Single-storey industrial buildings

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Lecture 9: 21/02/2014

European Erasmus Mundus Master Course
Sustainable Constructions
under Natural Hazards and Catastrophic Events
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Content

- Configurations, roof structure, roof bracings.
- Roof structure: decking, purlins, rafters.
- Column base plates, vertical bracing of longitudinal walls and gables, wall elements (cladding, posts, columns, rails, cassettes, bracings).
- Classification (second order effects) of structures
- Frames, detailing, space behaviour of halls.
- Design of crane runway beams.
Part I – Industrial buildings

Configurations, roof structure, roof bracings

Function

- protection against climatic effects
- arrangement of operation = traffic tracks

Categories of halls:

- **Standard**
  - ⊕ low cost (budget price)
  - ⊕ fast available - provided from stock
  - Θ lack of flexibility (difficult to adapt)
  - Θ light cranes only (if any…)

- **Purpose-made**
  - ... suitable for given production, use
  - (e.g. heavy cranes, lightening, ventilation ...)

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L9 - 2C08 Single storey Industrial buildings
Terminology

- one-bay
- two-bay
- more-bay (longitudinal and transverse bays)

Crane overlap

Frame spacing \( \ell \)

Bay span \( L \)
Terminology of cross section with roof truss

alt. 1
Hot rolled purlins and rails

alt. 2
Thin-walled purlins and cassettes
Example of a two-bay frame industrial hall

Translucent lights
Ventilators
Mainframe
Side rails
Purlins
Roof cladding
Doors
Wall cladding
Insulation
Gutters
Foundations
Vertical wall bracing (rafter bracing in roof)
Rail bracing

by courtesy of
Dowling – Knowles – Owens:
Structural Steel Design 1988
Cross-section of halls (i.e. common frames and gables)

1. Cross sections (with hinged supported rafter/truss, hinged/fixed base)
   
   - in roof support by bracing is necessary (transfer to gables)

2. Frames
   
   - Pitched portal frames:
     - two-hinged, three-hinged, built-in, combinations
     - small basements,
     - aesthetical structure,
   
     • sensitive to settling of supports and temperature effects
     • at crane halls: crane vibrations up to roof
3. Gables

Solution

- common frame with additional framing

- gable wall
  - hall may easily be extended
  - the frame is heavy, expensive

- gable bearing wall: gable posts + rails + rafter + bracings

static scheme of the column

- gable rafter
- gable posts
- bracing („truss tower“)
Longitudinal direction of halls

Dilatation segments:

The temperature effect on bearing behaviour may be neglected for this arrangement.
**Roof bracings** (bracings in the space of roof trusses)

1. **transversal bracings** (always, transfers wind from gables to wall vertical bracings)
2. **longitudinal bracings** (occasionally, but always suitable for keeping geometry)
3. **vertical roof bracings** (securing verticality of trusses, not used for portal frames)

- Sometimes: - ties or props between purlins,
  - bracings at level of bottom chords of trusses.

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**Transversal (rafter) bracing ①:**
- by gables,
- intermediate (max. gap 36 m).

**Longitudinal bracings ②:**
- max. 12 m

**Vertical bracing ③:**
- above supports (if the truss is laid on bottom chord)
- at apex (or ≤ 12 m)
Roof structure: decking, purlins, rafters

Roof decking

- **single-layer roofs**
  - Unvented
  - Vented
  
  (common, suitable for relative humidity < 75 % at 20ºC)

- **double-layer roofs** (particularly for higher humidity)

Composition

- **roofing (determines roof slope, sometimes self-supporting)**
  - waterproof coating (0-18%): asphalt strips, foil strips, seamless coating …,
  - or cladding: formerly corrugated sheeting and eternit (18 %), nowadays thin-walled sheeting (min. 10 %, jointless 5 %).

- **complementary layers**
  - insulation, roof underlay, steam-proof, microventing etc.,

- **bearing layer**
  - usually steel sheeting (also as a sandwich part), silicate panels,
  - formerly also corrugated sheeting, eternit, timber formwork etc.
  - presently usually fabricated sandwiches of various fabricators.
Bearing layer

1) Trapezoidal sheeting economic spans \( L = 1 \div 3 \text{ m} \) (up to 6 m)
   - usually galvanized 275 g/m².
   - superior with additional coating of polyester 15-25 \( \mu \text{m} \),
   - perfect protection PVDF 25 \( \mu \text{m} \),
   - or also protection against mechanical damage: PVC 200 \( \mu \text{m} \).

fixing to purlins:
   - self-tapping screws
   - cartridge fired pins

sidelap connection between sheeting:
   - blind rivets
   - special bolts for sheeting \[ \text{max. at } 500 \text{ mm} \]

(welding inadmissible due to corrosion; possible if embedded in concrete only)

Typical arrangements:
   • without insulation
- **insulated**
  - cladding from thin-walled sheeting (steel, aluminium, stainless steel)

  ![Distance profile](image1)

  or

  ![Steam-proof barrier](image2)

  breaking of thermal bridge
  (self-adhesive tape 30x8 mm)

- with waterproof coating

  ![Roof with purlins](image3)

  ![Roof without purlins](image4)

  - Sandwich panels

  ![Many types](image5)

  many types, e.g.
2) Silicate slabs
   • reinforced/prestressed concrete slabs \((L \approx 3 \text{ m})\) or panels \((L \approx 6 \text{ m})\),
   • reinforced light concrete slabs (cellular concrete, liapor - keramzite, etc).

3) Corrugated sheeting, eternit, others

3) Translucent panels
   • polycarbonate plates planar, corrugated, lenses, skylights,
   • glass in grid structure.

**Purlins** - support cladding or decking

position of purlins:
- web purlins: \(\perp\) to roof plane
- lattice purlins: vertically
### Survey of purlins and usual application:

<table>
<thead>
<tr>
<th>Statically structure</th>
<th>Suitable span</th>
<th>Common</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple girder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>thin-walled Z, C, zeta, sigma</td>
<td>6 m</td>
<td>-</td>
</tr>
<tr>
<td>hot-rolled IPE</td>
<td>6 m</td>
<td>-</td>
</tr>
<tr>
<td>lattice</td>
<td>≥ 12 m</td>
<td>yes</td>
</tr>
<tr>
<td>castellated</td>
<td>≥ 9 m</td>
<td>-</td>
</tr>
<tr>
<td>Continuous girder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>thin-walled Z, C, zeta, sigma</td>
<td>6 ÷ 8 m</td>
<td>yes</td>
</tr>
<tr>
<td>hot-rolled IPE</td>
<td>6 ÷ 8 m</td>
<td>yes</td>
</tr>
<tr>
<td>Hinged (Gerber's) girder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hot-rolled IPE</td>
<td>6 ÷ 9 m</td>
<td>-</td>
</tr>
<tr>
<td>Propped and suspended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hot-rolled IPE, thin-walled</td>
<td>9 ÷ 12 m</td>
<td>-</td>
</tr>
</tbody>
</table>

### Loading:

\[ F_w (\text{wind}) \]

\[ g (\text{self weight}) \]

\[ s (\text{snow}) \]

\[ q (\text{live loading}) \]

\[ Q (\text{single load}) \]

### Checks:

**ULS**

**SLS:**

\[ \delta_2 \leq \frac{L}{200} \]

Walkable roofs:

Frequency \( f_1 \approx \delta_{\text{max}} \leq 28 \text{ mm} \)
Hot-rolled purlin

Generally loaded in bi-axial bending and torsion (giving $\sigma$, $\tau$)

For bending, the verification can be done using:

$$\frac{M_{y,Ed}}{\chi_{LT} W_y} + \frac{M_{z,Ed}}{W_z} + \frac{B_{Ed}}{W_w} \leq f_y / \gamma_{M1}$$

Roof cladding/decking however has great bending stiffness:

This curvature is small (see EN 1993-1):
- given by bending stiffness $EI_{cladding}/L$
- by stiffness of connection

Therefore, usual assumption is:

$\chi_{LT} = 1$ no lateral-torsional instability occurs,
$B = 0$ no torsion occurs (but attention at steep slopes!!).

According to the roof cladding/decking plate stiffness, the roofs are:

- **non-rigid** (deflection as in the picture),
- **rigid** (deflection in the roof slope direction is negligible).
a) Non-rigid roofs

- assembly stages of rigid roofs, great slopes of roofs,
- trapezoidal sheeting not sufficiently connected in sidelaps and to purlins,
- non-rigid bearing layer (translucent soft panels, fragile eternit, etc.).

Biaxial bending arises due to deflection \((M_y, M_z)\).

E.g. for intermediate purlin, small shear, Class 2 of cross-section:

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

can be reduced by ties

b) Rigid roofs

- silicate roofs after imbedding,
- trapezoidal sheeting: - with sidelap connection at \(\leq 500\) mm,
  - connected to purlins at \(\leq 300\) mm.

Due to deflection arises only bending about \(y\) \((M_y)\).

E.g. similarly as above:

Class 2 cross-section: \(M_{y,Ed} \leq M_{c,Rd} = W_{pl}f_y / \gamma_{M0}\)

Class 4 cross-section: \(M_{y,Ed} \leq M_{c,Rd} = W_{eff}f_y / \gamma_{M0}\)
Loading in slope direction \( (q_z) \) of rigid roofs is transferred by roof plate to:

- a. eaves purlin,
- b. eaves bracing,
- c. connection at apex (namely in thin-walled purlins),
- d. connection of roof plate to rafters (particularly in roofs without purlins).

a) Eaves purlin (loaded from smaller loading width in comparison to intermediate purlin)

\[
\begin{align*}
q_z \quad \Rightarrow \text{loaded in bi-axial bending}
\end{align*}
\]

b) Eaves bracing (suitable for greater roof width)

\[
\begin{align*}
q_z/2 \quad \Rightarrow \text{the purlin profiles usually as for intermediate purlins}
\end{align*}
\]
**Ties for reduction of moment $M_z$ in non-rigid roofs:**

- **Principle:**
  - bending $M_y$
  - bending $M_z$

- **Note:** In non-rigid roofs, the eaves purlin is loaded as intermediate purlins, but with smaller loading width.

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**Tie structure:**
- rod bar
- prop profile L
- thin walled latch lock
Purlin to rafter connection (standardized dimensions in tables):

assembling bolt

(upper chord of rafter)

Apex purlin:

small slope
g + s

greater slopes
\( g + s_1 \)
\( g + s_2 \)

aggravating of apex purlin by tie:
both-sided snow

transfer of loading \( q_z \)
sheet
clips
ties

one-sided snow
Thin-walled cold-formed purlins

Profiles according to fabricators:

• Class 4 cross sections (EN 1993-1-3),
• exceptionally according to test results, incl. plasticity.

Design:

Resistances / admissible loadings commonly available in tables.

Systems:

1. Staggered purlins running continuously over two spans

2. System with sleeves

Example: Support for continuous cold-formed Z-shaped purlin
**Example**

All lap lengths are to be a minimum of 0.1 of the maximum span, measured from bolt centre to bolt centre each end of the lap, positioned equally each side of the portal rafter.

\[
L = \text{Span length}
\]
Example
www.Lindab.com

Overlapped + additional profile in 1st and last span
Continuous hot-rolled purlin over 2 spans

When Class 1 cross section, plastic global analysis is available (redistribution of moments using kinematic mechanism).

Check for rigid roofs: $M \leq M_{b,Rd}$

Continuous purlins are usually staggered to ensure the same loading of main frames. The reactions are: $0.375 \, qL + 1.25 \, qL + 0.375 \, qL$

Advantages:
- redistributed moments are 31% lower,
- deflections are approx. 40% lower.
Hinged purlins (Gerber’s girder)

Pins are usually in staggered spans (suitable for assembly).

Choice of pin location (c) depends on whether ULS or SLS decides:

- to balance moments $c \approx 0.15 \ L$  \quad (M = 1/16 \ qL^2)

- to balance deflections $c \approx 0.21 \ L$

Detail of hinge:
(in acc. to roof slope)
Lattice purlins (joists)

- parallel chords

- parabolic bottom chord

Light girders without gusset plates, fabricated in production lines
Height $h \sim L/15$ up to $L/20$
Critical length of diagonals $l_{cr} \sim l$ between chords.
Propped and suspended purlins

- **propped**

(The system also provides for the stability of the framework)

- **suspended**
  (Zeppelin roofs)

The system is statically indeterminate (use software or design tables):

+ Light, substitute vertical roof bracings.
- Laborious, unaesthetic.
Roof rafters/main frames

Support purlins or directly roof cladding (in purlin-less roofs).

Plate girders
  a) simple beams,
  b) frame rafters (usually)

Structure:
  • Hot-rolled I profiles
  • Castellated beams
  • Welded plates
  • Girders with predeformed webs:

Longitudinal shape of simple girders:

Plate girders:
+ less laborious than trusses, have lower depth,
  are more elegant,
- but more weighty.
Roof trusses
Types:

- Pratt
- Warren
- Vierendeel
- Mansard
- Alternating web members
- Truss frame
- Truss with parabolic bottom chord
- Garland girder

... also parallel chords, either with verticals or perpendiculars
Structural details

- shop connections are mostly welded
- site connections bolted (may be also welded).

Site connections: Portal frames
**Site connections:**

**Lattice girder frames**

1. **Connection along vertical**
   - each element has its own vertical and gusset, which bolted together

2. **Connection along diagonal**
   - upper chord: contact end plate connection
   - diagonals: connection with gusset plates
   - bottom chord: either end plate connection or splice connection
Rafter support on a stanchion:

- stiff pin
  - rotation free
- deflection must be enabled
- detail example:
  - long holes (or spring connection)

Rafter is usually placed on centralized plate.
Rarely (in narrow columns) directly without centralized plate.

web stiffener to prevent local buckling
This lecture was prepared for the 1st Edition of SUCOS (2012/14) by Prof. Josef Macháček (CTU) and Michal Jandera, PhD. (CTU).

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