Single-storey industrial buildings

Florea Dinu

Lecture 9: 21/02/2014

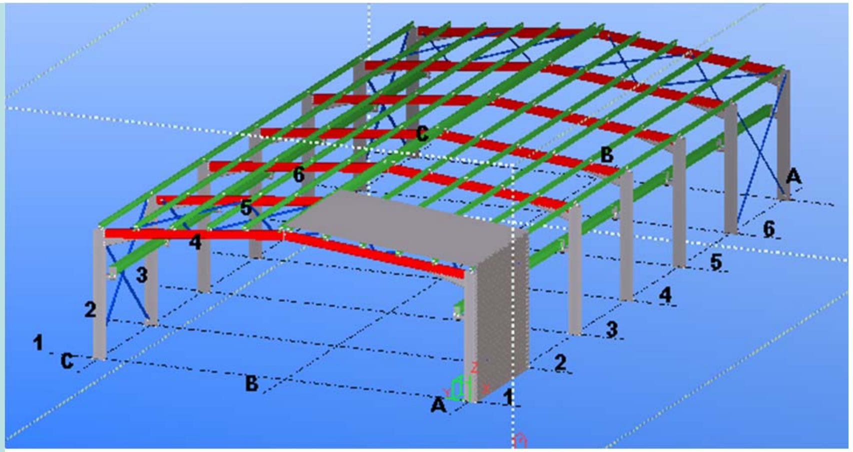
European Erasmus Mundus Master Course

Sustainable Constructions
under Natural Hazards and Catastrophic Events

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

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
  - ⊖ lack of flexibility (difficult to adapt)
  - ⊖ light cranes only (if any…)
- Purpose-made ... suitable for given production, use (e.g. heavy cranes, lightening, ventilation ...)


Warehouse

Production

Comercial



Agriculture, farm

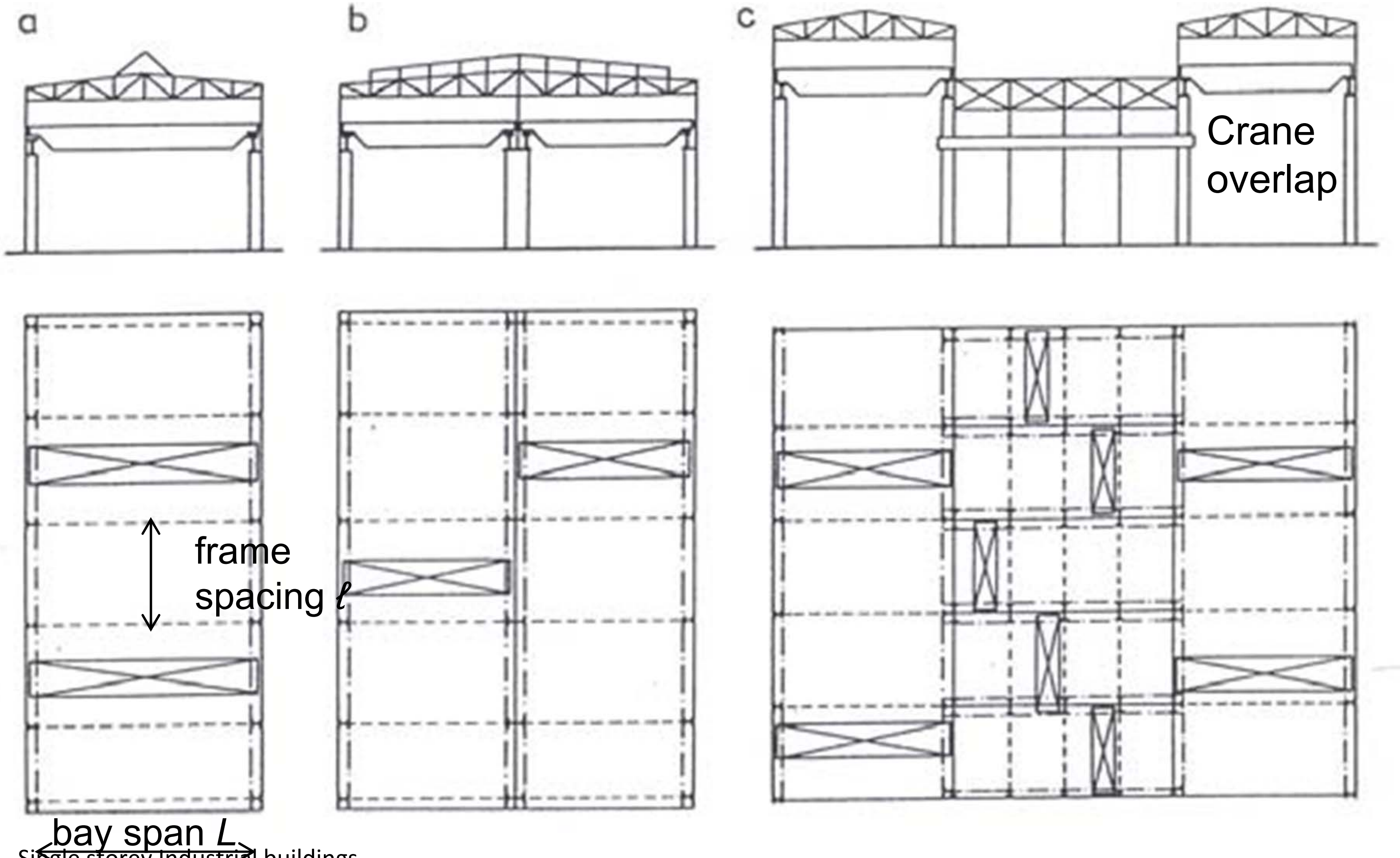
Sport

www.lindab.com

Part I – Industrial buildings

Terminology

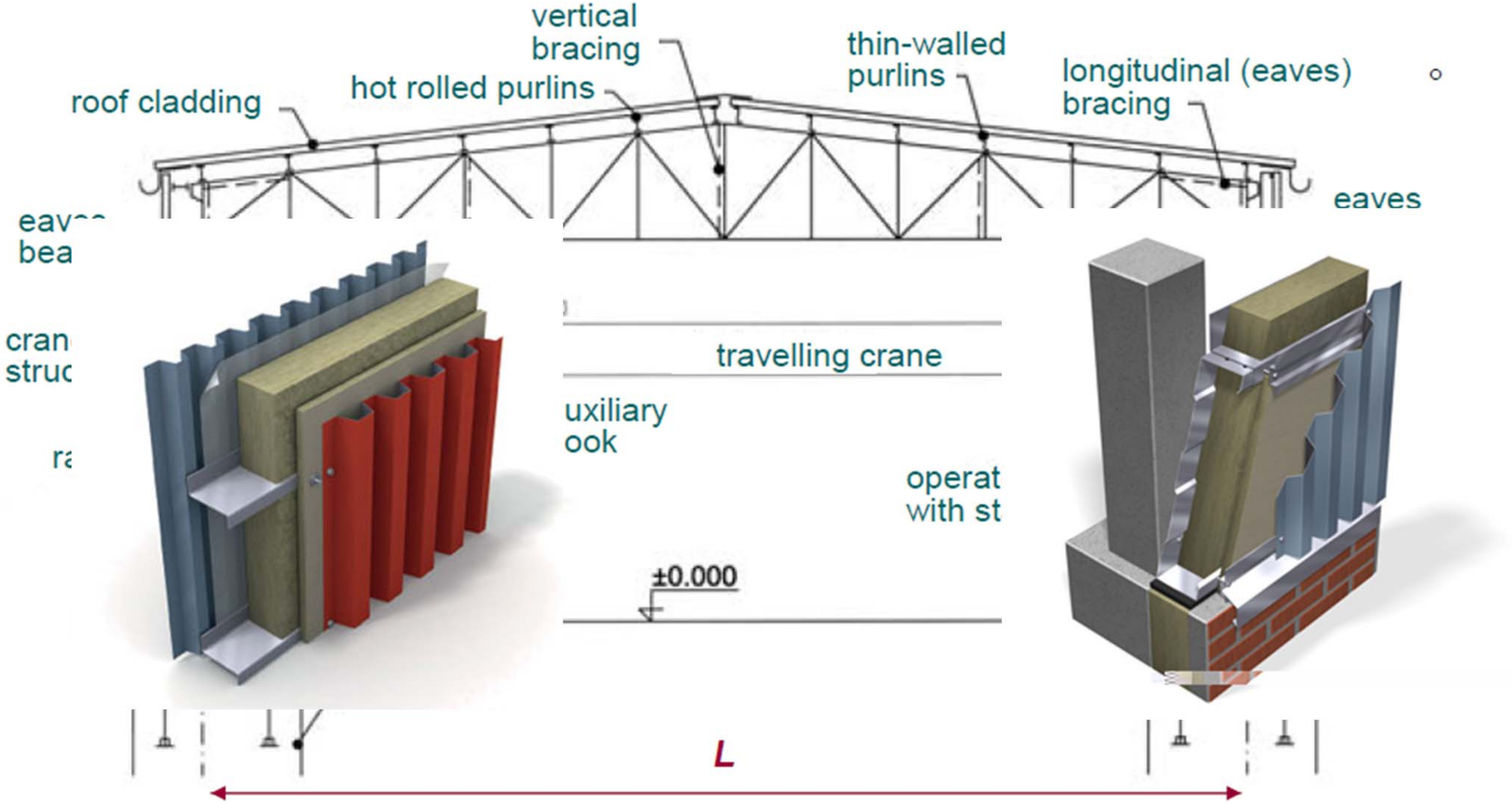
one-bay two-bay more-bay (longitudinal and transverse bays)



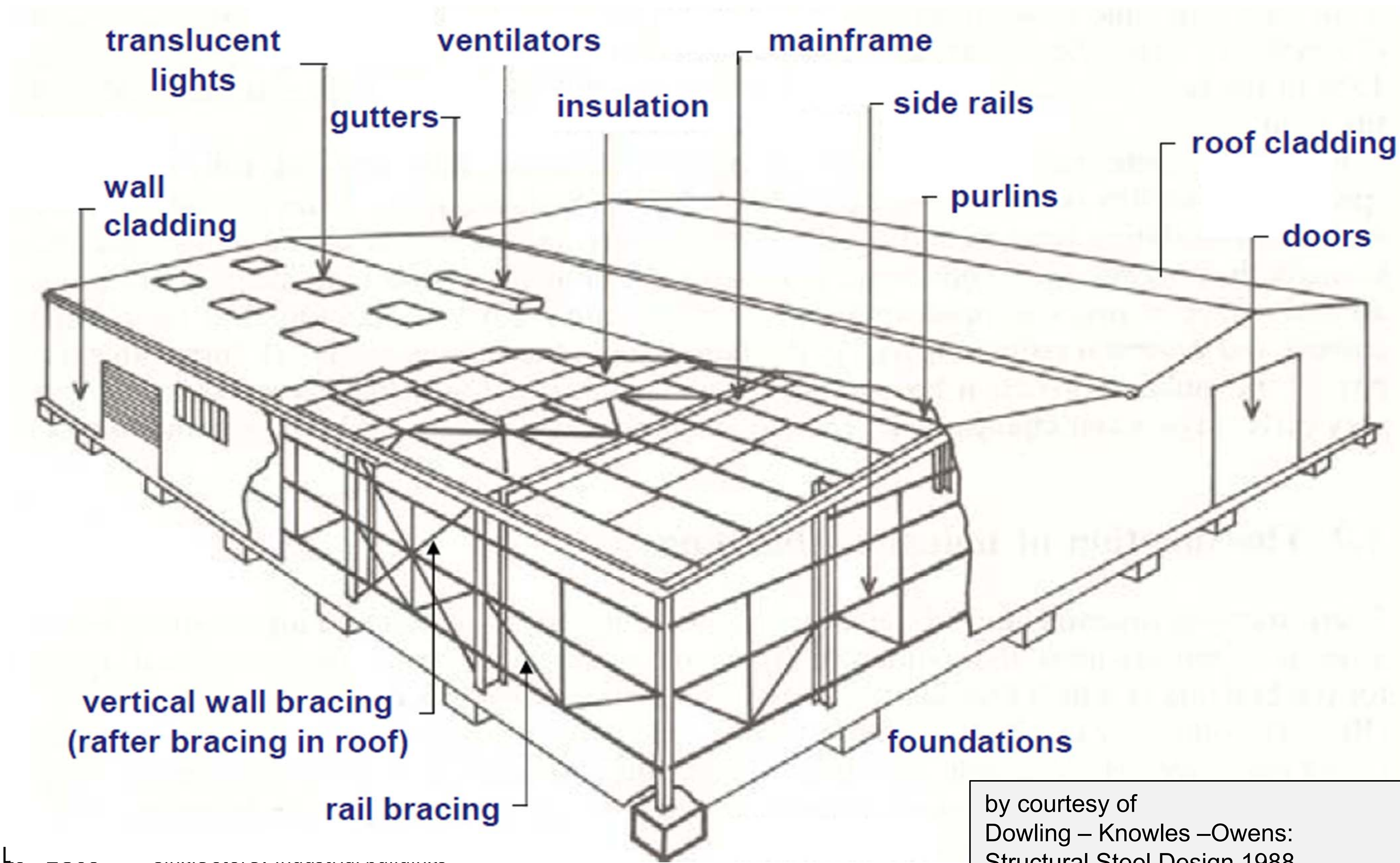
Terminology of cross section with roof truss

alt. 1
Hot rolled purlins and rails

alt. 2
Thin-walled purlins and cassettes



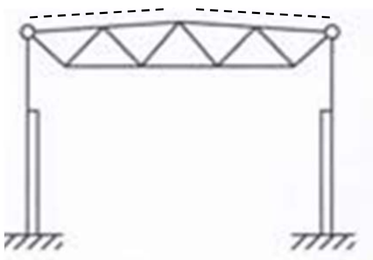
Example of a two-bay frame industrial hall



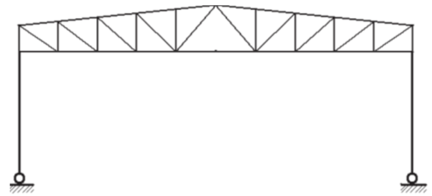
by courtesy of
Dowling – Knowles –Owens:
Structural Steel Design 1988

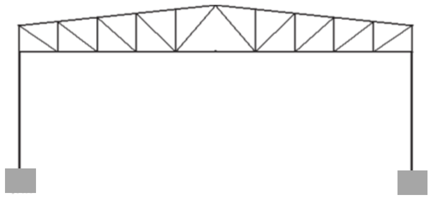
Cross-section of halls (i.e. common frames and gables)

1. Cross sections (with hinged supported rafter/truss, hinged/fixed base)

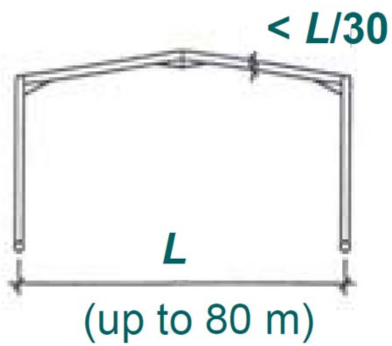


in roof support by bracing is necessary (transfer to gables)





2. Frames



Pitched portal frames:
two-hinged, three-hinged, built-in, combinations

⊕ small basements,

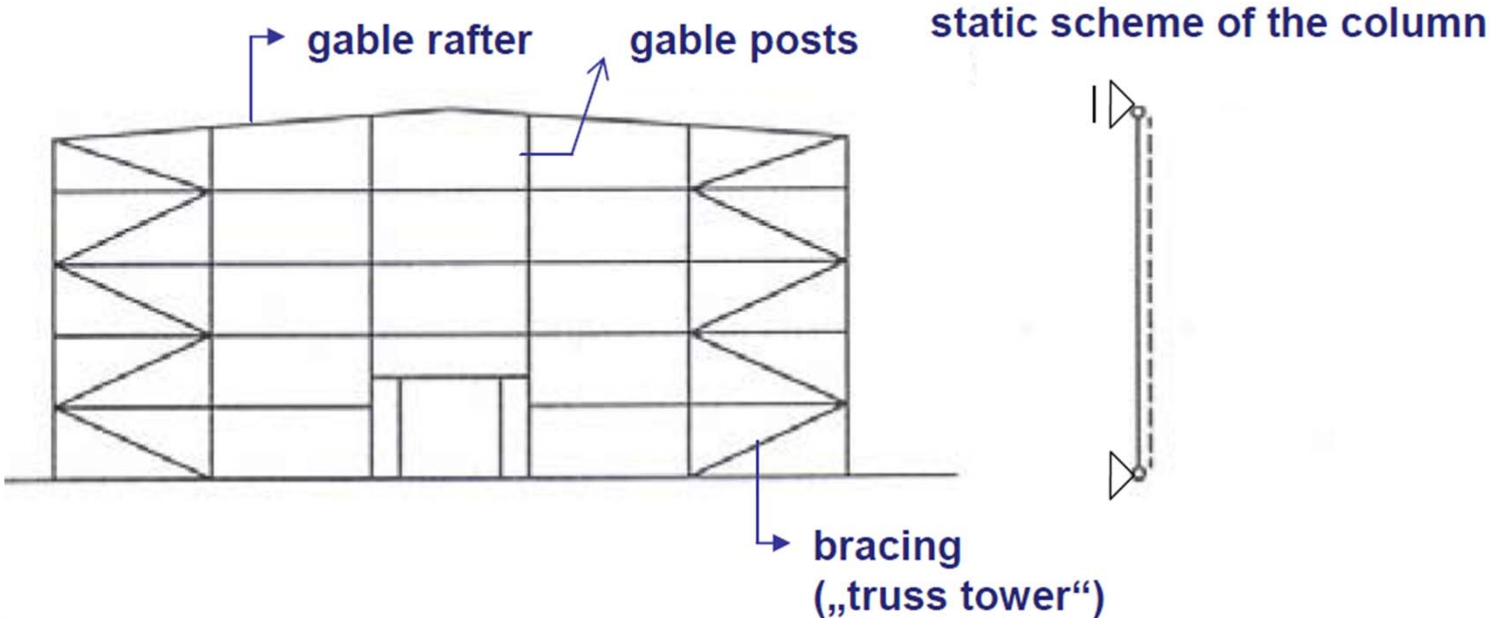
⊕ aesthetical structure,

- sensitive to settling of supports and temperature effects
- at crane halls: crane vibrations up to roof

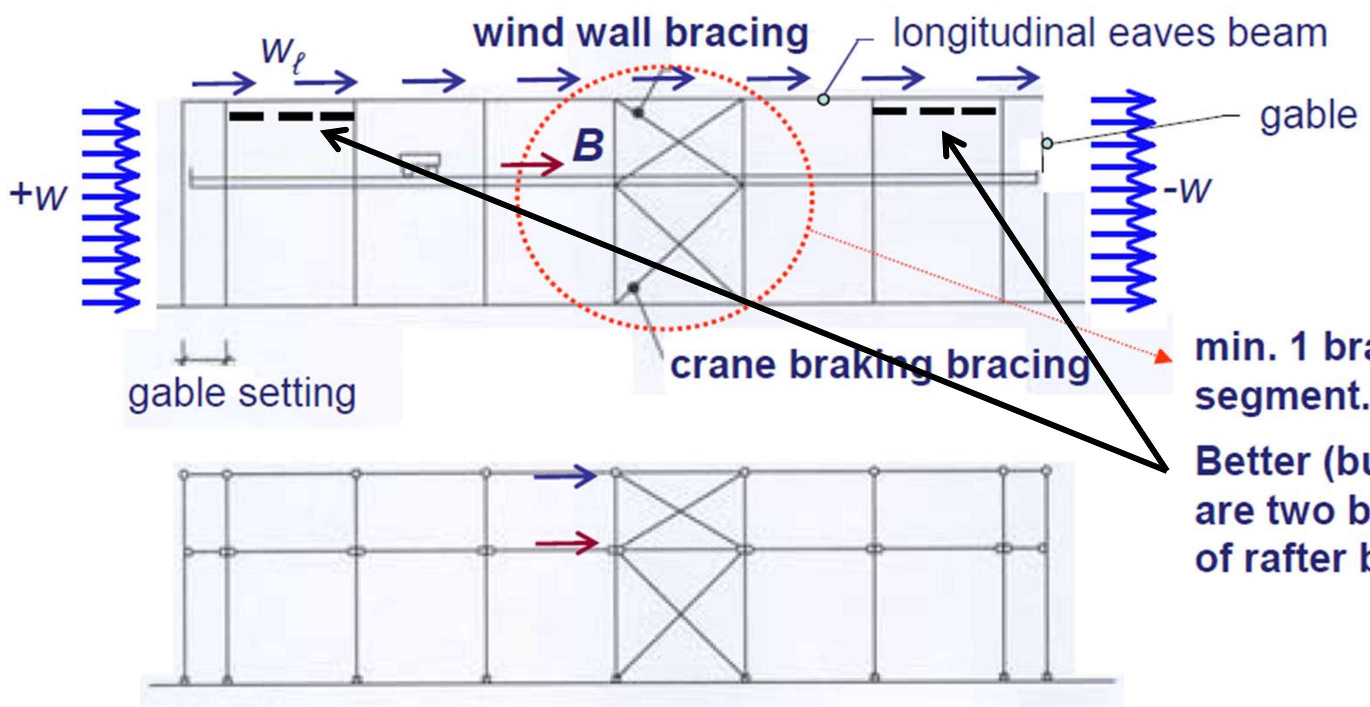
3. Gables

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



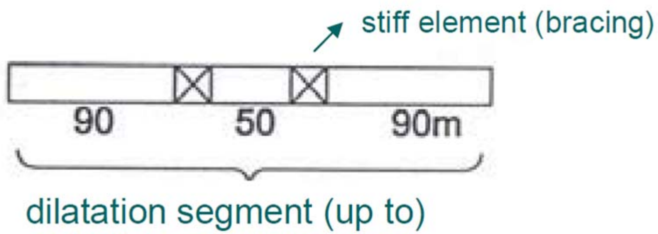
Longitudinal direction of halls



min. 1 bracing in a dilatation segment.

Better (but more expensive) are two bracings at locations of rafter bracings

Dilatation segments:

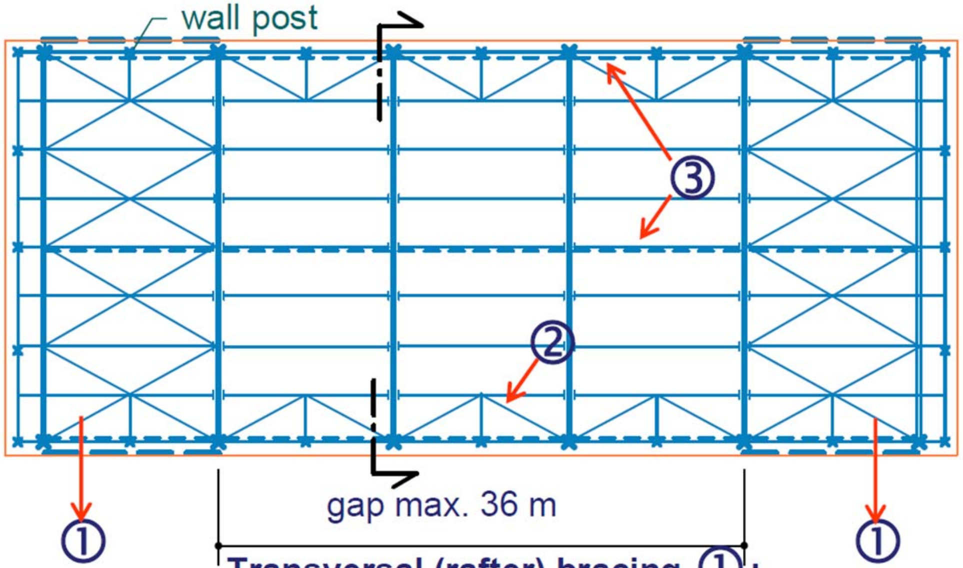


The temperature effect on bearing behaviour may be neglected for this arrangement

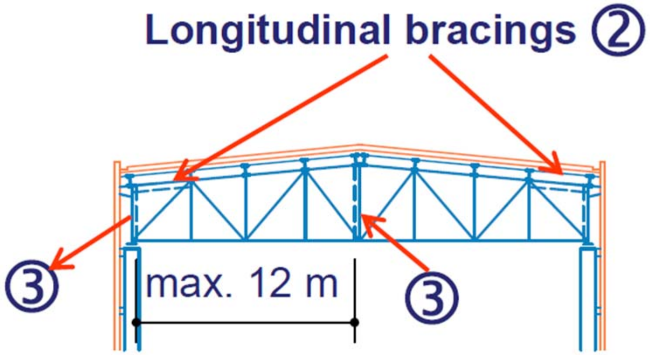
Roof bracings (bracings in the space of roof trusses)

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.



Transversal (rafter) bracing ①:
- by gables,
- intermediate (max. gap 36 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 ÷ 3 m (up to 6 m)

- usually galvanized 275 g/m2.
- superior with additional coating of polyester 15-25 μm,
- perfect protection PVDF 25 μm,
- or also protection against mechanical damage: PVC 200 μm.

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

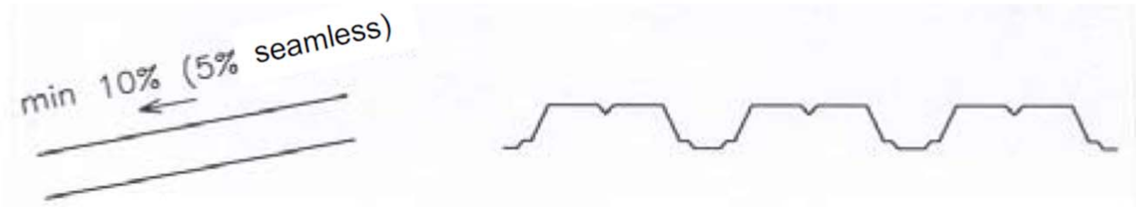
sidelap connection between sheeting:
- blind rivets
- special bolts for sheeting

max. at 500 mm

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

Typical arrangements:

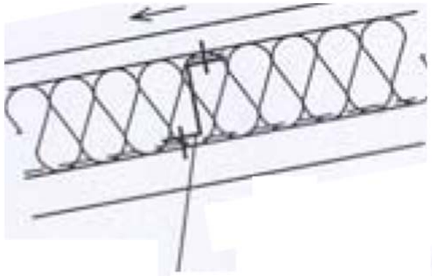
• without insulation

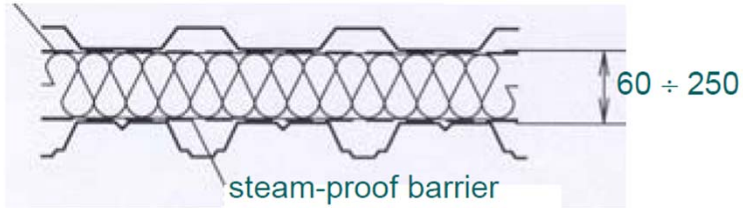


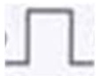
- **insulated**

  - cladding from thin-walled sheeting (steel, aluminium, stainless steel)

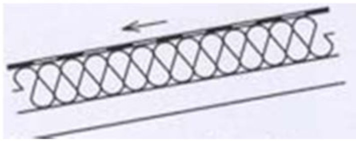
breaking of thermal bridge
(self-adhesive tape 30x8 mm)



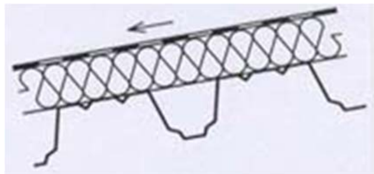


distance profile  or  (blind rivet connections)

  - with waterproof coating



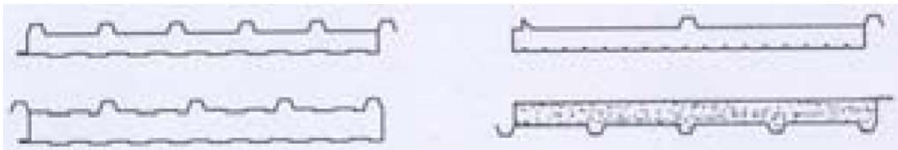
roof with purlins



roof without purlins

  - Sandwich panels

many types, e.g.



2) Silicate slabs

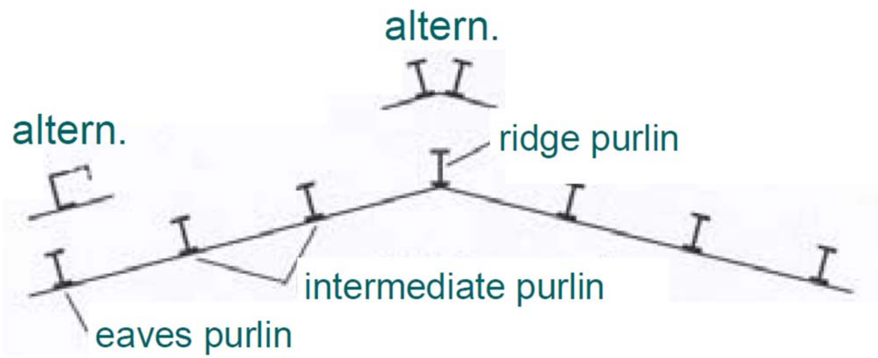
- reinforced/prestressed concrete slabs ($L \approx 3$ m) or panels ($L \approx 6$ m),
- reinforced light concrete slabs (cellular concrete, liapor - keramzite, etc).

3) Corrugated sheeting, eternit, others

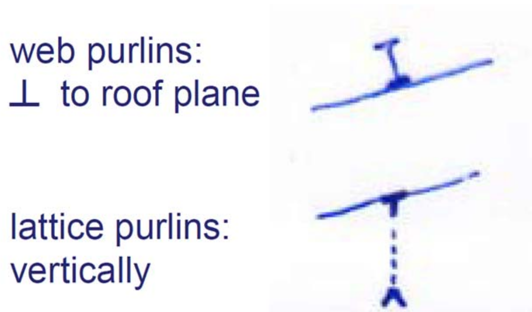
3) Translucent panels

- polycarbonate plates planar, corrugated, lenses, skylights,
- glass in grid structure.

Purlins - support cladding or decking



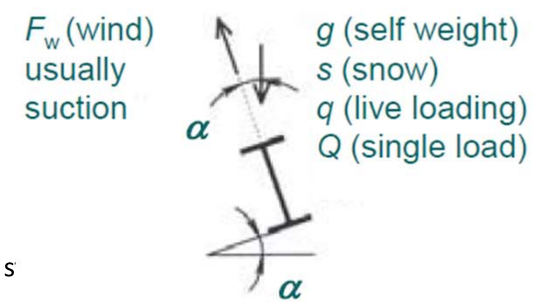
position of purlins:

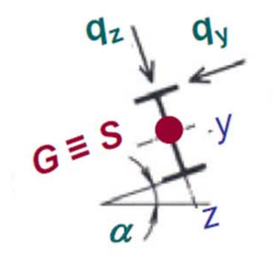


Survey of purlins and usual application:

statically	structure	suitable span	common
simple girder	thin-walled Z, C, zeta, sigma	6 m	-
	hot-rolled IPE	6 m	-
	lattice	≥ 12 m	yes
	castellated	≥ 9 m	-
continuous girder	thin-walled Z, C, zeta, sigma	6 ÷ 8 m	yes
	hot-rolled IPE	6 ÷ 8 m	yes
hinged (Gerber's) girder	hot-rolled IPE	6 ÷ 9 m	-
propped and suspended	hot-rolled IPE, thin-walled	9 ÷12 m	-

Loading:





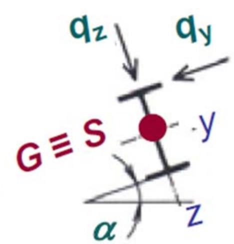
Checks:

ULS

SLS: $\delta_2 \leq \dfrac{L}{200}$

Walkable roofs:
frequency $f_1 \geq 3$ Hz ≈ $\delta_{max} \leq 28$ mm

Hot-rolled purlin

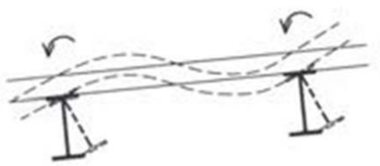


Generally loaded in bi-axial bending and torsion (giving σ, τ)

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:

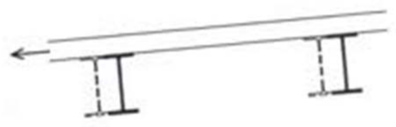


this curvature is small (see EN 1993-1):
- given by bending stiffness $EI_{cladding}/L$
- by stiffness of connection

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:

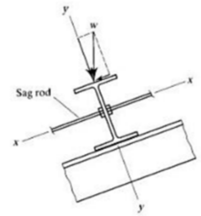


- **non-rigid** (deflection as in the picture),
- **rigid** (deflection in the roof slope direction is negligible).

a) Non-rigid roofs

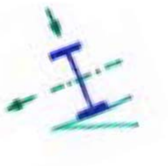
- **assembly stages of rigid roofs, great slopes of roofs,**
- **trapezoidal sheeting not sufficiently connected in sidelaps and to purlins,**
- **non-rigid bearing layer (translucent soft panels, fragile eternit, etc.).**

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



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

can be reduced by ties



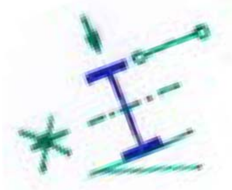
$$\left(\frac{M_{y,Ed}}{M_{y,Rd}}\right)^2 + \frac{M_{z,Ed}}{M_{z,Rd}} = \left(\frac{M_{y,Ed}}{W_{pl,y} f_y / \gamma_{M0}}\right)^2 + \frac{M_{z,Ed}}{W_{pl,z} f_y / \gamma_{M0}} \leq 1$$

b) Rigid roofs

- **silicate roofs after imbedding,**
- **trapezoidal sheeting:** - with sidelap connection at ≤ 500 mm,
  - connected to purlins at ≤ 300 mm.

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

E.g. similarly as above:



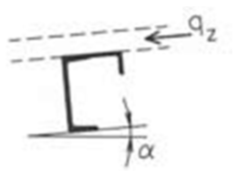
Class 2 cross-section: $M_{y,Ed} \leq M_{c,Rd} = W_{pl} f_y / \gamma_{M0}$

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:

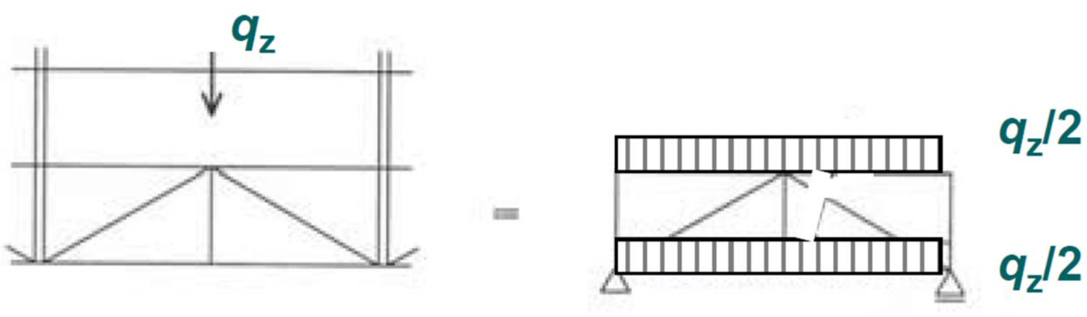
a. eaves purlin,
b. eaves bracing,
c. connection at apex (namely in thin-walled purlins),
d. connection of roof plate to rafters (particularly in roofs without purlins).

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



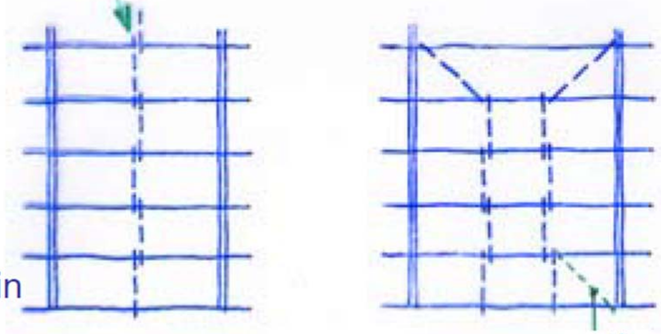
transfers loading q_z from the roof apex to eaves
(⇒ loaded in bi-axial bending)

b) Eaves bracing (suitable for greater roof width)



⇒ the purlin profiles usually as for intermediate purlins

Ties for reduction of moment M_z in non-rigid roofs:

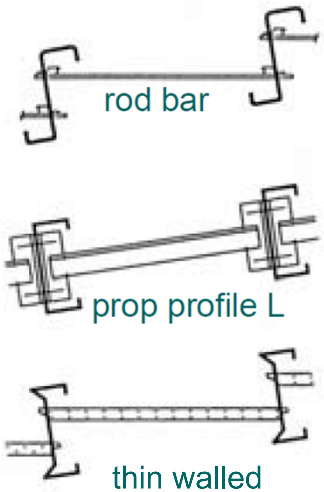


Principle:

bending M_y

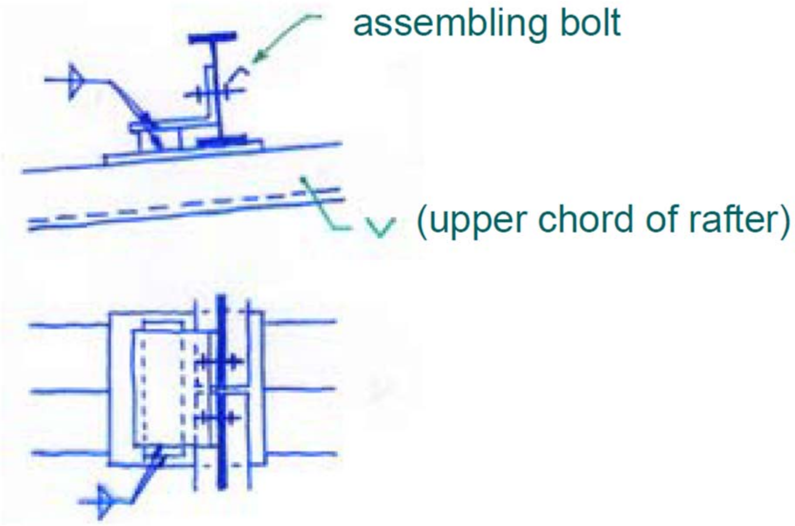
bending M_z

Tie structure:

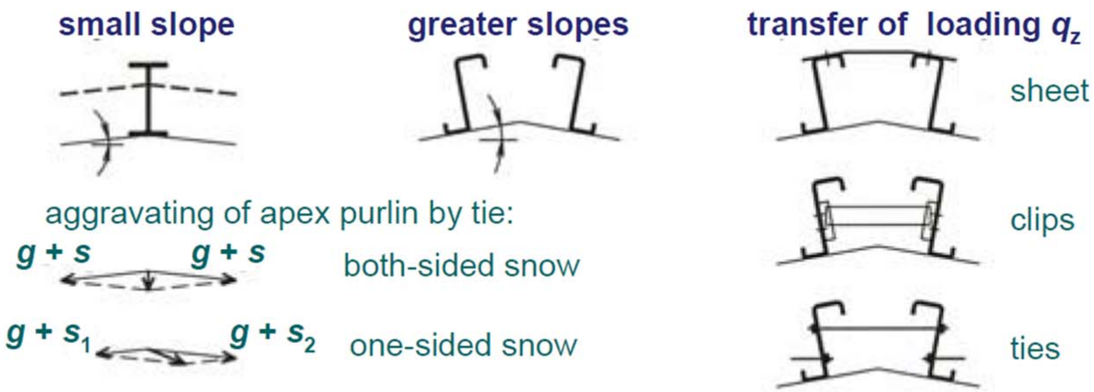


Note: in non-rigid roofs, the eaves purlin is loaded as intermediate purlins, but with smaller loading width.

Purlin to rafter connection (standardized dimensions in tables):

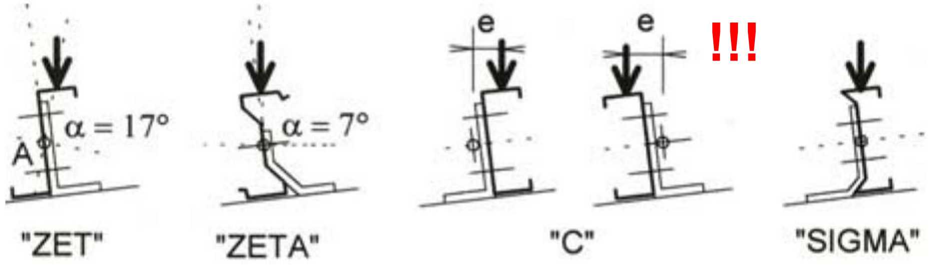


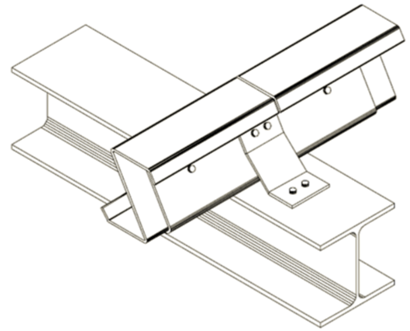
Apex purlin:



Thin-walled cold-formed purlins

Profiles according to fabricators:





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

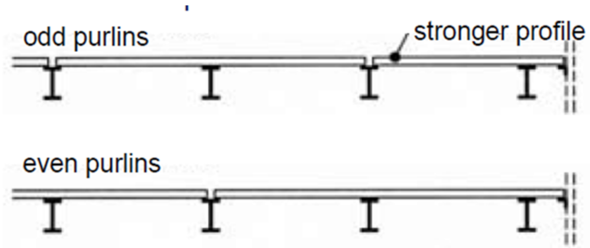
Design:

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

Resistances / admissible loadings commonly available in tables.

Systems:

1. Staggered purlins running continuously over two spans

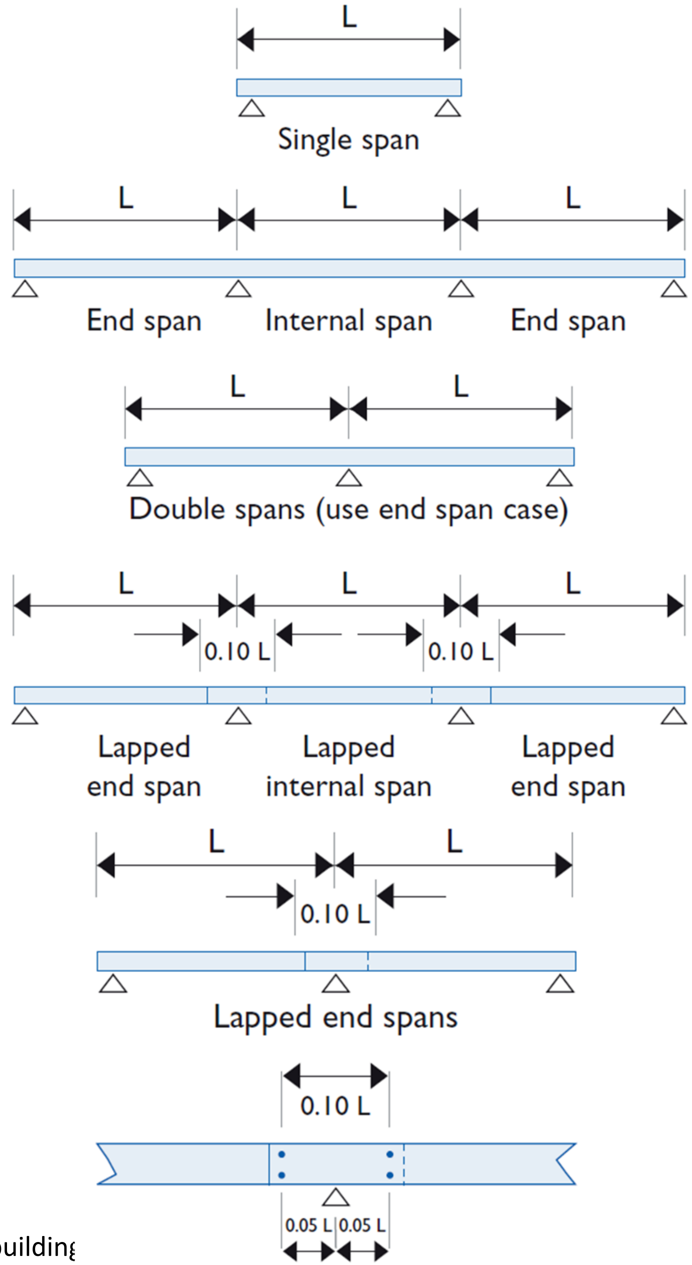


2. System with sleeves

3. System with overlaps

Example

www.dimond.co.nz



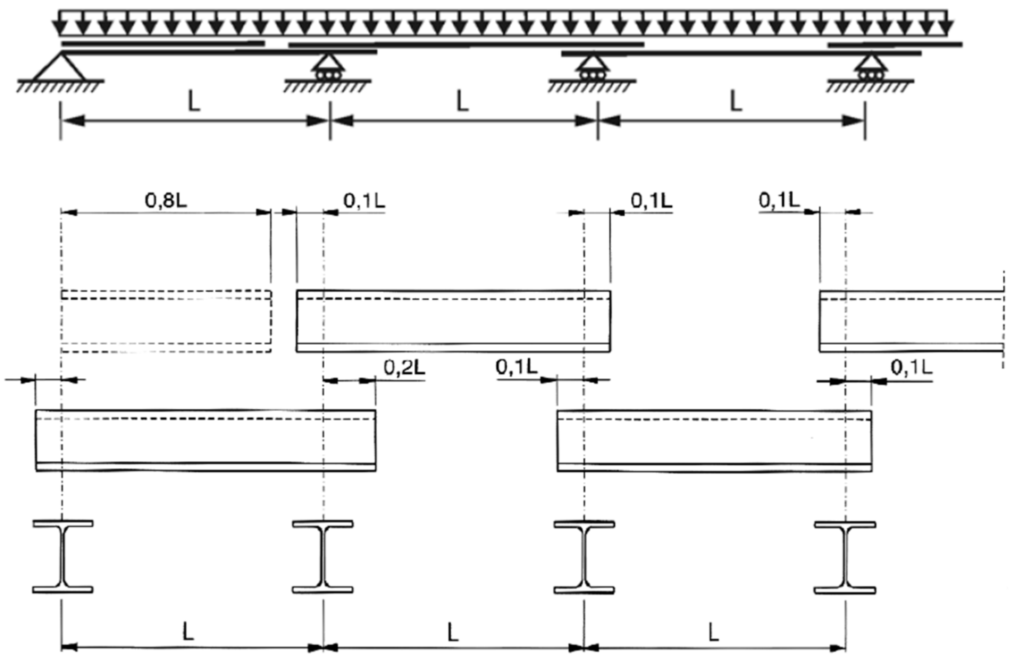
All lap lengths are to be a minimum of 0.1 of the maximum span, measured from bolt centre to bolt centre each end of the lap, positioned equally each side of the portal rafter.

L = Span length

Example

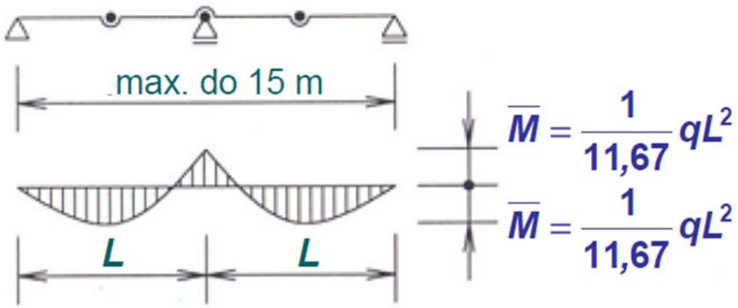
www.Lindab.com

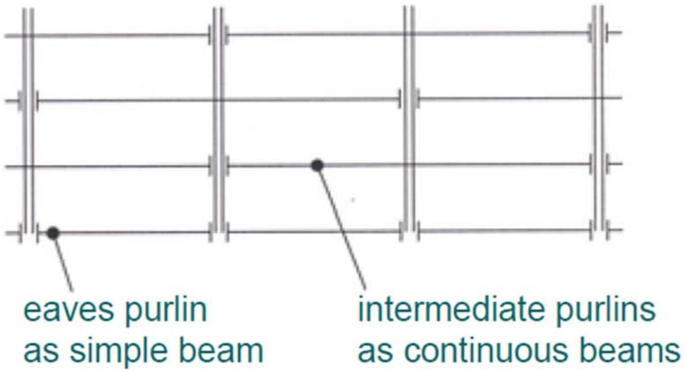
Overlapped + additional profile in 1st and last span



Continuous hot-rolled purlin over 2 spans

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





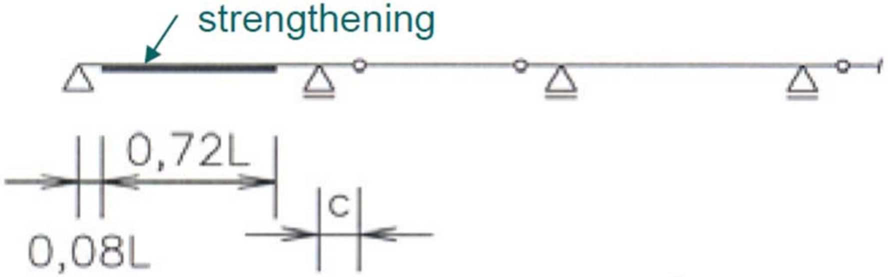
Check for rigid roofs: $\overline{M} \leq M_{b,Rd}$

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.

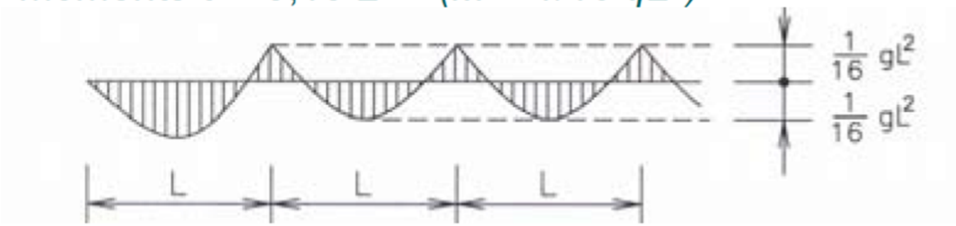
Hinged purlins (Gerber's girder)

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



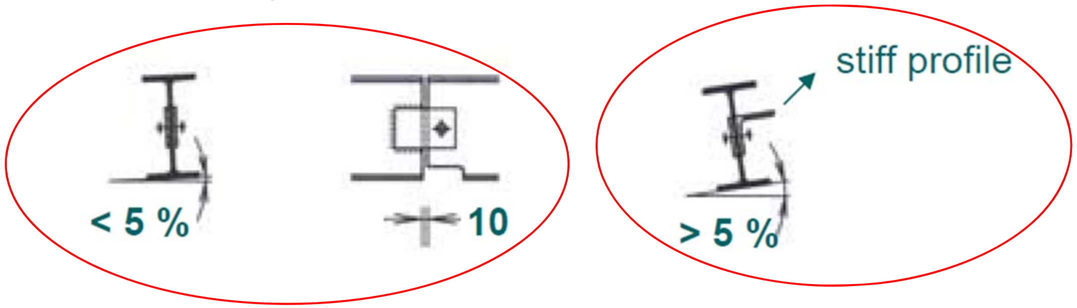
Choice of pin location (c) depends on whether ULS or SLS decides:

- to balance moments $c \approx 0{,}15\ L$ $(M = 1/16\ qL^2)$



- to balance deflections $c \approx 0{,}21\ L$

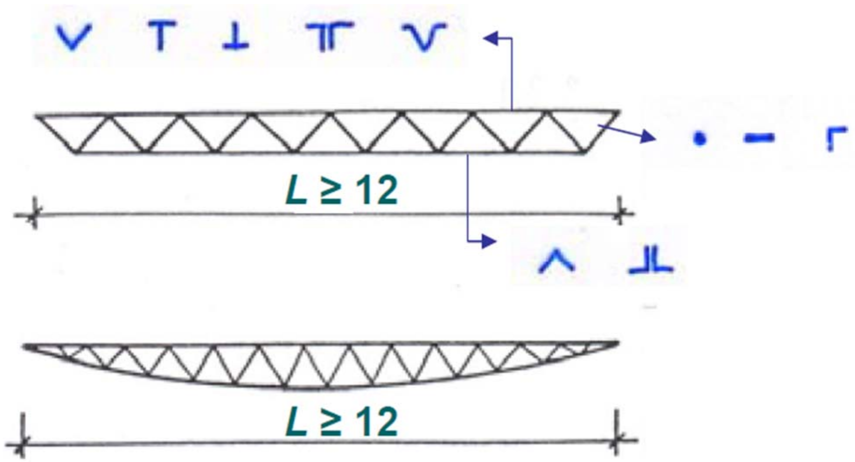
Detail of hinge:
(in acc. to roof slope)



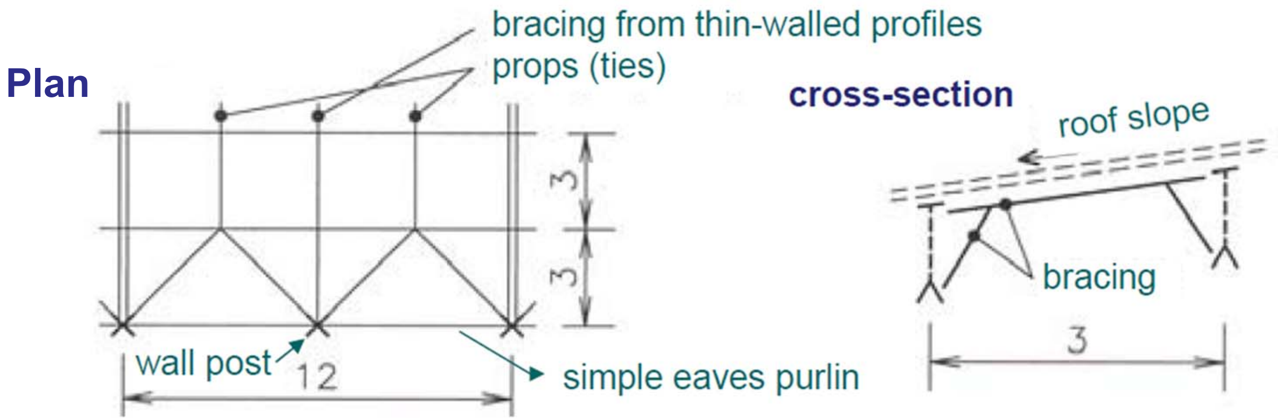
Lattice purlins (joists)

- **parallel chords**

- **parabolic bottom chord**



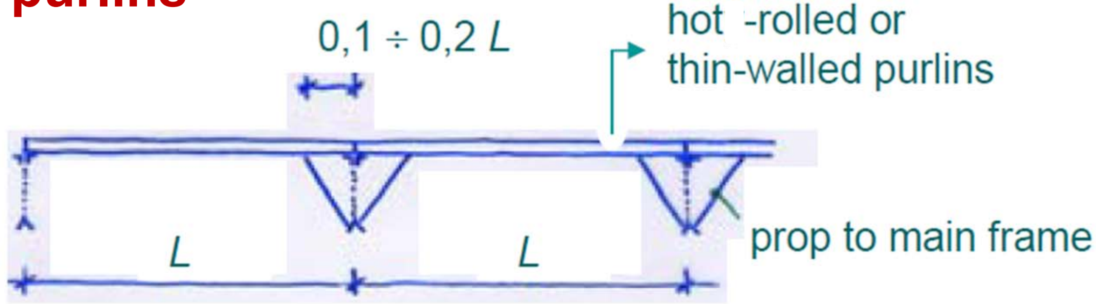
Light girders without gusset plates, fabricated in production lines
Height h ~ L/15 up to L/20.
Critical length of diagonals lcr ~ l between chords.



Propped and suspended purlins

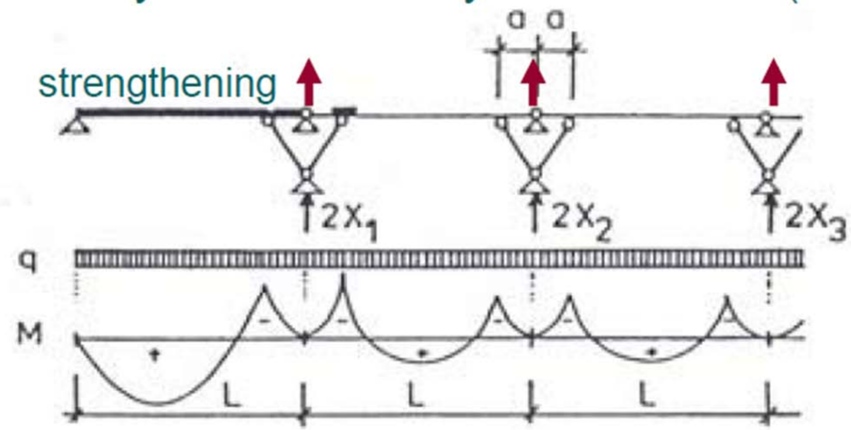
- **propped**

(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).

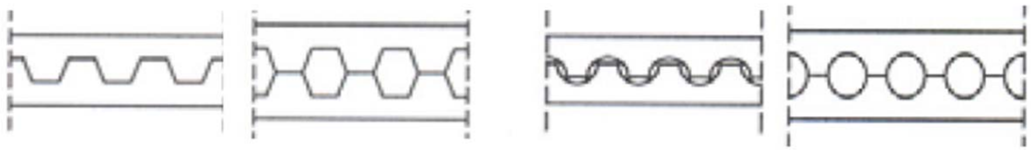
Plate girders

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:

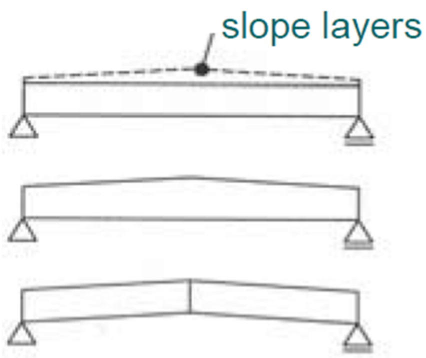
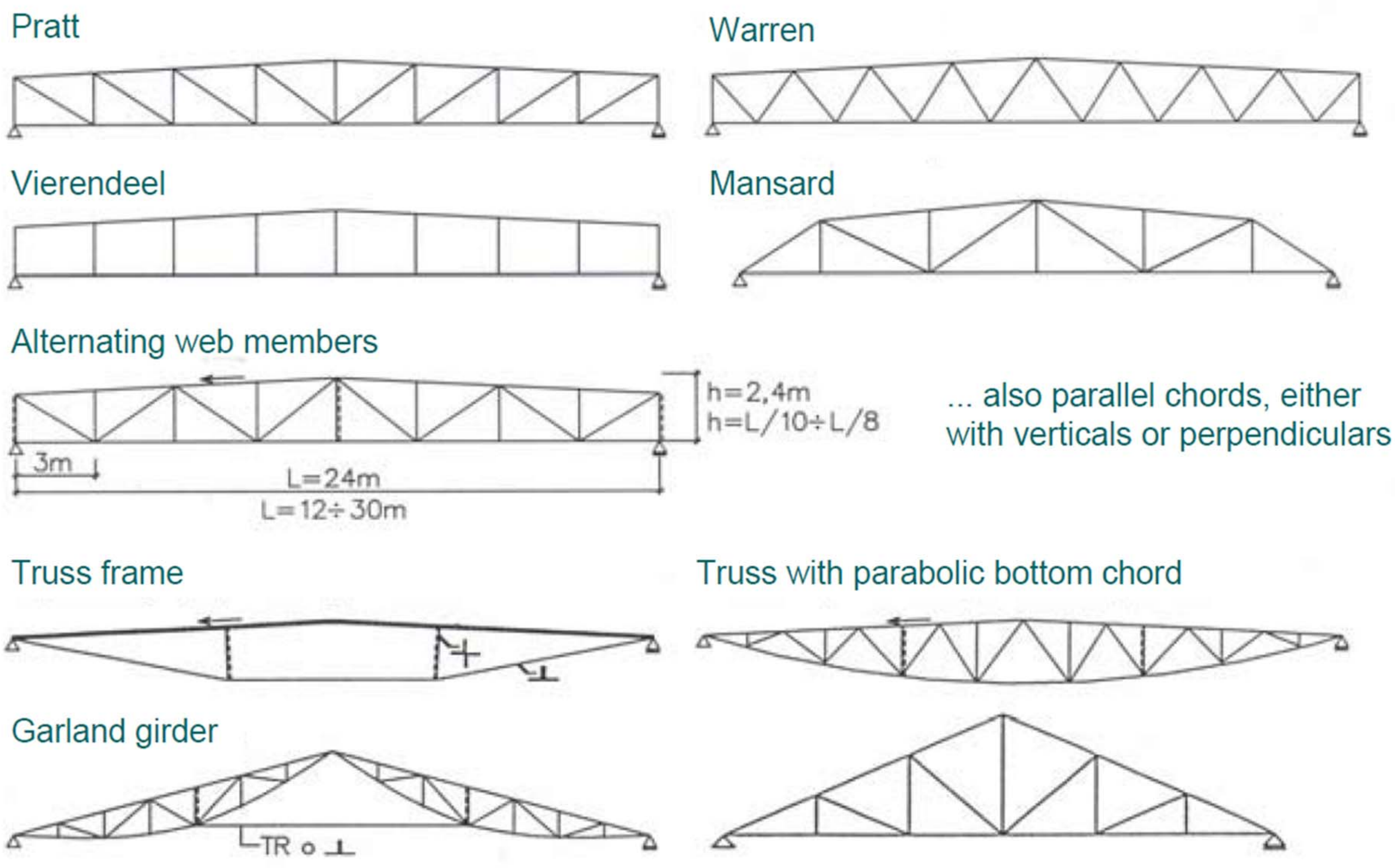


Plate girders:

+ less laborious than trusses, have lower depth, are more elegant,
- but more weighty.

Roof trusses

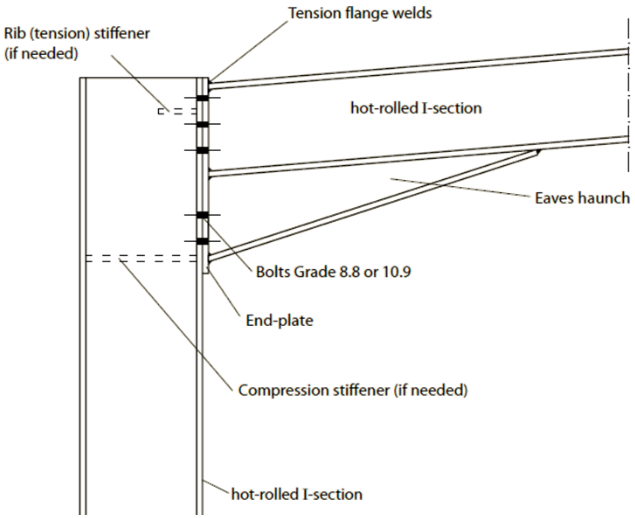
Types:

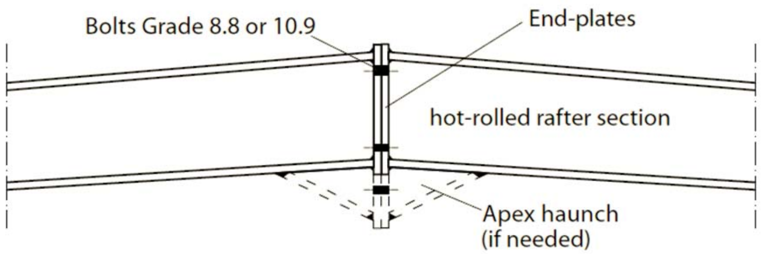


Structural details

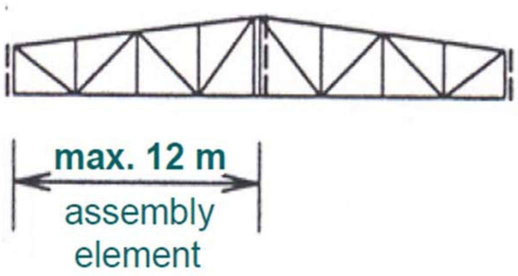
- shop connections are mostly welded
- site connections bolted (may be also welded).

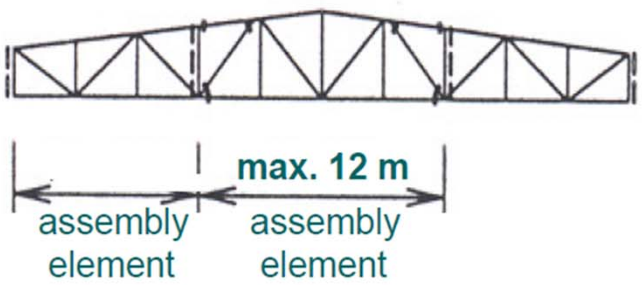
Site connections: Portal frames



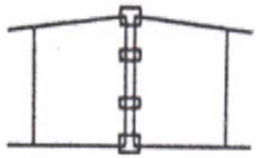


Site connections: Latice girder frames



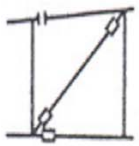


1. Connection along vertical



each element has its own vertical and gusset, which bolted together

2. Connection along diagonal

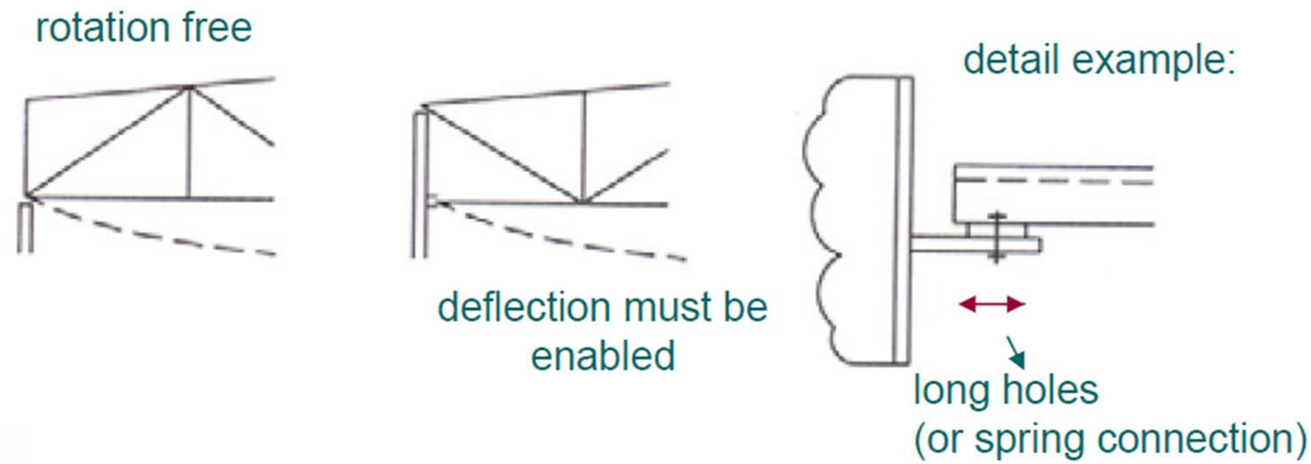


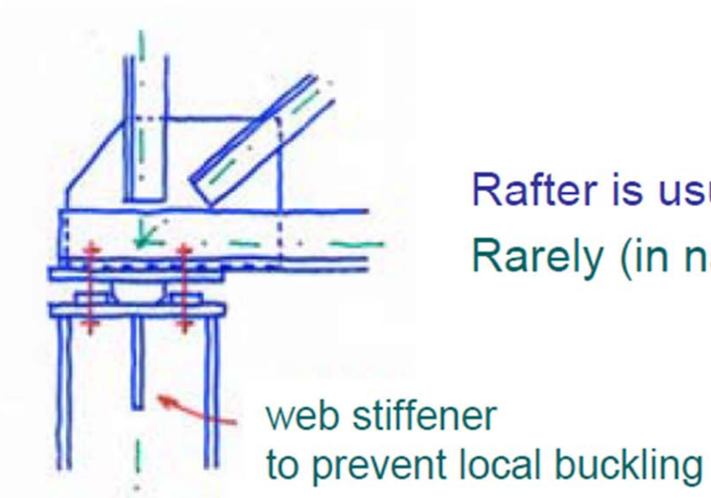
upper chord: 
contact end plate connection

diagonals:
connection with gusset plates

bottom chord:
either end plate connection
or splice connection

Rafter support on a stanchion:





Rafter is usually placed on centralized plate.

Rarely (in narrow columns) directly without centralized plate.

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

Adaptations brought by Florea Dinu, PhD (UPT) for 2nd Edition of SUSCOS

SUSCOS

florea.dinu@upt.ro

http://steel.fsv.cvut.cz/suscos

European Commission
ERASMUS MUNDUS