gamma_{M1}} + \frac{M_{z,Ed}}{W_{pl,z} f_y / \gamma_{M0}} \leq 1$$



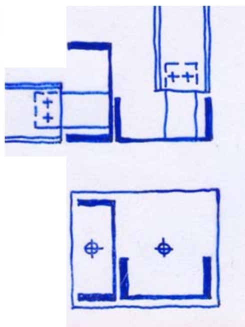
↳ **(lateral torsional buckling with imposed axis of rotation):**

SLS: $\delta_{max} \leq \frac{L}{250}$ (glassed wall $\delta_{max} \leq \frac{L}{300}$)

Rail to column connection

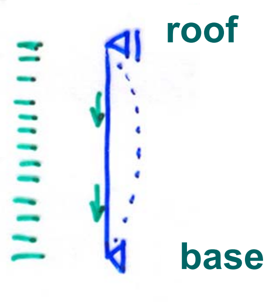


Gable wall side column



Gable wall column verification

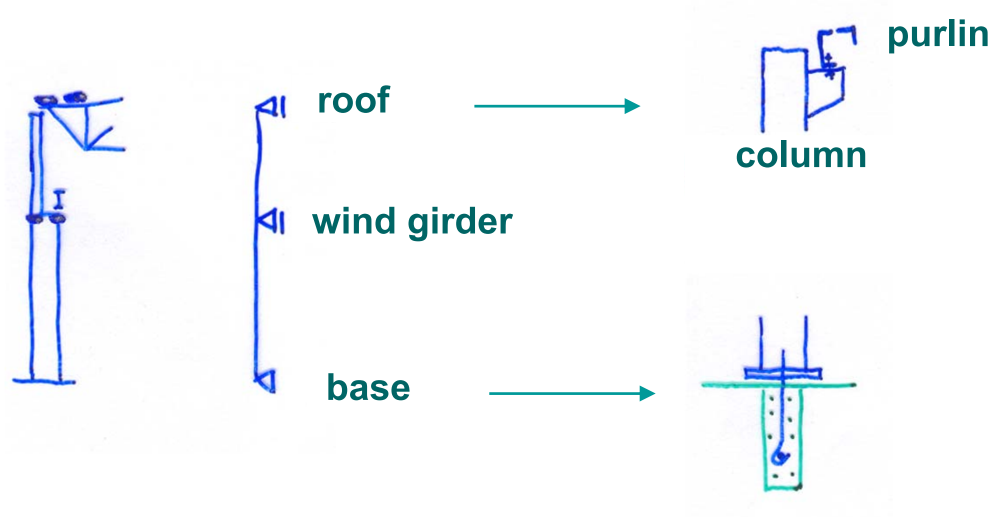
- **low wall**



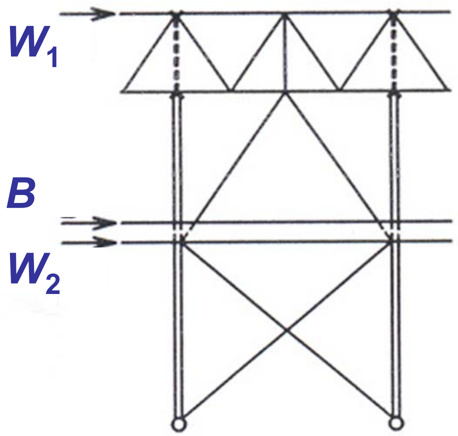
internal force *N*, M_y:

$L_{cr,y} = L$
$L_{cr,z}$ = rails distance (connected to bracings)

- **tall wall**



Tall industrial building with overhead cranes - additionally *B*, W_2:

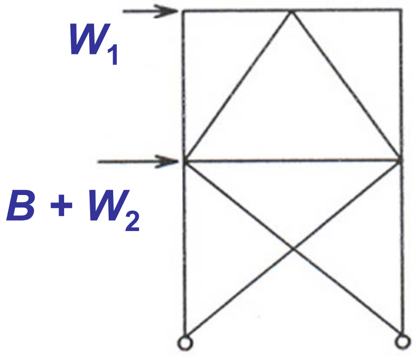


vertical bracing
roof bracing

vertical bracing
(wind only)

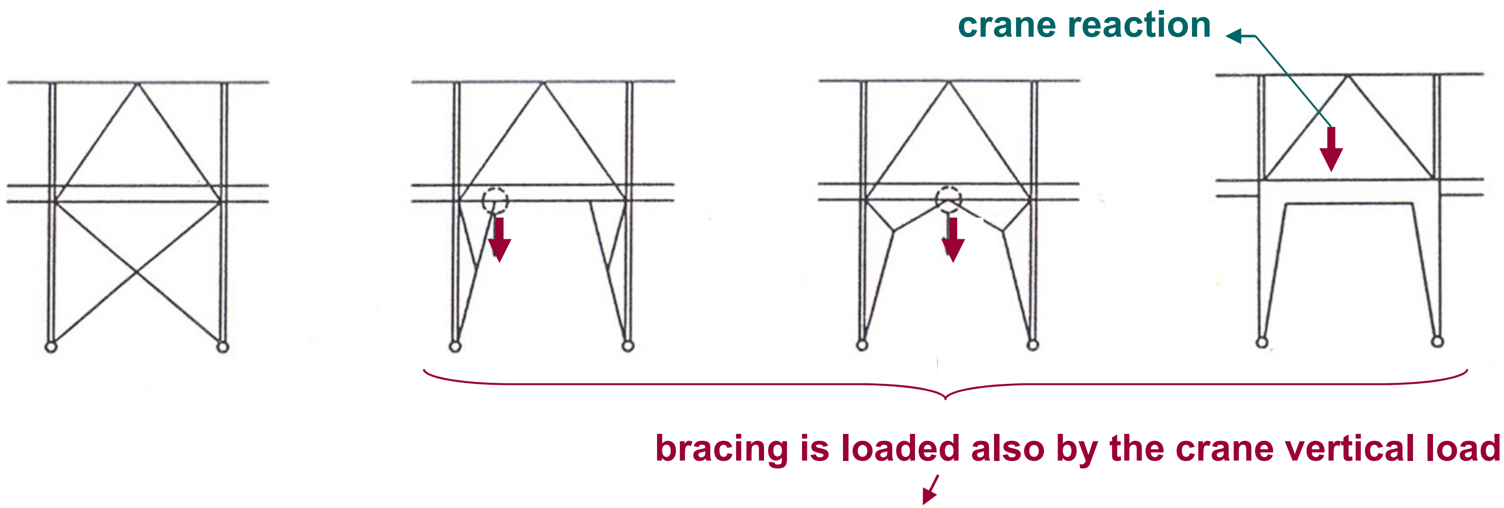
vertical bracing
(wind + crane braking
or acceleration)

structural system:

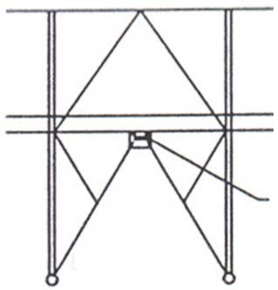


W_1 - horizontal roof bracing reactions + wind friction,
B - acceleration of braking of crab or hoist block ,
W_2 - horizontal girder reactions.

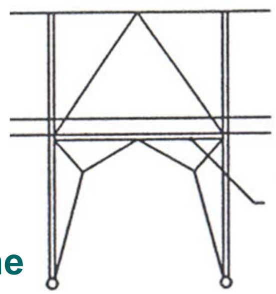
Vertical bracing geometry in the longitudinal direction:



Possible modification avoiding the increased internal forces:

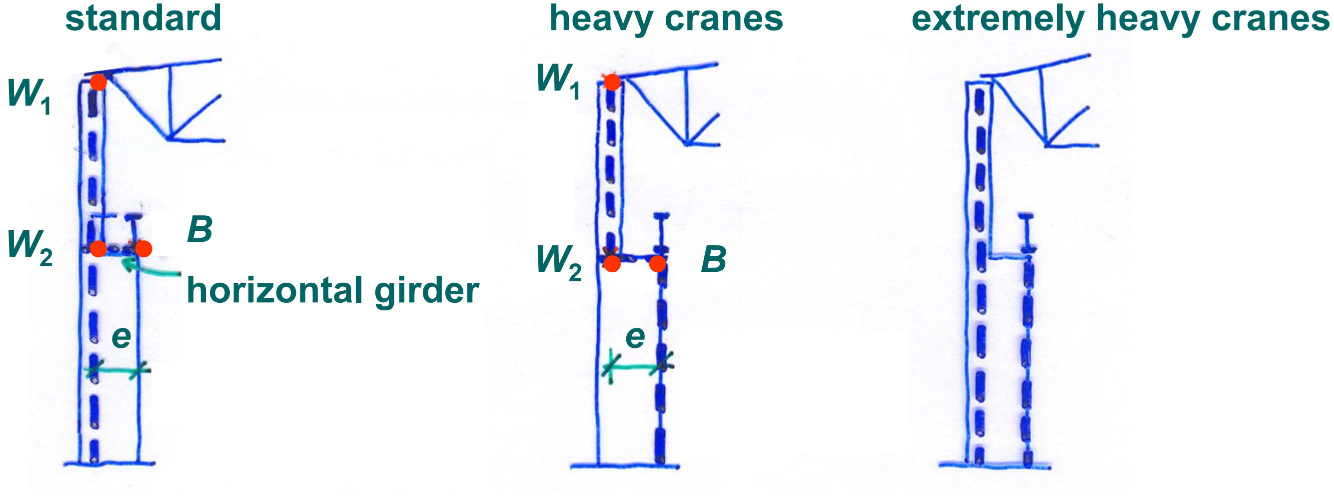


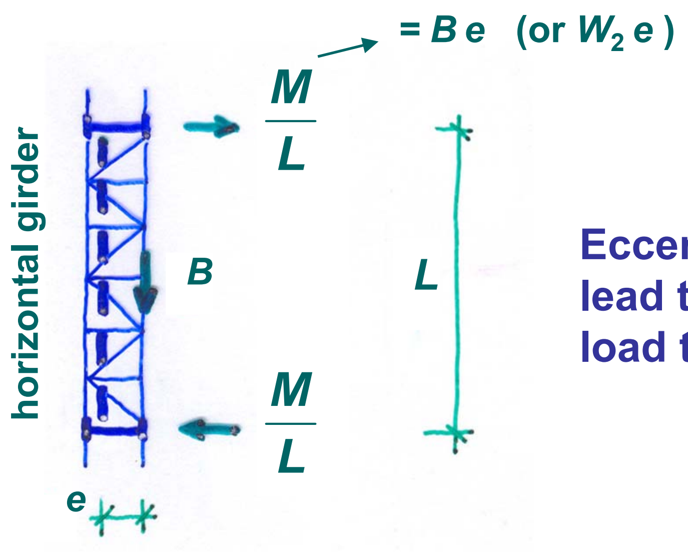
modified connection using slotted holes:
- free vertical deflection of the runway beam,
- but transfers horizontal load.



additional member under the runway beam

Vertical bracing for wind load and crane braking or acceleration :

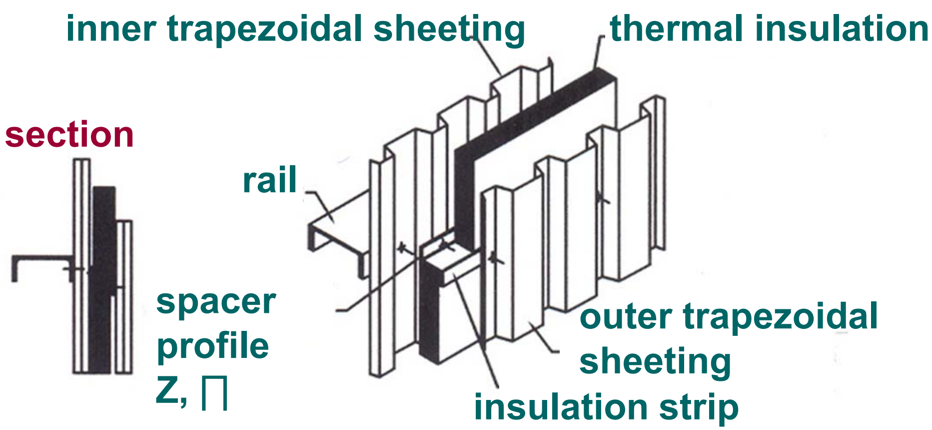


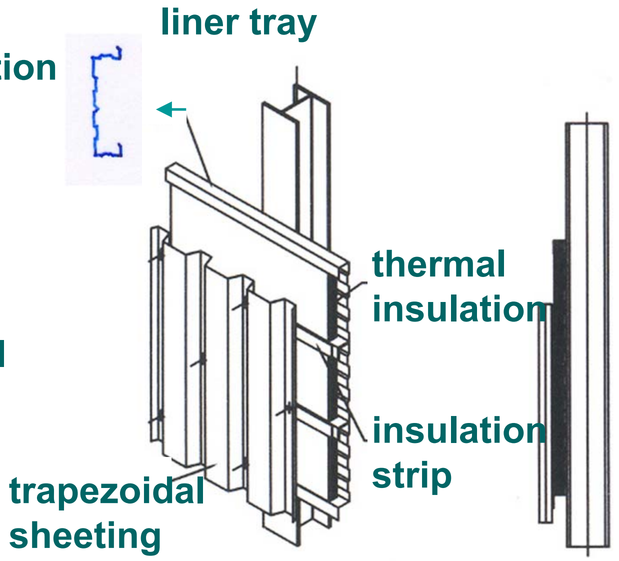


Eccentrically placed bracing lead to an additional horizontal load to the frame column.

Cladding

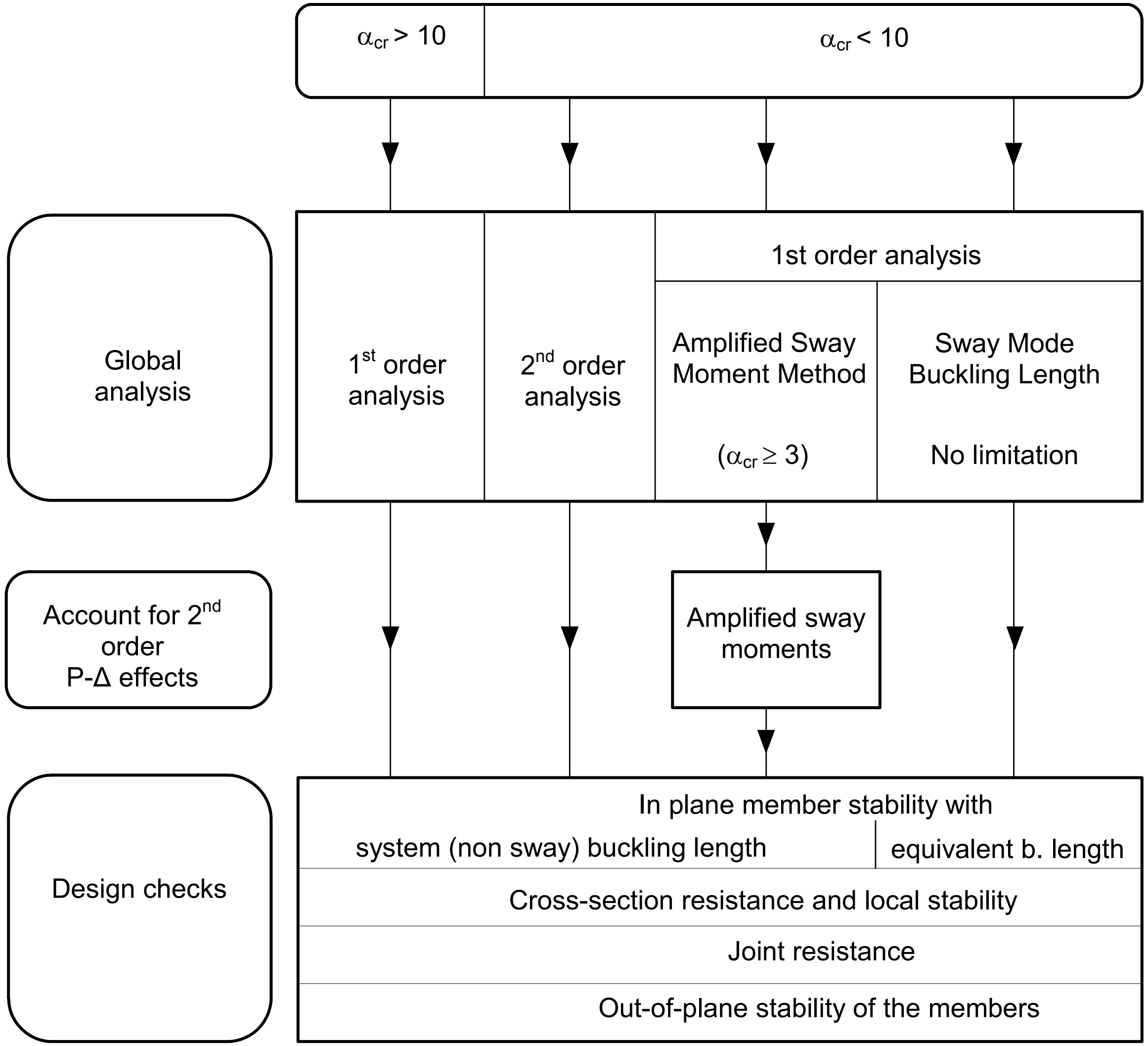
- masonry filling: thickness 15 cm, area < 18 m^2, not much used any more
- profiled sheeting (similarly for roofing):





- panels: sandwich panels mostly
  (connection to the rail similar to the roof panel – purlin connection)
- glass (glass panels connected to secondary supporting structure)

Global analysis - summary of possible approaches according to EN 1993-1-1

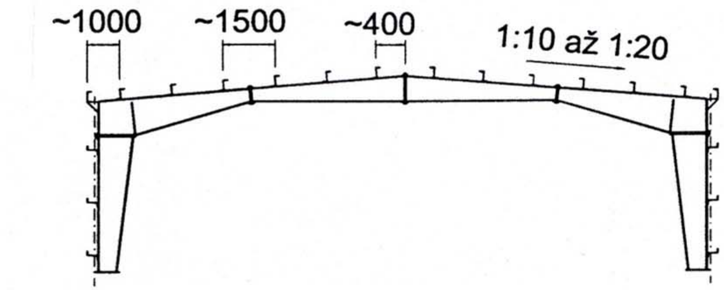


If GMNIA is used (both sway and member imperfections), no stability check (usually just in-plane) is necessary.

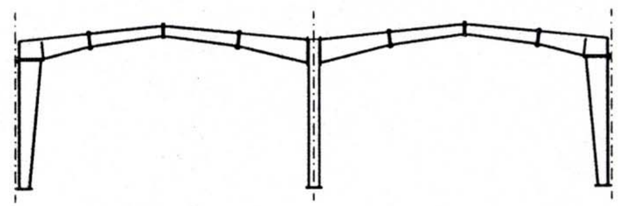
Frames

Cross sections of portal frames

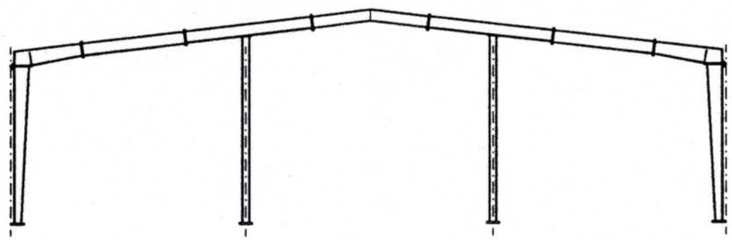
One-bay (portal) frame: span up to 80 m



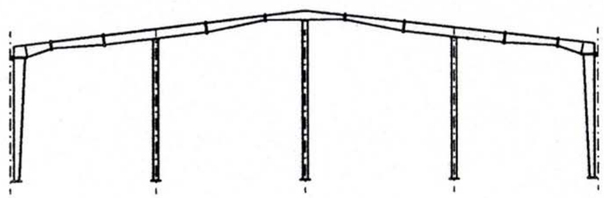
Two-bay frame: span up to 2x80 m



Three-bay frame: span up to 3x70 m

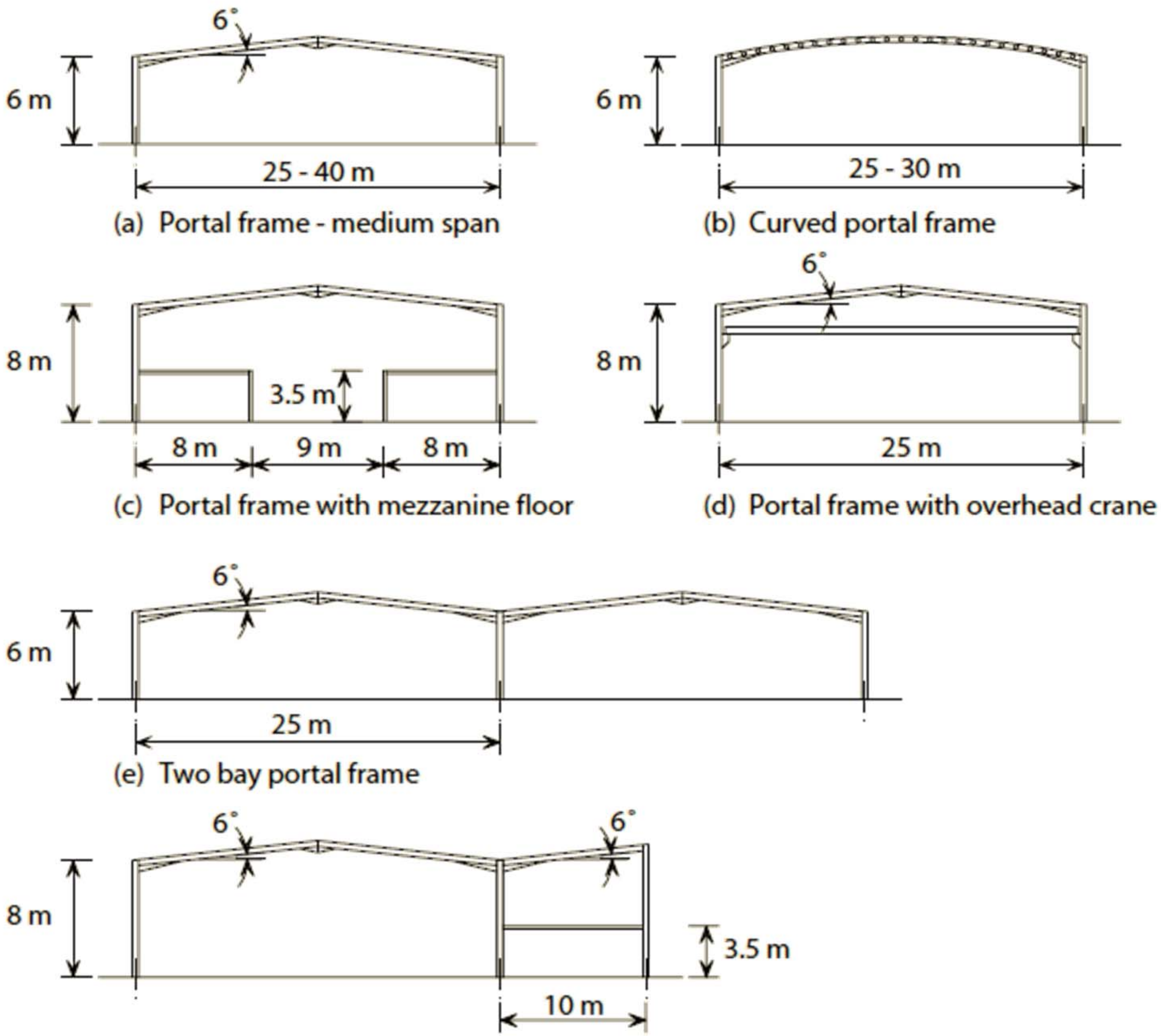


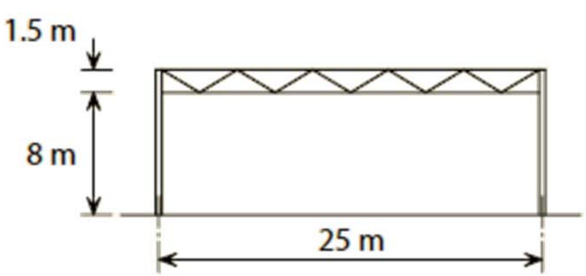
Four-bay frame: span up to 4x70 m



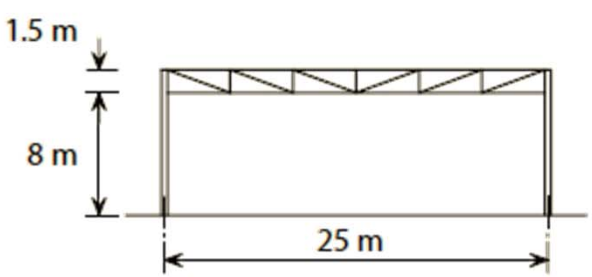
At present usually:

- **pinned based columns (or ”erection stiff”),**
- **site connections mostly with end plates and pretensioned bolts (instead of splices),**
- **haunched rafters and columns.**

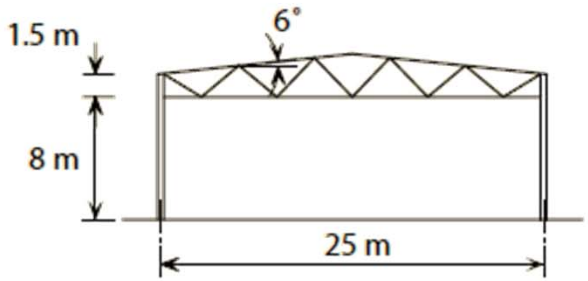

6°
6 m
25 - 40 m
(a) Portal frame - medium span
6 m
25 - 30 m
(b) Curved portal frame
8 m
3.5 m
8 m
9 m
8 m
(c) Portal frame with mezzanine floor
6°
8 m
25 m
(d) Portal frame with overhead crane
6°
6 m
25 m
(e) Two bay portal frame
6°
6°
8 m
3.5 m
10 m



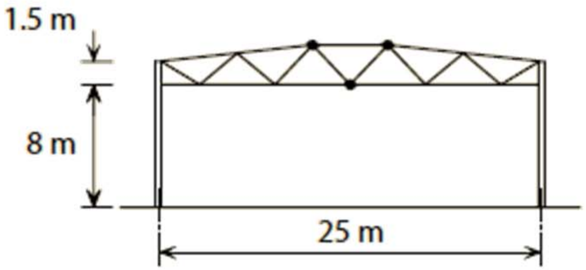
(a) Lattice girder - W form



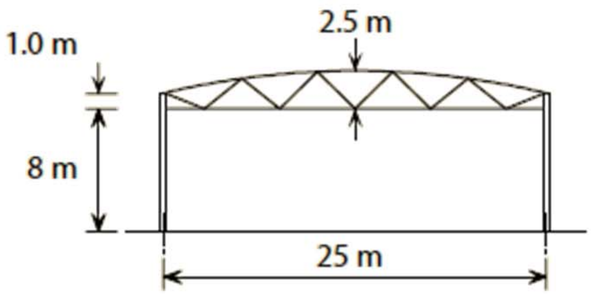
(b) Lattice girder - N form



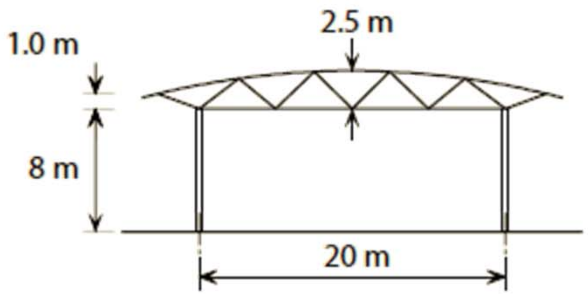
(c) Duo-pitch lattice girder



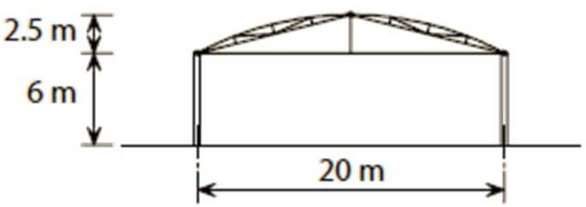
(d) Articulated lattice girder



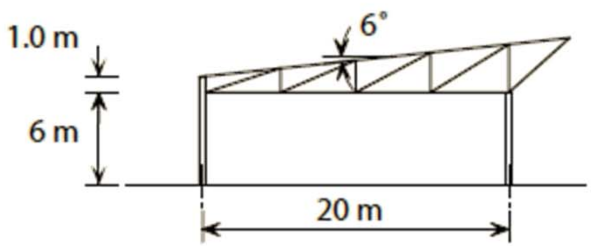
(e) Curved lattice girder



(f) Curved lattice truss and canopy

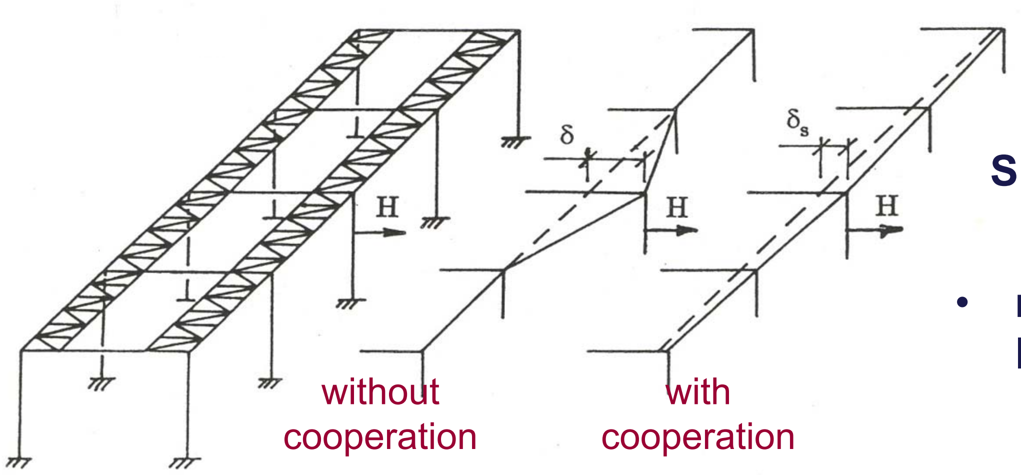


(g) Articulated bow-string



(h) Mono-pitch lattice girder with canopy

Space behaviour of frames



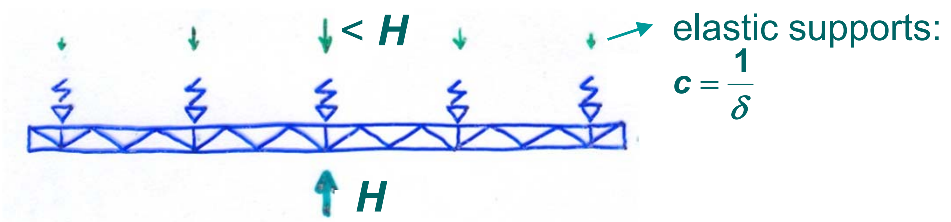
Substantial for local loading (e.g. cranes):

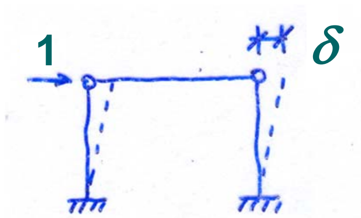
- **roof bracing distributes the loading to more mainframes**

Analysis:

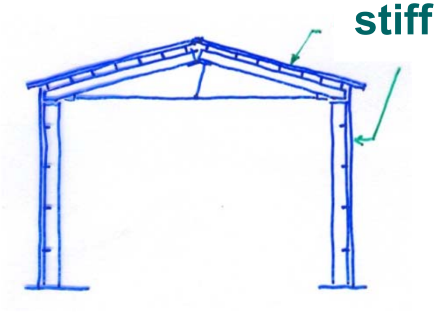
a) **Space analysis of the building as a whole (demanding);**

b) **Approximate analysis using continuous girder on elastic supports:**



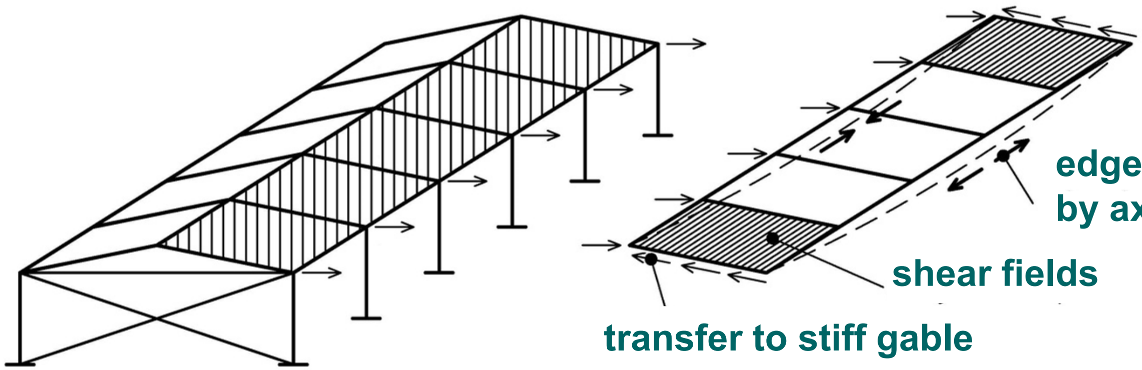


2. Stressed skin design



stiff cladding (trapezoidal sheeting, monolithic deck):

- acts as a web of high girder, the flanges of which are purlins (in side-walls rails);
- unloads mainframes, transfers the transvers horizontal loading to stiff gables;
- usually changes classification of frames for $\alpha_{cr} \geq 10$.



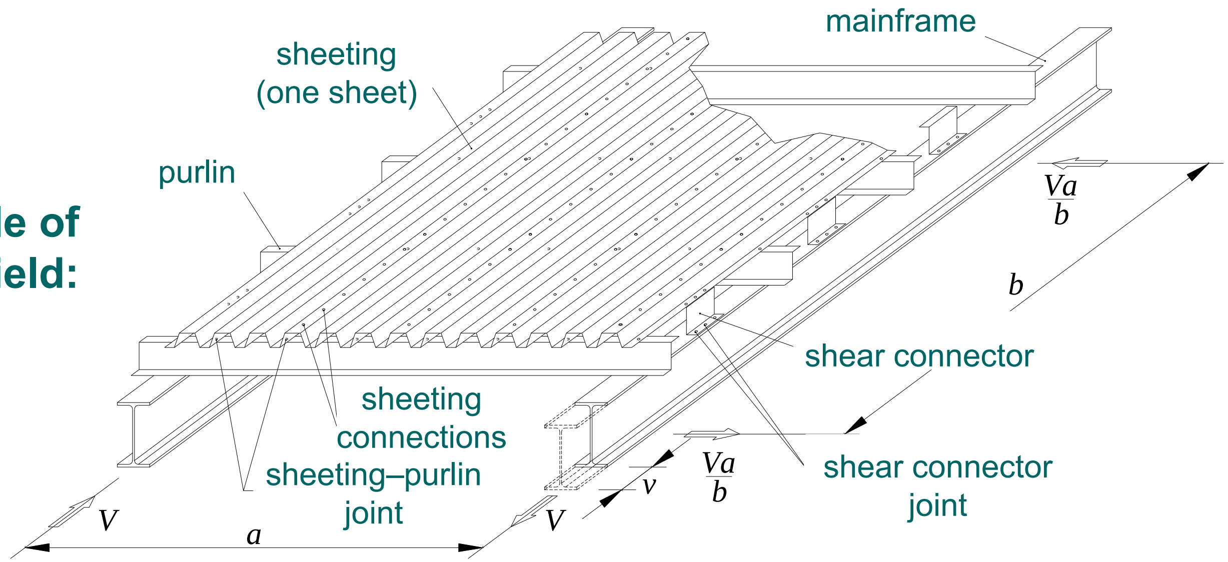
Requirements:

- during assembly the structure is non-stiff, secure by temporary bracings, props ...
- the cladding must be effective all the structure life (mind fire, rebuilding ...)
- suitable for short industrial buildings (*L*/*B* < 4), with stiff gables.

Design progress (demanding, usually for repeated use only):

- design of cladding for common bending loading,
- global analysis of non-sway frame (supported by stiff roof plane),
- subdividing the roof into shear fields (diaphragms),
- determination of shear strength and rigidity of the shear field including sheeting connections and joints (for design procedure see e.g. guideline ECCS No.88),
- determination of cladding effects (unloading of internal frames and design of the high web girder),
- design of gables.

Example of shear field:



Cranes

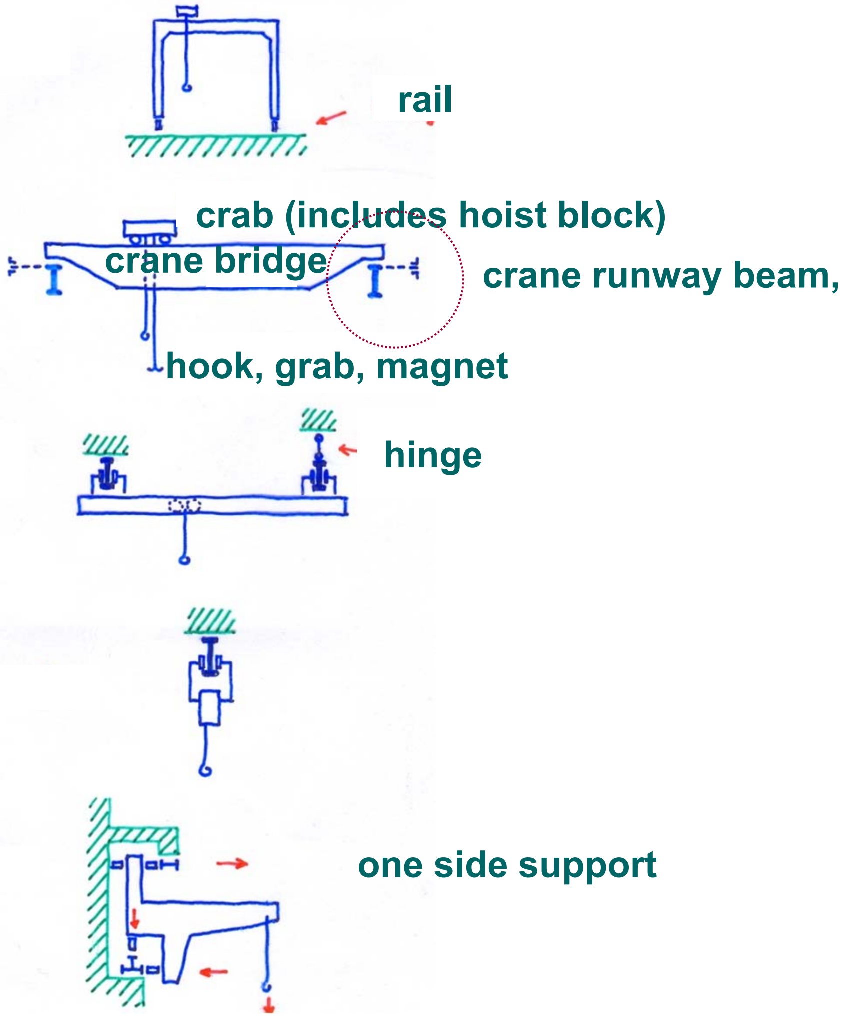
portal crane

overhead travelling crane (top-mounted)

underslung crane

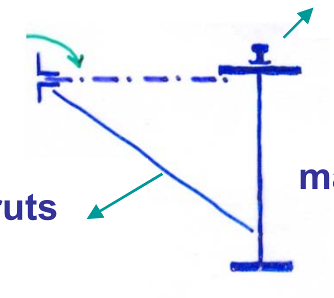
hoist

cantilever crane

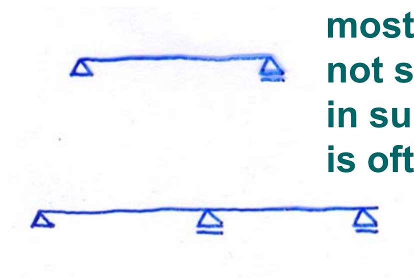


Overhead cranes

Crane runway beam

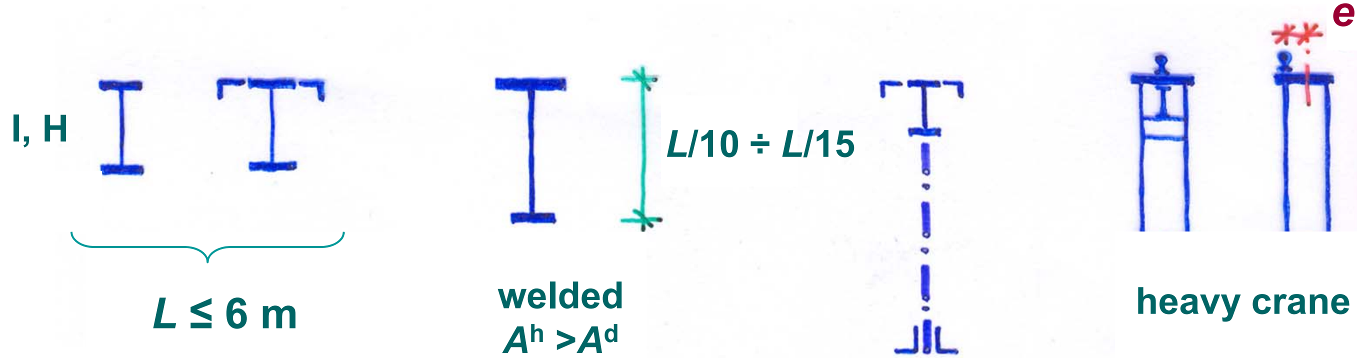


beam supports:



most common:
not sensitive for settling in support, but deflection is often limiting >> heavy

Main beam section



truss
for L> 15 m (expensive)

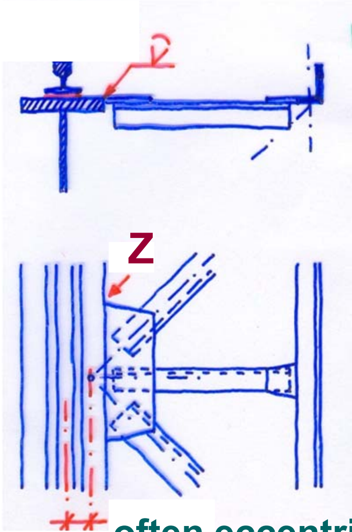
welded (up to12 m)

bolted (rarely)

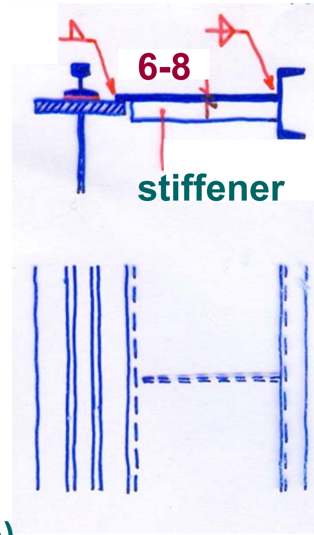
Horizontal girder:

not always needed (beam designed for torsion)

truss



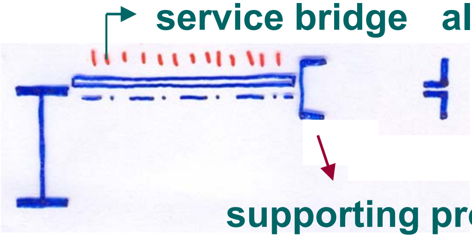
plate



often eccentrically (smaller plate)

Supporting end profile:

service bridge **alt.**

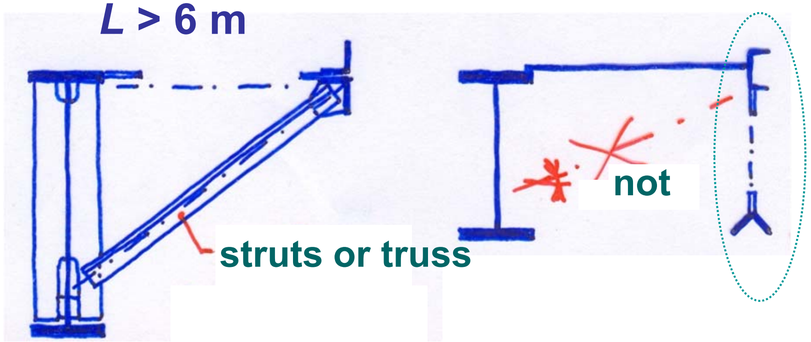


supporting profile

L **≤ 6 m**

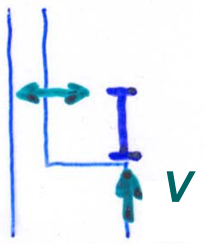
L **> 6 m**

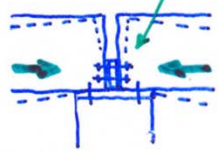
truss

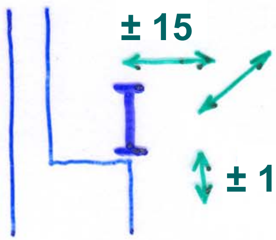


Crane beam connection

Connection requirements:





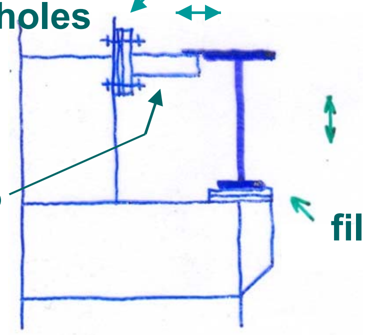


1. carry the reactions
2. free rotation
3. possible rectifying

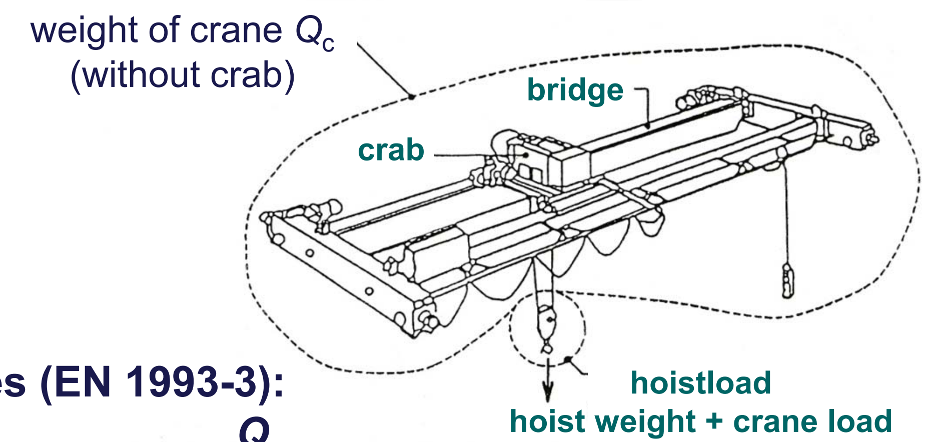
Rectifying principles:

a) Connection with bolts in tension

b) Connection using bolts in shear

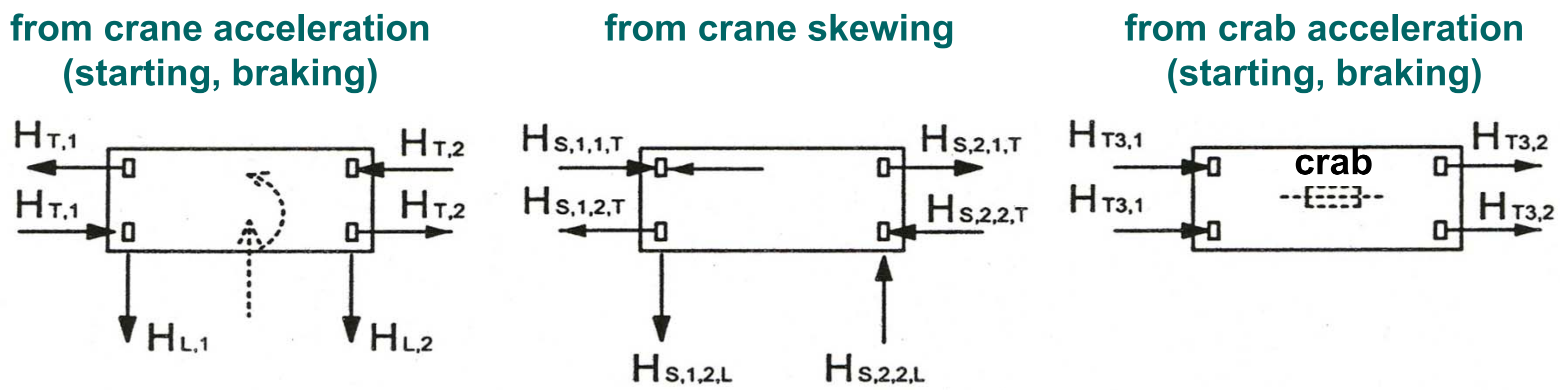


Loadings



Actions of overhead cranes (EN 1993-3):

- **selfweight of the crane** Q_c
- **variable:**
  - **- vertical action of cranes** Q_H **(hoist load given in crane tables)**
  - **- horizontal actions acts at rail vertex:**



- further loading (buffer loads, tilting loads, test loading ...)

Dynamic effects:

- introduced approximately by dynamic coefficients φ_1 up to φ_7:

e.g.: for vertical actions φ_1 up to φ_4, depends on hoisting speed, crane type ...

for drive horizontal actions φ_5 according to drive, etc.

SLS:

Generally is checked vibration.

Practical calculation consists in determination of deflections (δ_{max} < L/600 ≤ 25 mm).

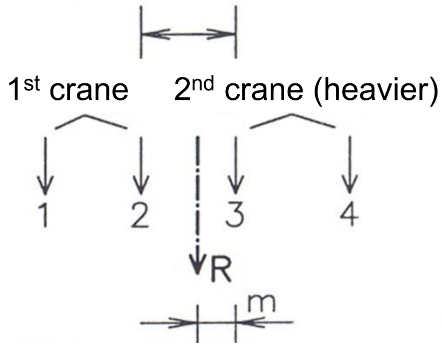
Global analysis

In case of moving loading the influence lines should be used. E.g. for M_{max} in section x the Winkler criterion is valid:

$$\sum F_i \lessgtr R\frac{x}{L}$$

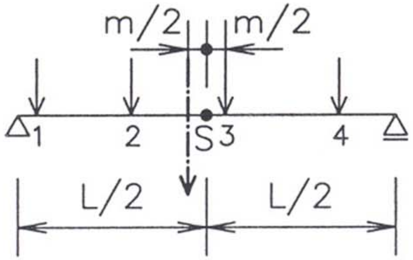
However, usually M_{max} and V_{max} within all girder length is required:

e.g. 4 forces

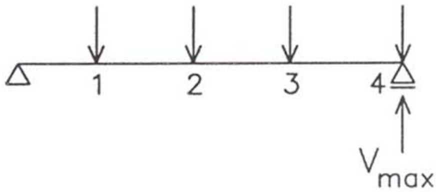


arithmetic mean load: P3

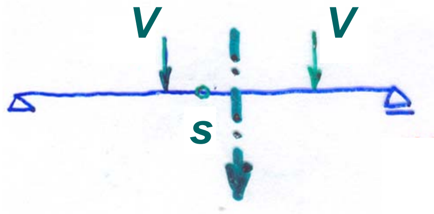
position for $M_{max} = M_3$



position for V_{max}



Example:

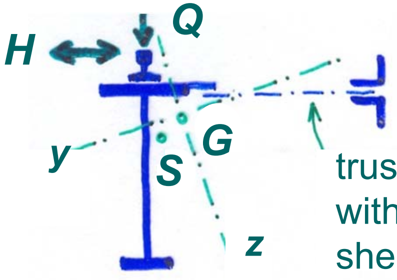


(necessary to try numerically)

Design of a crane runway beam

1. Correct design:

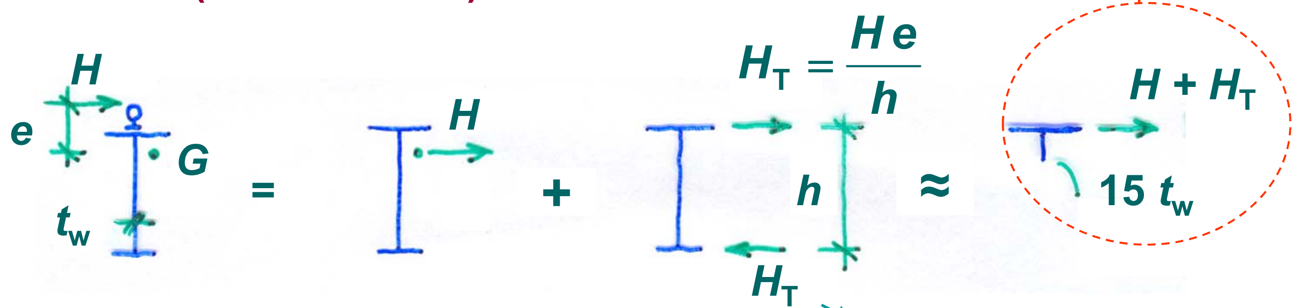
- requires space (3D) calculation, incl. torsion
(resulting internal forces $N, M_y, M_z, B, V_y, V_z, T_t, T_w$)



truss may be replaced by a plate with thickness t_{eff} of the same shear stiffenes

2. Approximate (conservative) introduction of *H*:

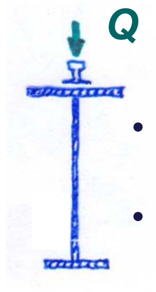
assign to upper flange



for design of bottom flange

3. Usual design (on unsafe side, torsion neglected):

Main girder:



- vertical loading (mind interaction of buckling due to *M*, *N*, *V*, *F*)
- longitudinal horizontal loading (implicates *N*, *M*)

Horizontal girder:

$15\ t_w$

- transverse horizontal loading

Fatigue of crane runway beams

Check for equivalent characteristic stress range (γ_{Ff} = 1,00):

For σ :
(similarly for τ)

$$\gamma_{Ff}\Delta\sigma_{E,2} \leq \frac{\Delta\sigma_C}{\gamma_{Mf}}$$

$\Delta\sigma_C$ ← "fatigue strength" for 2.10^6 cycles **according to category detail**

γ_{Mf} → 1,15

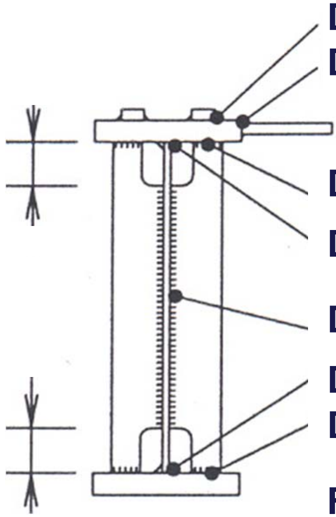
$\Delta\sigma_{E,2}$ ↓ **equivalent constant amplitude direct stress range**
(must be < 1,5 f_y including dynamic coefficient φ_{fat})

Equivalent constant amplitude stress range:

$$\Delta\sigma_{E,2} = \varphi_{fat}\,\lambda\,\Delta\sigma$$

- $\Delta\sigma$ → stress range caused by the fatigue loads acc. to EN 1991
- λ → damage equivalent factor, corresponding to 2×10^6 cycles (given by EN 1991-3 acc. to crane category)

Structural details (requirement: prevent notches)



max. 100 (buckling)

acc. need

DC 80

DC 45 up to DC 90 ⟶ plan view:

DC 80

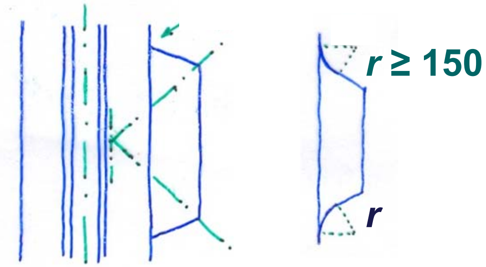
DC 112 (for manual weld DC 100)

DC 80

DC 112 (for manual weld DC 100)

DC 80

Detail category 40 DC 90



For web to flange fillet welds:

$\tau_{\parallel}$ → DC 80

$\tau_{\perp}$ and $\sigma_{\perp}$ → DC 36*

This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by Prof. Josef Macháček (CTU) and Michal Jandera, PhD. (CTU).

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European Commission
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