Single-storey industrial buildings

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Sustainable Constructions
under Natural Hazards and Catastrophic Events
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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
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. \( L \approx 2\ell \)

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

\[
N + T - C = 0 \quad \Rightarrow T \quad (used \ for \ \varnothing \ of \ bolts)
\]
Elastic resistance

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

Equilibrium conditions:

\[ \begin{align*}
\begin{cases}
\text{for elastic distribution } \sigma \\
\text{and ratio due to the elastic behaviour:}
\end{cases}
\end{align*} \]

\[ x = \frac{L - d}{f_{jd}} \left( f_{jd} + \frac{T}{n A_a} \right) \]

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):

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).

*reactions from all roof bracings + wind friction*

*longitudinal bracing*

*W/2*

*W/2*

*transverse horizontal roof bracing*

*bracing located next to the gable wall: more efficient but also more costly*

**Wall supporting system**

*Steel substrate (rails, secondary columns) +*

*filling (masonry etc.), cladding (sandwich panels, profiled sheeting...)*

*secondary column*

*window lintel*

*rails*

*socle*

*wall girder (usually not used, carries the gravity load)*

*Side view*

*Plan view*
Tall wall

Wiew 1 - 1'

wind girder (horizontal)

longitudinal wind girder

transverse wind girder

Rail design

wind load area

vertically supported wall

vertically unsupported wall
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

alternatively \( t \approx 8 \div 10 \text{ mm} \)

Gable wall side column

\[
\text{base plate}
\]
Gable wall column verification

- low wall

  internal force $N, M_y$:

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

- tall wall
Tall industrial building with overhead cranes - additionally $B$, $W_2$:

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

**Structural system:**

- $W_1$
- $B + W_2$
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:

- **Standard**
  - $W_1$
  - $W_2$
  - Eccentrically placed bracing lead to an additional horizontal load to the frame column.

- **Heavy Cranes**
  - $W_1$
  - $W_2$

- **Extremely Heavy Cranes**

**Load Distribution**

![Diagram showing load distribution for different types of cranes](image)

- $W_1$
- $W_2$
- $L$
- $M$
- $M/L$
- $B$
- $e$
- $= Be$ (or $W_2 e$)
Cladding

• masonry filling: thickness 15 cm, area < 18 m², not much used any more

• profiled sheeting (similarly for roofing):
  - inner trapezoidal sheeting
  - thermal insulation
  - outer trapezoidal sheeting
  - insulation strip
  - liner tray
  - trapezoidal sheeting
  - thermal insulation
  - insulation strip

• 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

<table>
<thead>
<tr>
<th>$\alpha_{cr} &gt; 10$</th>
<th>$\alpha_{cr} &lt; 10$</th>
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</thead>
<tbody>
<tr>
<td>1st order analysis</td>
<td>1st order analysis</td>
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<tr>
<td>2nd order analysis</td>
<td>Amplified Sway Moment Method</td>
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<tr>
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<td>Sway Mode Buckling Length</td>
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<tr>
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<td>($\alpha_{cr} \geq 3$)</td>
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</tbody>
</table>

- Amplified sway moments
- In-plane member stability with system (non sway) buckling length equivalent b. length
  - Cross-section resistance and local stability
  - Joint resistance
  - Out-of-plane stability of the members

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.
Lattice girder - W form

Lattice girder - N form

Duo-pitch lattice girder

Articulated lattice girder

Curved lattice girder

Curved lattice truss and canopy

Articulated bow-string

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:

\[ c = \frac{1}{\delta} \]
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
- rail
- crab (includes hoist block)
- crane bridge
- crane runway beam, hook, grab, magnet
- hinge
- one side support
Overhead cranes

Crane runway beam

Horizontal girder

Struts

Main beam

Rail (rail profile)

Beam supports:

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

Main beam section

I, H

$L \leq 6 \text{ m}$

Welded $A_h > A_d$

$L/10 \div L/15$

Truss for $L > 15 \text{ m}$ (expensive)

Heavy crane
**Horizontal girder:**
not always needed (beam designed for torsion)

- truss
- plate

**Supporting end profile:**
- service bridge
- supporting profile

- welded (up to 12 m)
- bolted (rarely)

- L ≤ 6 m
- L > 6 m
- struts or truss
- truss
- often eccentrically (smaller plate)
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:
    - from crane acceleration (starting, braking)
    - from crane skewing
    - from crab acceleration (starting, braking)

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

weight of crane $Q_c$
(without crab)
Dynamic effects:
- introduced approximately by dynamic coefficients $\varphi_1$ up to $\varphi_7$:
  e.g.: for vertical actions $\varphi_1$ up to $\varphi_4$, depends on hoisting speed, crane type ...
  for drive horizontal actions $\varphi_5$ according to drive, etc.

SLS:
Generally is checked vibration.
Practical calculation consists in determination of deflections ($\delta_{\text{max}} < L/600 \leq 25 \text{ mm}$).

Global analysis
In case of moving loading the influence lines should be used. E.g. for $M_{\text{max}}$ in section $x$
the Winkler criterion is valid:
$$\sum F_i \leq R \frac{x}{L}$$
However, usually $M_{\text{max}}$ and $V_{\text{max}}$ within all girder length is required:
  e.g. 4 forces

1st crane       2nd crane (heavier)
\[\begin{array}{cccc}
1 & 2 & 3 & 4 \\
\end{array}\]

arithmetic mean load: $P_3$

\[\begin{array}{cccc}
\Delta_1 & 2 & S_3 & 4 \\
\end{array}\]

position for $M_{\text{max}} = M_3$

\[\begin{array}{cccc}
\Delta & 1 & 2 & 3 & 4 \\
\end{array}\]

position for $V_{\text{max}}$

\[\begin{array}{cccc}
m/2 & m/2 & m/2 & \text{L/2} \\
\end{array}\]
Example:

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 $H$:

   $H_{T} = \frac{He}{h}$

   $H + H_{T} \approx 15t_{w}$

   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:**
- Transverse horizontal loading

**Fatigue of crane runway beams**

**Check for equivalent characteristic stress range ($\gamma_{Ff} = 1.00$):**

For $\sigma$:

$\gamma_{Ff} \Delta \sigma_{E,2} \leq \frac{\Delta \sigma_C}{\gamma_{Mf}} \Rightarrow 1.15$

Equivalent constant amplitude direct stress range

(must be $< 1.5 f_y$ including dynamic coefficient $\rho_{fat}$)
Equivalent constant amplitude stress range:

\[ \Delta \sigma_{E,2} = \varphi_{\text{fat}} \lambda \Delta \sigma \]

- \( \varphi_{\text{fat}} \lambda \Delta \sigma \) stress range caused by the fatigue loads acc. to EN 1991
- \( \lambda \) damage equivalent factor, corresponding to \( 2 \times 10^6 \) cycles (given by EN 1991-3 acc. to crane category)

Structural details (requirement: prevent notches)

- DC 80
- DC 45 up to DC 90
- DC 112 (for manual weld DC 100)
- DC 80
- DC 112 (for manual weld DC 100)
- DC 80

For web to flange fillet welds:

- \( \tau_{||} \rightarrow \text{DC 80} \)
- \( \tau_{\perp} \) and \( \sigma_{\perp} \rightarrow \text{DC 36}^* \)
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