Scheme development: Purlin structure design

*Provides the information required for designing the purlin structure of a steel-frame building. Gives details on the interaction between purlins and roofing.*

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1. Introduction – function of purlins

1.1 Basic function

The principal function of roofing purlins is to transfer the forces on the roof of a building to its main structure. The wall rails perform the same role on the facades. Purlins and wall rails are important components in the secondary structure of a building.

It should be noted that, in a large number of steel-frame buildings, with a single ground floor, the weight of the purlins and wall rails constitutes an important element in terms of the overall weight of the structure (15 to 20%); failure to optimize on this could lead to a deal being lost in a highly competitive situation.

The purlin structure of a building is designed in accordance with the type of roofing to be used. The nature of the roofing, in particular, directly influences the spacing between purlins; it also determines what purlin-roofing interaction we can expect for dimensioning the purlins (see Section 3).

A purlin structure includes not just the purlins themselves (see different types in Section 2), but also any splice connections that make the purlins continuous (see Section 4), the cleats that join the purlins to the main structure (see Section 5), and any sag bars and batten plates responsible for holding the purlins laterally (see Section 6).

The loads to be considered (see further information on these in Section 7) are primarily:

- the actual weight of the roofing, the purlins and their accessories
- the actual weight of any equipment carried by the roofing
- the imposed loads suspended inside (e.g. a sprinkler system, lighting, etc.)
- the maintenance load of the roofing
- snow
- wind

Under gravity loads (self weight, snow, maintenance, etc.), the purlin is subjected to a deflection along the strong inertia of its section, and to a lateral deflection of its top flange (where the load is transferred to) which may or may not develop, depending on the role of the roofing.

Under loads perpendicular to the roof pitch (wind, upwards or downwards loads), the purlin is subjected to a deflection along the strong inertia of its section.

Figure 1.1 Purlin loads
Note: In Figure 1.1, the purlin is represented with the web perpendicular to the roof pitch, which is almost always the case. It is very rare for purlins to be used with their web vertical: this would mean having to place the roofing on bevel wedges.

1.2 Strut purlins

In addition to the principal function described above, the purlins can also be given the function of transmitting the wind load from the head of the gable posts to the roofing windward beam (if this windward beam is not situated in the span adjacent to the gable): see Figure 1.2.

In addition to the deflection caused by their principal function, the purlins are then subjected to direct force, either compression or tension, which may be eccentric.

![Diagram of Roofing of a building – Plan view](image)

**Figure 1.2 Roofing of a building – Plan view**

In Figure 1.2, the forces represented are the loads exerted, under the effect of wind, by the posts structuring the gable in row F1 and which rest against the head on certain purlins. Under the effect of these forces, the purlins serving as struts, which are drawn in blue and referenced as B, are compressed. The purlins serving as stanchions of the roofing windward beam are drawn in red and referenced as M (see Section 1.3 below).

It should be noted that, under the same wind load (same direction and same sense), the posts structuring the gable in row F8 (downwind) exert tensile force on the purlins they are resting on: this effect is not represented in Figure 1.2 but it is to be included in the effect represented, particularly for the windward-beam calculation.
Again we see that at the ridge, midway between rows A and B, the purlin is double: a ridge purlin at the top of each roof pitch forms the usual layout which provides the best possible way of laying the roofing.

If we want to avoid adding the strut function to the principal function of the purlins, we can place separate struts between the gable post heads and the windward beam (see Figure 1.3).

![Diagram of purlin structure](image)

**Figure 1.3** Transmission with or without strut-purlin

### 1.3 Wind beam stanchion purlins

Purlins may also be given the function of a stanchion of the roofing windward beam: see, in Figure 1.2, the stanchion purlins of the roofing windward beam, referenced as M and drawn in red. These purlins may thus be highly compressed in the functioning of the windward beam: the diagonals positioned in the form of a Saint Andrew’s cross are usually dimensioned so as to resist tensile force only and, for this reason, the stanchions are compressed.

As with the “strut” function, if we wish to avoid giving the purlins the function of windward beam stanchion, separate elements (often tubes) can be used for this function, particularly when the compression force in the windward beam stanchions becomes considerable (area with high winds, wide-span windward beam).

### 1.4 Stabilizing the elements of the main structure

The roofing purlins of a building are also frequently given the function of providing lateral stability to those elements of the main structure carrying them (portal-frame rafter, for example).

The purlins can stabilize the flange of the portal-frame rafter (or the chord of the lattice rafter) onto which they are attached (generally the top flange for a portal frame inside the building). All the purlins resting against the roofing windward beam can be considered as support points; in order to consider the other purlins as support points, we will have to take the roof as being a diaphragm (see more about this in Section 3).

Purlins can also be used to stabilize the bottom flange of the portal-frame rafter (or the lower chord of the lattice rafter): bracings are then installed as shown in Figure 1.4.
Bracing on one side only: it does not create an additional support for the purlin; the static diagram is not modified. The purlin undergoes a stabilizing force from the flange being held.

Bracings on either side of the rafter held laterally: they create additional supports for the purlin. We refer to them as “braced purlins”.

Holding the rafter lattice lower chord by vertical bracing on purlin (scissor hold)

**Figure 1.4  Lateral stabilizing of the main structure by the purlins**

## 2. Different types of purlins

One of the design elements of a purlin structure is the type of purlin selected. As a general rule, the choice is made between hot-rolled beam purlins, most often IPEs, and thin cold-formed purlins, with lattice-purlins only very rarely being used.

This choice, if left to the constructor of the steel structure, is based more on organizing the production rather than a choice associated with the performance of either product. IPE purlins and thin cold-formed purlins may, in effect, fulfil the same functions.

Thin cold-formed purlins and their accessories are more often designed and manufactured by a specialized manufacturer possessing roll-forming machines: the constructor responsible for making the steel structure of a building purchases the purlins from one of these manufacturers. However, IPE purlins are more often designed and manufactured by the constructor of the main structure. One of the criteria for choosing between the two options depends on the constructor’s workload in the workshop: if very busy, he will prefer to purchase the cold-formed purlin; if less busy, he will prefer to manufacture it itself.

Whatever the type of purlin to be used, the type of roofing determines a maximum spacing between purlins. The documents defining the performance of roofing products generally
provide tables for determining their maximum span length (and thus the maximum spacing between purlins) depending on the span length load.

The type of thermal roofing insulation, if installed inside the building, may also influence the choice of purlin: spacing, minimum height of the section.

### 2.1 Hot-rolled beam purlins (IPE)

The range of low-height IPE beams (up to about IPE 240) is widely used for making purlins.

In Table 2.1 below, an indication is given on the choice of section to be used in the IPE range, depending on the purlin span length (varying from 5 to 10m) and in accordance with the line load per metre of the purlin at the SLS.

These indications are based on a deflection criterion of 1/200 of the span length at the SLS, and on a resistance criterion under a load of 1.5 times the SLS load. The resistance criterion is when elastic capacity is reached under simple deflection of the section, with the following assumptions:

- S235 Steel
- No reduction of the moment on support due to the presence of splice connections
- No direct force in the purlin (no strut function)
- Partial factors: $\gamma_M = \gamma_f = 1.0$
- No lateral deflection accounted for
- No lateral torsional buckling

The last two assumptions are, in particular, dependent on the method used for lateral stabilization of the purlins (roofing function: see Section 3; purlin coupling: see Section 6).

The options mentioned in Table 2.1 therefore provide a rough guide: in no way do they take the place of calculations justifying the resistance of purlins.

In Table 2.1, indication (f) distinguishes between cases in which the deflection criterion leads to selection of a section superior to that produced by the resistance criterion: this happens systematically – or almost – in “statically determinate purlin” configurations, as well as in “continuous” configurations for wide span lengths. It should be noted that the deflection criterion would become predominant in a much larger number of cases with S355 steel.

We can also see in the table that making purlins continuous systematically results in a reduction of their section.
### Table 2.1  Choice of purlin section in the IPE range

<table>
<thead>
<tr>
<th>Span length</th>
<th>IPE size, for imposed load</th>
<th>1.0 KN/m</th>
<th>1.5 KN/m</th>
<th>2.0 KN/m</th>
<th>2.5 KN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 m</td>
<td>Statically determinate</td>
<td>IPE 100</td>
<td>IPE 120 (f)</td>
<td>IPE 120 (f)</td>
<td>IPE 140</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 100</td>
<td>IPE 100</td>
<td>IPE 100</td>
<td>IPE 120</td>
</tr>
<tr>
<td>6 m</td>
<td>Statically determinate</td>
<td>IPE 120 (f)</td>
<td>IPE 140 (f)</td>
<td>IPE 140 (f)</td>
<td>IPE 160 (f)</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 100</td>
<td>IPE 120</td>
<td>IPE 120</td>
<td>IPE 140</td>
</tr>
<tr>
<td>7 m</td>
<td>Statically determinate</td>
<td>IPE 140 (f)</td>
<td>IPE 160 (f)</td>
<td>IPE 160 (f)</td>
<td>IPE 180 (f)</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 120</td>
<td>IPE 120</td>
<td>IPE 140</td>
<td>IPE 160</td>
</tr>
<tr>
<td>8 m</td>
<td>Statically determinate</td>
<td>IPE 160 (f)</td>
<td>IPE 180 (f)</td>
<td>IPE 180 (f)</td>
<td>IPE 200 (f)</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 120</td>
<td>IPE 140</td>
<td>IPE 160</td>
<td>IPE 160</td>
</tr>
<tr>
<td>9 m</td>
<td>Statically determinate</td>
<td>IPE 180 (f)</td>
<td>IPE 200 (f)</td>
<td>IPE 200 (f)</td>
<td>IPE 220 (f)</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 140 (f)</td>
<td>IPE 160 (f)</td>
<td>IPE 180 (f)</td>
<td>IPE 180</td>
</tr>
<tr>
<td>10 m</td>
<td>Statically determinate</td>
<td>IPE 180 (f)</td>
<td>IPE 200 (f)</td>
<td>IPE 220 (f)</td>
<td>IPE 240 (f)</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>IPE 160 (f)</td>
<td>IPE 180 (f)</td>
<td>IPE 180</td>
<td>IPE 200</td>
</tr>
</tbody>
</table>

Note.: in the table, continuous purlins have at least 4 supports
Key : (f) : deflection criterion governs design
Note: in some countries, IPE purlins are designed as a “Gerber system” with hinges placed to get equal moments at supports and in the spans (generally one hinge in each span)

### 2.2 Thin gauge cold-formed purlins

#### 2.2.1 General

Thin gauge cold-formed purlins are generally manufactured by profiling a piece of steel sheeting, a manufacturing process used to obtain all forms imaginable. However, the main section forms used for purlins are Sigma and Zed forms.

![Diagram of Sigma and Zed sections](image)
For Sigma and Zed forms, the range of heights and thicknesses are more or less the same:

- Height $h$ of the section, between 140 and 350 mm
- Thickness of the profiled sheeting, between 1.5 and 4 mm

The width of flange $b$ is often about 70 mm. It should be noted that for Zed purlins, the widths of the top flange and of the bottom flange differ slightly in order to make the purlins continuous by fitting them together.

While for hot-rolled section purlins, the span length does not generally exceed 10 m, for cold-formed sections, the span lengths may reach 12 to 15 m, allowing the number of portal frames to be reduced. These values relative to the spans may be different from one country to the other.

2.2.2 Proprietary systems

Thin gauge cold-formed purlins and side rails are often supplied as proprietary systems that are specified from manufacturers’ data. The design data are usually calculated using empirical models based on an extensive programme of tests. These tests take account of the direction of loading (downward and uplift) and the interaction between the profiled metal cladding and the purlins.

Where proprietary systems are used, it is normally adequate for the structural engineer to choose the appropriate section size from the manufacturer’s load/span tables or software without performing additional design checks on the purlin resistance. This approach is justified by the fact that the manufacturers have undertaken the necessary structural evaluation themselves (by analysis, testing, or a combination of analysis and testing) in accordance with the relevant Codes, Standards and Regulations.

2.3 Lattice purlins

These are seldom used.

Lattice-purlins with parallel chords can be designed, as shown in Figure 2.2. The main issues involved in designing this type of purlin are those associated with the design of all lattice beams:

- Controlling secondary deflection moments caused by:
  - The continuity of bars or the end restraint of the bars on each other
  - Any eccentricity in the diagrams of internal forces
  - Loads applied between nodes
- Controlling additional movement due to the clearance in the bolted connections

The $L/H$ ratio is approximately 15.
In the lattice-purlins section, we can classify the triangulated beams carrying a saw-tooth roof (see Figure 2.3), spanning between main lattice beams: this design is still used for building workshops (e.g.: automobile industry). The north-facing, sloping glass roof provides effective natural lighting.

Another major parameter of a purlin structure design is the function given to the roofing. Can the roofing be used to stabilize the purlins laterally?

It is important that the option chosen be clearly defined in the contractual documentation, particularly if construction of the steel structure, on the one hand, and that of the roofing, on the other hand, are entrusted to different companies (which is often the case in certain countries, especially France). Such contractual clarification enables all those involved to allow for the same assumptions.
3.1 Case where roofing is made of profiled steel sheets, either combined or not combined with other materials, and screwed to the purlins

Stabilizing the purlins via the roofing is covered in EN 1993 1-3.

If the contractual documents exclude such use for the roofing, the construction is said to be “class 3”, in the sense of EN 1993 1-3. If, however, the contractual documents do require such use for the roofing, the construction is said to be “class 2”. For completeness, in a “class 1” construction, the roofing is used for overall stabilization of the building (not the case envisaged here).

In a class 3 construction, whatever the type of purlin (hot-rolled sections – IPEs – or cold-formed purlins):

- The component of gravity loads along the slope of the roof pitch (see Figure 1.1) is taken up by lateral deflection of the top flange of the purlins. All that needs to be done is to control the stresses and displacements caused by this deflection, by providing a sufficient number of sag bars (see Section 5). The magnitude of these lateral displacements must be strictly limited in order for them to be compatible with the assumption that forces will not be transmitted to the horizontal plane of the roofing (for example, 1/500 of the distance between sag bars).

- The purlins must be stable under lateral torsional buckling (and buckling if they have a strut function) without having recourse to the roofing.

In a class 2 construction:

- The component of gravity loads along the slope of the roof pitch is transmitted by the roofing direct to the main structure (portal frames, for example), without subjecting the purlins to lateral deflection.

- The purlins are held, under lateral torsional buckling, by the roofing:
  - A rigid hold for lateral torsional buckling is provided when the compressed flange is the one on which the roofing is screwed (general case: compressed top flange of the purlins under a sagging bending moment)
  - A semi-rigid hold for lateral torsional buckling is provided when the compressed flange is not the one on which the roofing is fixed (general case: compressed bottom flange of the purlins under a negative bending moment). This semi-rigid hold is produced by the purlin-roofing end restraint; see Figure 3.1.

- The roofing takes on a structural function:
  - The party responsible for designing the purlin structure must also take into account stabilization of the purlins by the roofing, when defining the forces produced in the horizontal plane of the roofing (functioning as a diaphragm)
  - The party responsible for designing the roofing must take account of these interface forces when justifying the resistance of the product implemented and its fastenings.
  - The owner of the building is responsible for using no fittings in the building which could alter the resistance of the horizontal section of the roofing, as accounted for in the purlin study.
It is clear that stabilization of the purlins by the roofing allows for **important saving of the cost for the purlins because of smaller sections and reduced number (or elimination) of sag bars.**

This gain is obtained at the cost of introducing interface forces in the horizontal section of the roofing. In the majority of cases, these forces have no influence on the roofing dimensioning (they are usually low with respect to the capacity of the horizontal plane of the roofing). Particular attention should, however, be paid to the resistance of connection points between the roofing-diaphragm and main structure (see section 5) where the transmission of forces in the horizontal plane of the roofing are concentrated.

Note should also be made of the change in “administrative status” of roofing that takes on a structural role.

Reminder: stabilization of purlins by a roofing of screwed profiled steel sheets has for a long time been implicitly used because it is physically indisputable that such roofing, in its horizontal plane, is significantly stiffer than the purlins acting in side deflection. With the classification defined by EN 1993 1-3, the use of this roofing is explicit.

![Diagram](Figure 3.1)  
**Figure 3.1**  
**Stabilizing the bottom flange by the flexible purlin-roofing end restraint**
Each stabilized purlin transmits interface forces to the roofing. The hatched roofing panel forms a diaphragm resting on the two portal frames (main structure) which border it: the function of this diaphragm is to transmit all the interface forces applied to it by the purlins, to the main structure, without the purlins being deflected laterally. It should be ensured that the diaphragm-main structure connection is sufficiently resistant.

The loading in the plane of the roof is only represented for one panel, the panel being delimited by two rafters.

Figure 3.2 Plan view of a roof pitch – basic diaphragm between portal frames

3.2 Other materials

For other roofing materials that behave in a similar way to profiled steel sheets, a similar approach can be adopted.

For translucent materials (roof lights) used in industrial buildings to create natural light, it is usual not to consider them suitable for stabilizing purlins.

If it is wished to maintain the diaphragm function of a roofing primarily made up of screwed profiled steel sheets, into which translucent elements (roof lights) are incorporated, the following rules must be observed:

- No translucent plate (roof lights) should be placed within at least a 1 metre strip on either side of the centre line of the portal frame or of the beam supporting the purlins.
- The ridging purlins and low part of the roof pitch cannot be used to support the translucent plates (roof lights).
- All translucent plates (roof lights) are carried by 2 supports only and are always inserted along the roof pitch between two steel plates.
4. Continuous purlins

4.1 What continuity provides: deflections, moments, reaction forces on supports

The fact of making a roofing purlin continuous on 3 supports or more considerably alters the stresses and deflections.

For a purlin under uniaxial deflection (along its strong inertia):

- **Maximum deflection under the effect of a uniformly distributed load q:**
  - Statically determinate purlin, on 2 simple supports: \( f_0 = 5 q L^4/(384EI) \)
  - Purlin on 3 supports, perfect continuity: \( f = 0,4 f_0 \)
  - Purlin on 4 supports and more: \( f = 0,5 f_0 \)

Making a purlin, subjected to a uniformly distributed load, continuous, enables its deflection to be halved (compared to the purlin on two simple supports).

- **Maximum moment under the effect of a uniformly distributed load q:**
  - Statically determinate purlin, on 2 simple supports
    \( M_0 = q L^2/8 \)
  - Purlin on 3 supports, perfect continuity
    \( M_{\text{min}} = -M_0 \) (on central support)
    \( M_{\text{max}} = 0,56 M_0 \) (on span)
  - Purlin on 4 supports and more
    \( M_{\text{min}} = -0,84 M_0 \) (on first and last intermediate supports)
    \( M_{\text{max}} = 0,63 M_0 \) (on interior spans)

Making them continuous on at least 4 supports reduces the absolute value of the main deflection moment.

- **Maximum reaction force on support under the effect of a uniformly distributed load q:**
  - Support receiving a statically determinate purlin on either side: \( R_0 = q L \)
  - Purlin on 3 supports, on central support: \( R = 1,25 R_0 \)
  - Purlin on 4 supports and more, on the 1st intermediate support: \( R = 1,1 R_0 \)

Making purlins continuous increases the reaction force of the purlins on certain supports. This should be taken into account when dimensioning support structures (portal frames, for example).

The following conclusions can be drawn from the above:

- Making purlins continuous is of particular advantage when the deflection criterion is predominant and, therefore, for use with long spans (above around 6 m)
If the purlins are continuous along the whole length of the building, the reaction force on the first and last intermediate supports is increased with respect to the statically determinate distribution.

If the purlins are made continuous by sections along the length of the building, minimization of the increased force on certain portal frames will be sought by moving the supports with increased reaction force from one purlin line to another (especially if the purlins are made continuous by dual-span sections).

Note: in some countries, IPE purlins are designed as a “Gerber system” with hinges placed to get equal moments at supports and in the spans (generally one hinge in each span).

4.2 Methods for making IPE purlins continuous

It is usual to make rolled section purlins (IPEs) continuous by a bolted assembly.

Two types of assembly are possible:

- Assembly in which the forces transmitted are perpendicular to the bolt shanks
- Assembly in which the forces transmitted are parallel to the bolt shanks

In both types of assembly, it is usual not to use controlled prestressed bolts, but rather what are called “ordinary” bolts. This means that in the first assembly family, the bolts act in shear/bearing (and in the second, the bolts are act in tension).

The most widely-used practice is continuous splice connection using bolts in shear/bearing, as shown in Figure 4.1.
1 Splice connection on support: the most common case. Check splice connection-cleat compatibility (see Section 5)
2 Splice connecting moved with respect to the support
3 Channel section

Continuity is achieved by a web splice connection of the two purlin sections that are to be made continuous: the flanges are not connected because connecting the top flange would impede the purlin roofing support; connecting the bottom flange would impede the main structure purlin support if continuity is carried out on supports.

Splice connection is symmetric with respect to the horizontal section of the web (a splice connection on either side): the bolts work by two shear planes.
Note: restricting the oversizing of the bolt holes may avoid having only partial continuity (see illustrative calculation in Section 4.4)

**Figure 4.1** Continuous splice connecting with bolts acting in shear/bearing

Continuity is achieved by using butt welded end plates at the end of each purlin section and bolted together. Outer bolts cannot be used on the top flange side because these would impede laying of the roofing. Outer bolts (drawn in blue dots) can only be used on the bottom flange side if the continuity joint is moved away from the support; this arrangement, however, is only of interest if the bottom flange is under strong tension in the section where continuity is being carried out, which is rare.

The usual arrangement for end plate connections is thus without outer bolts.

Continuity using splice connections is more often used than end plates because it makes assembly easier.

**Figure 4.2** Continuity using end plates and bolts acting in tension
4.3 Methods for making cold-formed purlins continuous: cases where Zed sections fit together and Sigma sections are splice connected

In all industrialized purlin structure systems based on cold-formed sections, purlin continuity is achieved on supports, for ease-of-assembly.

- Continuity of **Zed purlins** is achieved by fitting one section into another:

![Diagram showing continuity of Zed purlins](image)

- **T1, T2, T3, T4**
- **R 1-2** Overlap zone 1-2

*Figure 4.3  Continuity of Zed purlins*

Overlapping is achieved by making the sections longer than the span length. In general, this additional length is approximately \(0.1 \, L\) after each support (a typical section thus having a length of \(1.2 \, L\)). For the edge sections, a little more additional length is often given, approximately \(0.15 \, L\) after the first intermediate support, due to the fact that the moment on this support has the maximum absolute value (an edge section thus has a length of \(1.15 \, L\)).

The rigidity of the assembly, especially in cases of short overlapping, must be assessed by testing (or experience).

- The continuity of the **Sigma purlins** is achieved by connecting splices.

  The splice connections are generally cold formed, like the purlins, but using thicker steel sheeting (approximately 4 mm). This method of manufacturing gives them a form perfectly suited to their function, and continuity is achieved both bolts in shear/bearing (as shown in Figure 4.1) and by fitting the splice connection into the web of the Sigma profiles.

  Given the form of the section of the purlins, the splice connection is placed on a single side, with the bolts acting in shear in one plane.

  The rigidity of the assembly, especially in cases of short overlapping, must be assessed by testing.

4.4 Semi-rigidity of continuous assemblies: simple calculation illustrating the development of rotation due to the clearance in short splice connections

Care should be taken in view of the fact that the benefits of continuous purlins may quickly be lost if the assembly made between two consecutive sections is not sufficiently stiff.

EN 1993-1-3 further requires that any semi-rigidity of this assembly be taken into account for...
calculating stresses and deflections. This stipulation must be extended to all types of purlin, either IPE or thin gauge cold-formed.

If we take the example of a 10 m two span purlin, made continuous by a splice connection:

![Diagram of two span purlin](image)

**Figure 4.4  Example: two span purlin**

The total length of the splice connection is 1 m (500 mm on either side of the support); the splice connection assembly on each purlin section is achieved using 4 x 16 mm diameter bolts, within 18 mm diameter holes (2 mm of clearance).

This clearance allows a rotation of $4/350 = 0.0114$ rad, which corresponds to the release, at the support, of a moment of $0.0114 \times (3EI/L)$.

If we suppose that the purlin has been dimensioned by the deflection criterion of $L/200$ to the SLS, using the assumption of perfect continuity:

$$L/200 = 2 \frac{q_{SLS} L^4}{384 EI} \rightarrow EI = 400 \frac{q_{SLS} L^2}{384}$$

The moment released at support is: $0.0114 \times 1200 \frac{q_{SLS} L^2}{384} = \frac{q_{SLS} L^2}{28}$

The additional span deflection is approximately: $(q_{SLS} L^2 / 28)(L^2 / 16) = \frac{q_{SLS} L^4}{(448EI)}$

The deflection has therefore increased by 43% and is no longer acceptable.

**Attention should thus be paid to controlling any clearance in continuity assemblies.**

5. **Connection of purlins to the main structure**

5.1 **Function of purlin/main structure connections**

The function of these connections is to transmit the forces applied to the roofing (everything comprising the purlin structure and the roofing) to the main structure.

The forces transmitted have:

- a component perpendicular to the roof pitch horizontal plane, upwards or downwards
- a component parallel to the roof pitch horizontal section, generally in the direction of the slope.

The component perpendicular to the roof pitch results from the deflection of the purlin along its strong inertia. The component parallel to the roof pitch is caused:
Either by the lateral deflection of the top flange of the purlin, if the roofing does not have a stabilizing function.

Or by the roofing functioning as a basic diaphragm, if it is given a stabilizing function (see Section 3)

5.2 Different types of connection

The purlin / main structure connection can be achieved:

Either (1) by direct bolting of the bottom flange of the purlin to the top flange of the main beam (in general, portal-frame rafter)

Either (2) by means of a single or double cleat

Or (3) via a double angle on the main beam web

Solution (2), via a cleat, is the one most used because it is the easiest to assemble and also because it provides the required rigidity to the connection with respect to the forces parallel to the roof pitch. Furthermore, in the case of thin cold-profiled purlins, it avoids the problem of crippling of the web on the support.

Solution (3) is rarely used.
Solution 1: Direct bolting of the purlin to the flange of the portal frame rafter. Under the effect of an uplift force, the bottom flange of the purlin is deflected and the fastening bolts are in tension. Under the effect of a force parallel to the roof pitch, the purlin web is deflected.

Solution 2-a: Assembly using a simple cleat: the cleat is made by means of a folded flat plate strip; it is dimensioned when deflected under the effect of an uplift force and a force along the roof pitch. This type of fastening is only suitable for moderate forces.

Solution 2-b: Assembly using a double cleat: allows greater forces to be transmitted.

Solution 2-c: Assembly using a stiffened double cleat

Note: Attention should be paid to compatibility between cleat and continuity splice connection, when splices are located at supports.

Solution 3: Assembly using twin angles for each purlin section for connection to the bearing beam web (portal frame rafter)

Key:
1 Roofing
2 Purlin
3 Top flange of portal frame rafter

Figure 5.1 Different types of purlin / main structure connections
Connection using a flat folded single cleat for Sigma purlin – the purlin is “suspended” to avoid local compression of the web – also used for fitting together Zed purlins.

The same connection, with stiffened cleat

Figure 5.2 Different types of purlin / main structure connections for Sigma purlin or Zed purlin

6. Sag bars and batten plates

6.1 Functions of sag bars and batten plates

Roofing purlin coupling has the following functions:

- During assembly of the building, to ensure that the purlins are straight before laying the roofing:
  - To ensure correct roofing / purlin fastenings (self-tapping screws in the flat part of the purlin flange)
  - To obtain a satisfactory appearance of the purlins as seen from inside the building
  - Not to disturb the structural behaviour of the purlins

- During use of the building, to hold the purlins laterally:
  - In connection with the roofing, if the roofing is to have a diaphragm function to stabilize the purlins
  - Autonomously, if the roofing does not have a stabilizing function (see Section 3)

Holding the purlins laterally implies:

- Restricting the span length of the stabilized purlin (or of its insulated top flange) with respect to lateral forces (along the roof pitch)
- Restricting the lateral torsional buckling length under negative and/or positive bending moment
- Restricting the lateral buckling length for compressed purlins (those with a strut function)

In order to fulfil these functions correctly, a stiff structural element must be created in the horizontal section of each roof pitch: the sag bars alone are not sufficient (the sag bars alone even out the lateral displacement of the purlins but do not eliminate it), they must be joined
with “batten plates”, which form a lattice-beam in the roof pitch and whose chords are two adjacent purlins, the stanchions are the sag bars and the diagonals are the batten plates.

This lattice-beam is generally formed at the top of the roof pitch in such a way that the sag bars are in tension under gravity loads, except for their upper section (at lattice-beam level), the batten plates also being positioned so as to be in tension.

Along the length of the roof pitch, it may be necessary to place an intermediate sag bar beam: allow for a course of batten plates at approximately every 15 metres of roof pitch.

If the roofing serves as a diaphragm, the stability of certain purlins may be justified without having to use sag bars; the sag bars (or equivalent elements) are still necessary however during erection.

The approximate width of spacing between sag bars is given by:

- Purlin span length lower than 6 metres: a mid-span sag bar
- Span length between 6 and 8 metres: two sag bars at one-third points
- Span length between 8 and 10 metres: three sag bars at one-quarter points

In the cases where the sag bars are only used for erection purpose (not necessary for resistance with roofing in place), these spacing values can be increased considering the erection process.

The elements described above are shown in Figure 6.1.

![Plan view of a roof pitch](image)

**Figure 6.1** Plan view of a roof pitch
6.2 Different types of sag bars

If sag bars are used, it is important that they are effective in the function they are given, primarily in the service phase of the building on which the roof is to be laid: are they to be used to laterally hold the top flange of the purlins? the bottom flange? both flanges?

The function given to sag bars is, as we have seen, dependent on the function given to the roofing. For example, if the roofing is given a diaphragm function (roofing in steel profiled sheets, screwed onto the purlins), the sag bars do not need to be given the function of stabilizing the top flange of the purlins (the one on which the roofing is screwed). If the purlin / roofing end restraint is sufficient, it may not be necessary to stabilize the bottom flange by the sag bars either.

If, however, the roofing has not been given a diaphragm function, the coupling of purlins is used for lateral stabilization:

- top flange: the sag bars form a support for the top flange with respect to the loads along the roof pitch, and with respect to lateral torsional buckling of the purlin under a positive bending moment (on a span under downwards loads, on supports under upwards loads)
- bottom flange: the sag bars thus form a support for the bottom flange with respect to lateral torsional buckling under a negative bending moment (on a span under upwards loads, on supports under downwards loads)

In order to be effective, the sag bars must be relatively stiff: an 8 mm diameter threaded shank placed at mid-height of the web (as sometimes seen) is generally ineffective; sag bars made of angle or tube sections are a preferred option. Other solutions, giving similar stiffness, are possible.
7. Characteristics of actions

7.1 Snow

Snow is often one of the predominant loads for dimensioning roofing purlins, particularly when the weight of the roofing itself is low. The weight of snow to be considered in the calculations depends on the area in which the building is constructed, the height of the site, and the shape of construction.

Attention should be paid in particular to accumulation phenomena (drifting) (non-uniform distribution of snow on the roofing) associated with the shape of constructions.
For cold-formed purlins, it is easy to obtain a greater resistance with constant profile height: all that is required is to increase the thickness of the sheeting used to form the purlin.

On the other hand, for IPE purlins, it is generally not economical to use HEBs of the same height, but better to adopt a solution which brings the purlins closer together in the area with the greatest load.

Figure 7.1 b) Same phenomenon along a long-section parapet (low part of a roof pitch): in this area, purlins with a higher resistance with constant spacing, or purlins closer together, are needed.

7.2 Wind

- Lifting of roofing in open buildings
  In a large number of common configurations, the force exerted by the wind on roofing is an uplift action. Great attention should be paid to openings in the vertical walls of the building which may cause a considerable increase in this uplift force. Significant uplift of the roofing has a great influence on the purlin structure design: compressed bottom flange of purlins in span (for restraining to lateral torsional buckling), cleats with high loads, etc.

- Downwards force of wind on buildings with a set back in elevation
  In some specific cases, the wind may cause a significant downwards force on one part of the roofing. This is particularly the case for roofing with a set back in elevation.
Key: 1 Wind direction
Area where the wind exerts a downwards force on roofing. Attention should be paid to accumulative effect with snow!!!

Figure 7.2 Downwards force of wind on roofing

- Compressed purlins
  When the gable of a traditional building is hit by wind (see Figure 1.2), the purlins serving as struts or wind-beam stanchions are compressed.

It is important during structural design, that any eccentricity in the transmission of these compression forces is controlled.

Figure 7.3 Design for a gable generating a strong moment in the purlin

7.3 Imposed loads

- Suspended loads
  The method for applying imposed loads inside a building influences the design of purlins.

  The loads suspended from the bottom flange may generate local stresses which should be restricted as much as possible:
Gravity loads have a component along the roof pitch which produces a lateral deflection of the bottom flange: to reduce this deflection, these loads should be passed on to the nearby sag bars stabilizing the bottom flange.

The loads hanging from the edge of the flange cause this flange to deflect (stress perpendicular to the general stresses in longitudinal direction, and which accumulate in a Von Mises combination).

Equipment placed on roofing

When equipment is placed on roofing, the loads produced by their weight should obviously be taken into account in the purlin calculation. The influence they have on the climatic loads on the roofing should also be assessed (accumulation of snow around equipment, local wind forces, snow + wind combinations).

Also worth mentioning in this section are roof dormers in the form of arches, which exert a force at the base of the arch along their line of support (generally horizontal).

Figure 7.4  Roof dormer

7.4 Maintenance loads

A roofing load which is sometimes forgotten when dimensioning purlins is the maintenance load. It may have an important influence when the roofing is waterproofed with many layers, insofar as the maintenance load accounts for storage in the roofing for replacement materials during repair work.

The maintenance load, therefore, more frequently has a value per m$^2$ higher than that of snow (with which it is not combined, because it is considered that carrying out major work on roofing is avoided during snowy weather), and may therefore have a direct influence on the dimensioning of the purlins.

In addition, the maintenance load is local: it only affects a single span of continuous purlins, producing an increase factor for the bending moment on the span and deflection.

Attention should be paid to deflection of the purlins, so that the maintenance load does not create an opposite slope on the roofing (multi-layer roofing has a gradual slope): the combination of maintenance and snow load may be excluded but the possibility of heavy rainfall during repair work should not be excluded. The presence of an opposite slope thus introduces a phenomenon of water accumulation (ponding).
7.5 Risks of water accumulation: melting snow, rain

Roofing with a gradual slope (lower than 5%) is sensitive to water accumulation phenomena (ponding) (EN 1993 1-3 also requires that these be taken into account, but does not indicate how).

Scenario example: under the effect of heavy snow fall, purlins and roofing are deformed. If these deformations are such that the roofing slope is inverted, when the snow melts, the flow of thawed water downwards is prevented and pools form. The more flexible the roofing and purlins, the deeper and larger the pools. The water load may become greater than the snow load, or even greater than the resistance of the purlins. Furthermore, a succession of snowfalls, thawing, snowfalls and thawing, etc. cannot be excluded and aggravates the phenomenon. It is therefore important to design a sufficiently stiff purlin structure so that the water from the melted snow can always run off: no opposite slope under the ULS load combinations incorporating the snow load: this is one of the rare examples where it is important to check deformation criteria for ULS combinations.

Another scenario example: when a multi-layer roof is being repaired, purlins and roofing are deformed under the effect of the maintenance load. If these deformations are such that the roofing slope is inverted and there is a heavy rainfall, its flow is prevented and the phenomenon of accumulation begins, etc. It is thus important to design a sufficiently stiff purlin structure so that rain water can flow away in such circumstances: deformation criterion to be checked under ULS combinations, including the maintenance load.
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