Conceptual Design and Determination of Action Effects for Single-Storey Buildings

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The client guide presents the benefits that steel construction can provide to the owners and occupiers of single storey buildings. It offers guidance to clients on how to obtain best value from steel construction.

1. Introduction
2. The European market for single story steel buildings
3. Advantages of steel for single storey buildings
4. Achieving value from the whole: Form of contract and choice of suppliers
5. Overall design issues
6. Conclusions
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Introduction

Single storey buildings contribute substantially to the built environment of Europe. They accommodate manufacturing, warehousing, transport, sports, retail and leisure activities.

Steel construction can offer the occupants, owners and developers for these wide ranging activities exceptional value, as evidenced by the overwhelming market shares that it achieves in some European countries.

The purpose of this document is to:
• **Demonstrate the benefit** that steel construction can bring to its customers
• **Highlight the success of steel single storey construction** in major national markets
• **Illustrate the wide range of steel solutions** that are available.
• Give some **guidance on how to obtain best value from the market place.**
The European market

Market size and distribution
The European market for steel for single storey industrial buildings comprises approximately 100 million square metres of covered space per annum, with a value of about 6 billion euros.

Factors influencing choice of material
• presence of large developers who repeatedly procure single storey buildings
• development of supply chain teams of main frame manufacturers, purlin and side rail system suppliers, cladding manufacturers and equipment (e.g. doors) suppliers who work efficiently together in long term relationships.
• wide spread use of forms of contract that suit this form of construction (e.g. Design and Build in the UK).
• strong industry infrastructures that support the supply chain, for example by ensuring that design, construction and contractual guidance is readily available and that the regulatory framework is benign for steel

Advantages
• Speed of construction
• Flexibility in use
• Maintenance
• Sustainability
• Value for money
• Examples

Kingswood Lakeside Business park, Cannock
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Kingswood Lakeside Business park, Cannock
In a single storey building, the contributions to the overall value of the superstructure are typically:
- Primary frames 35%
- Secondary structure, purlins and side rails 15%
- Cladding 50%

All three components are clearly important individually. As discussed in more detail below, there are also very significant structural and performance interactions between these three components. All components are supplied by specialists. Whatever form of contract is adopted, it is therefore essential that all significant suppliers have an opportunity to contribute to the development of the design and construction specification, if client value is to be maximised.

Overall Design Issues

- General
- Choice of primary frame
- Interdependence of frames and envelopes
- Energy performance
- Air-tightness
- Design Coordination
- Mainly architecture
- Mainly Engineering
- Influences on structural design and costs
- Sustainable constructions
  - Economic considerations
  - Social aspects
  - Environmental considerations
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For single storey buildings, steel offers:

- Cost efficiency in construction
- Low maintenance throughout a building’s life
- Long spans that can accommodate changes in building occupancy and activity, thus extending a building’s economic life.
- Highly sustainable contributions to Europe’s Built Environment.
- Single storey steel buildings are one of the most efficient sectors in the construction industry, with optimised approaches to the primary frames, secondary structure and cladding from specialist suppliers.
- Single storey steel buildings should be provided in a way that ensures that all the specialist suppliers can make maximum contributions to overall client value.
-Clients should interact with both the design and supply teams to ensure best value for their projects.
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Access Steel highlights the benefits of steel as the primary construction material through detailed short case studies of successful buildings

- New Air Cargo Hub for DHL at Nottingham East Midlands Airport, UK
- ELUZ Building in Croissy-Beaubourg, France
- Airforge building, Pamiers, France
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New Air Cargo Hub for DHL
(45 million euro warehouse and office complex)

- 40 000 m² warehouse and truck canopy
- 9 000 m² office spans on 3 floors
- 30 truck bays and parking for 90 trucks
- 620 car parking spaces for staff and visitors
- 6 000 m² ramp equipment parking
- New, 165 000 m² apron providing 18 aircraft stands
- On-site refuelling for DHL trucks
- New roundabout to service the Hub
- Realignment of the A453
- New internal access roads
- 2 new balancing reservoirs with full pollution control system (holding 70 000 m³ of water)

ELUZ Building

- Construction of a single storey building covering a 7000 m² area without any internal column, in order to set up racks to store the products that the ELUZ company sells.
- Span of the main frames: 84 meters
- Height of the building at the top of the roof: 15 meters
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10 500 m² of industrial building carrying cranes with a capacity up to 140 t
5 halls of various spans: 16 m, 23 m, 22 m and 2 × 23 m
The total length of the building is 98 m and the main hall is 22 m high
1365 tons of structural steelwork completed in 8 months

Typical heavy industrial building,
with a height of 22 m and spans of up to 23 m.

15 documents

Concise information on proposal development guides the architect and engineer through all the decisions that have to be made to develop a best practice design

- Overview of structural system and form and function of mainframes
- Conceptual design (roofs, walls etc.)
- Form and function of purlins and side rails
- Conceptual design of portal frames from fabricated sections
- Conceptual design of truss and column solutions
- Eaves details / Apex (ridge) details
- Valley details for multiple bay roofs
- Overview of fire
- Movement joints / Expansion joints
- Corrosion
Airforge Building

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Overview of structural systems

This document describes the range of structural systems that are commonly used for long span single storey buildings. The descriptions include the main structural frames, secondary systems such a bracing and the purlins and rails to support the cladding.

1. Overview of applications for single storey buildings
2. Basics for design
3. Typical structural frame solutions
4. Connections
5. Acknowledgement

Overview of applications

- wide range of buildings, from small homes to the largest covered spaces, such as exhibition halls and stadia.
- Large buildings will use multi-span structures and may, on occasion, cover 100 000 m².
- origin of building form in industrial building and this description is still often applied but it is misleading
- uses are many and varied with considerable usage by the general public.
- Typical end uses
  - retail,
  - distribution centres,
  - call centres,
  - leisure facilities
  - indoor sports facilities.
- greater focus on the envelope in terms of aesthetics, insulation, airtightness etc. 
- title of industrial buildings has therefore been replaced by the broader term, single storey buildings.

While there has been considerable change in the appearance the basic structural forms have changed little other than to evolve in the details needed to support more varied cladding forms as described in later sections.
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Overview of components

1. Steel roof cladding
2. Primary steel frame
3. Side rails
4. Purlins
5. Wall cladding

Typical single storey building

Structural principles for frames

Layout with braced gable frames
1 Gable bracing
2 Roof bracing
3 Longitudinal bracing

Layout with portalised gable frames
1 Portalised end frame

Moment frame for stabilization in longitudinal direction
Overview of components

1. Steel roof cladding
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Moment frame for stabilization in longitudinal direction
Portal Frames

(a) Portal frame – medium span

(b) Curved portal frame

(c) Portal frame with mezzanine floor

(d) Portal frame with overhead crane

(e) Two bay portal frame

(f) Portal frame with integral office

(g) Mansard portal frame

(h) Portal frame from welded plates
Typical structural frame solutions

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Typical structural frame solutions

Innovative moment-resisting connections in an industrial building

Valley beam details for "hit" and "miss" frame

Installation process for modern portal frames

Overview    Client Guide    Case Studies
Scheme Development    Flow Charts    NCCI    Examples

Typical structural frame solutions

Secondary members

Figure 3.15  Restraints system at hinge positions

Typical purlin/rail solutions

Zed purlin  Modified Zed

C purlin  Sigma purlin

Support for continuous cold-formed Z-shaped purlin  Support for continuous hot-rolled purlin  Support for single-span hot-rolled purlin

Possible solutions for purlin to rafter connections

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Figure 3.15 Restraints system at hinge positions

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Possible solutions for purlin to rafter connections

Support for continuous cold-formed Z-shaped purlin

Support for continuous hot-rolled purlin

Support for single-span hot-rolled purlin
Connections

Each design activity is described separately by a flow chart:

- Plastic analysis of a portal frame
- Evaluation of wind loads
- Global analysis and overall cross-section checks
- Global analysis (elastic) of class 2, 3 or 4 sections
- Verifying out of plane stability
- Elastic design, uniform sections (rafter or column)
- Design of eaves / apex connections
- Design of fixed / pinned base connections
- Design model for welded joints in trusses using structural hollow sections
- Design of compression chord splices
- Purlin / side rail design
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- Design of compression chord splices
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This flowchart illustrates the process of plastic analysis for portal frames. The output of the analysis is the design forces and moments in members and connections.

**Overview**

1. **Material and cross section properties**
   - EN 1993-1-1 §5.6

2. **Vertical loads and horizontal reactions**
   - EN 1993-1-1 §5.3.2(4)B

3. **Calculate initial sway imperfection $\phi$**
   - EN 1993-1-1 §5.3.2(3)

4. **Evaluate design value of axial force in each column $N_{Ed}$ for each column**

5. **Add the equivalent horizontal forces $N_{Ed}$ at top of each column to the applied loading**
   - EN 1993-1-1 §5.3.2(7)

6. **Determine sensitivity to sway, calculate $\alpha_{cr}$**

7. **(For frames outside limits of Notes 1 & 2 to EN1993-1-1 §5.2.1(4))**
   - $\alpha_{cr} \geq 15$

8. **Determine member design forces for sway frames**
   - Second-order by amplified loads
   - Can start with $M_{pl,Rd} = M_{pl,Rd}$

9. **Calculate $M_{pl,Rd}$ for elements**
   - EN 1993-1-1 §6.2.10
   - EN 1993-1-1 §6.2.9(2), (4), (5)

10. **Perform First Order Plastic Global Analysis**
    - Design forces for elements and locations of hinges

11. **Recalculate $M_{pl,Rd}$ for elements**
    - Proceed to verification of elements (beams, columns & connections). **Members in compression should be checked taking the buckling length not higher than the system length.**
    - Values of $M_{pl,Rd}$ used in the analysis OK?
      - Yes
      - No

12. **Design forces for elements and locations of hinges**
    - If the axial forces are greater than assumed when $M_{pl,Rd}$ calculated, recalculate

13. **Stop**
This flowchart illustrates the process of plastic analysis for portal frames. The output of the analysis is the design forces and moments in members and connections.

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9. **Design forces for elements and locations of hinges**
   - EN 1993-1-1 §6.2.10
10. **Recalculate $M_{N,Rd}$ for elements**

**Requirements applicable to hinge positions should be met at the anticipated positions. Confirm later that actual positions are as anticipated.**

**Values of $M_{N,Rd}$ used in the analysis?**
- **Yes**: Stop
- **No**: Proceed to verification of elements (beams, columns & connections). **Members in compression should be checked taking the buckling length not higher than the system length.**
Determine member design forces for sway frames

1. **Start**
   - Check each column and introduce equivalent horizontal forces where condition is fulfilled, excluding those with hinges at both ends.

2. EN 1993-1-1 §5.3.2(6)
   - \( \alpha_{cr} \geq 3 \)
   - If true, continue; if false, go to **No**.

3. EN 1993-1-1 §5.3.2(3)+(7)
   - Calculate horizontal forces equivalent to initial bow imperfections
   - Add the equivalent horizontal forces (bow) to the existing loading

4. The equivalent forces representing sway imperfections were added into the loading in the preceding page

5. Select method of allowing for sway effects
   - Second-order by amplified loads
     - If \( a_0 \geq 3 \), continue; if not, go to **No**.

6. EN 1993-1-1 §6.2.9
   - Allow for second-order effects by amplifying all actions on structure
   - Design forces for members & connections, and locations of hinges

7. EN 1993-1-1 §6.2.10
   - Perform second order elastic-plastic global analysis
   - Ensure that values of \( M_{N,Rd} \) are appropriate to the axial forces in the members

8. SN033
   - Geometry
     - OK for use of amplified loads method?
       - Yes: Return to B
       - No: Go to **No**
Determine member design forces for sway frames

1. Check each column and introduce equivalent horizontal forces where condition is fulfilled, excluding those with hinges at both ends.

2. Select method of allowing for sway effects:
   - Second-order by amplified loads

3. Calculate horizontal forces equivalent to initial bow imperfections:
   - EN 1993-1-1 §5.3.2(6) ≤ 3\sqrt{\frac{\text{EN}}{N_{\text{cr}}}}
   - EN 1993-1-1 §5.3.2(3)+(7)

4. The equivalent forces representing sway imperfections were added into the loading in the preceding page.

5. Second order analysis can be used for any magnitude of sway parameter α_{cr}. However, the amplification of actions allows first-order analysis to be used if second-order elastic-plastic software is not available.

6. Select method of allowing for sway effects:
   - Second-order by amplified loads

7. Design forces for members & connections, and locations of hinges:
   - Allow for second order effects by amplifying all actions on structure

8. Ensure that values of M_{cr,Ed} are appropriate to the axial forces in the members:
   - EN 1993-1-1 §6.2.9
   - EN 1993-1-1 §6.2.10

9. Perform second order elastic-plastic global analysis:
   - Design forces for members & connections, and locations of hinges

10. Return to B or A as necessary.
This flow chart presents the design procedure for uniform sections (rafter or column) in portal frames.

1. **Start**
   - **Elastic design action effects**
     - $N_{Ed}, V_{Ed}, M_{y,Ed}, M_{z,Ed}$

2. **Classify cross-section**

3. **Element dimensions and material properties**

4. **Check if element subjected to shear and**
   - $\frac{M_{Ed}}{M_{Rd}} < \frac{\eta}{\varepsilon}$
   - $\theta < 72^\circ$
   - $\frac{t}{w} < \frac{\theta}{\varepsilon}$

5. **EN 1993-1-5 §5.3**
   - Determine effective cross-section properties

6. **EN 1993-1-1 §6.2.2.5**
   - Determine effective cross-section properties

7. **EN 1993-1-1 §5.5**
   - **Check if element subjected to shear and**
     - $\frac{M_{Ed}}{M_{Rd}} < \frac{\eta}{\varepsilon}$

8. **EN 1993-1-1 §6.2**
   - Determine design resistances of cross-section

9. **EN 1993-1-1 §6.3.3 (4)**
   - **Determine buckling resistance of cross-section**
   - **M_{Ed}, V_{Ed}, N_{Ed}**

10. **Check if element subjected to shear and**
    - $\frac{M_{Ed}}{M_{Rd}} < \frac{\eta}{\varepsilon}$

11. **EN 1993-1-5 §5.3**
    - Determine shear buckling resistance for webs

12. **Determine buckling resistance OK?**
    - Yes
      - Revise element size and reanalyze frame
    - No
      - Redetermine length between lateral or torsional restraints

13. **Elastic design action effects**
    - $N_{Ed}, V_{Ed}, M_{y,Ed}, M_{z,Ed}$

14. **Determine effective cross-section properties**

15. **Determine shear buckling resistance for webs**

16. **NOTE:** $\eta$ may conservatively be taken equal to 1,0

17. **Determine buckling resistance OK?**
    - Yes
      - Stop
    - No
      - Revise element size and reanalyze frame

18. **Determine design resistances of cross-section**

19. **En 1993-1-1 §6.2**
    - Determine design resistances of cross-section

20. **Redetermine length between lateral or torsional restraints**

21. **Revise element size and reanalyze frame**

22. **Stop**
This flow chart presents the design procedure for uniform sections (rafter or column) in portal frames.

1. **Start**
2. **Classify cross-section**
3. **Check if element subjected to shear and**
   - **EN 1993-1-1 §6.2.2.5**
   - **EN 1993-1-1 §6.5**
4. **Determine effective cross-section properties**
   - **EN 1993-1-1 §5.3**
5. **Determine shear buckling resistance for webs**
   - **Y**
   - **EN 1993-1-1 §6.3.3 (4)**
   - **NOTE: Take interaction criteria into account**
6. **Redetermine length between lateral or torsional restraints**
7. **Determine design resistances of cross-section**
8. **Check if element subjected to shear and**
   - **EN 1993-1-1 §5.3**
   - **EN 1993-1-1 §6.2**
9. **Determine buckling resistance of cross-section**
10. **Redetermine length between lateral or torsional restraints**
11. **Determine buckling resistance OK?**
12. **REVISE element size and reanalyze frame**
13. **Stop**

**NOTE:** \( \gamma \) may conservatively be taken equal to 1.0.
Start

- **EN 1993-1-1 §6.3.1.2**
  - Determine non-dimensional slenderness for flexural buckling for both axis

- **EN 1993-1-1 §6.3.1.2 (4)**
  - \( \frac{N_{zz} \left( \lambda_z \right)}{N_{xx}} > 0.2 \) or \( \frac{N_{yy} \left( \lambda_y \right)}{N_{xx}} > 0.04 \)
  - Yes
  - \( \chi(\lambda) = 1.0 \)

- **EN 1993-1-1 §6.3.1.2**
  - Determine reduction factor \( \beta_1, \beta_2 \)

- **EN 1993-1-1 §6.3.2.2 (1)**
  - Determine non-dimensional slenderness for lateral torsional buckling
  - \( \chi \)

  - Use §6.3.2.2 for the “general case” or §6.3.2.3 for “rolled sections or equivalent welded sections”

- **EN 1993-1-1 §6.3.2.2 (4)**
  - Determine whether §6.3.2.2 or §6.3.2.3 applies
  - Use 0.2 for §6.3.2.2 or 0.4 for §6.3.2.3

- **EN 1993-1-1 §6.3.2.2 (1)**
  - Determine interaction criteria

Flow Charts – Element elastic design
Flow Charts – Element elastic design

Start

EN 1993-1-1 §6.3.1.2

Determine non-dimensional slenderness for flexural buckling for both axis

EN 1993-1-1 §6.3.1.2 (4)

No

Yes

Determine reduction factor \( \lambda_{1}, \lambda_{2} \)

EN 1993-1-1 §6.3.1.2

EN 1993-1-1 §6.3.2.2 (1)

Determine non-dimensional slenderness for lateral torsional buckling

EN 1993-1-1 §6.3.2.2 (4)

Determine reduction factor \( \xi_{1}, \xi_{2} \)

Determine whether §6.3.2.2 or §6.3.2.3 applies

Use §6.3.2.2 for the "general case" or §6.3.2.3 for "rolled sections or equivalent welded sections"

EN 1993-1-1 §6.3.2

EN 1993-1-1

EN 1993-1-1 Annex A

EN 1993-1-1 Annex B

EN 1993-1-1 §6.3.3 (4)

Determine interaction criteria

Determine interaction factor \( k_{yx}, k_{xz} \)

Determine whether §6.3.2.2 or §6.3.2.3 applies

Use 0.2 for §6.3.2.2 or 0.4 for §6.3.2.3

Yes

No

\( \lambda_{1}, \lambda_{2} \)

\( \lambda_{1}, \lambda_{2} \)

\( \lambda_{1} = 1.0 \)

Return
This flow chart outlines the verification procedure for welded, uniplanar unreinforced joints in trusses using structural hollow section alone or in combination with open sections.
This flow chart outlines the verification procedure for welded, uniplanar unreinforced joints in trusses using structural hollow section alone or in combination with open sections.
Calculate axial joint resistance

SN040 Section 5

Yes

\[ N_{i,Rd} \leq N_{i,Ed} \]

SN040 Section 4

Revise structural geometry

SN040 Section 6

Determine the weld details and throat thickness

End

No

SN040 Section 5

Calculate, for the joint, axial resistance, in-plane moment resistance and out-of-plane moment resistance

\[ N_{i,Rd}, M_{op,i,Rd}, M_{in,i,Rd} \]

SN040 Section 5

Interaction formula OK?

Yes

Reanalyse

SN040 Section 6

Determine the weld details and throat thickness

End

No

Revise structural geometry

SN040 Section 6

Determine the weld details and throat thickness

End
Calculate axial joint resistance

\[ N_{i,Ed} < N_i, Rd \] ?

SN040 Section 4

SN040 Section 5

SN040 Section 6

Revised structural geometry

Determine the weld details and throat thickness

Reanalyse

End

Flow Chart – Design model for welded joints

SN040 Section 5

Calculate, for the joint, axial resistance, in-plane moment resistance and out-of-plane moment resistance

\[ N_{i,Ed}, M_{ip,i,Rd}, M_{op,i,Rd} \]

Interaction formula OK?

SN040 Section 5

SN040 Section 5

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Determine the weld details and throat thickness

Reanalyse

End

Flow Chart – Design model for welded joints
Non-contradictory, complementary information (NCCI) is presented that addresses all the information that the Eurocodes do not cover that is essential for design:

- Analytical models for trusses
- Design of asymmetric members under M&N
- Foundation stiffness for global analysis
- Practical analytical models for portal frames
- Design model for eaves / apex connections
- Design model for fixed / pinned base connections
- Deflection limits for single storey buildings
- Simple methods for second order effects
- Classification tables for rolled profiles
- General method for out of plane buckling
- Benefits of cladding
- Effective lengths of columns

This NCCI provides recommendations and guidelines for horizontal and vertical deflection for single storey buildings.

1. Introduction

No specific deflection limits are set in Eurocode 1993-1-1 [1]. According to EN 1993-1-1, § 7.2 and EN 1990 – Annex A1.4 [2], deflection limits should be specified for each project and agreed with the client. The National Annex to EN 1993-1-1 may specify limits for application in individual countries. Where limits are specified they have to be satisfied. Where limits are not specified, the following might be helpful when deciding relevant deflection limits.

2. Horizontal deflections for portal frames

![Definition of horizontal deflection](image)

Figure 2.1 Definition of horizontal deflection
Non-contradictory, complementary information (NCCI) is presented that addresses all the information that the Eurocodes do not cover that is essential for design.

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This NCCI provides recommendations and guidelines for horizontal and vertical deflection for single storey buildings.

1. **Introduction**

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2. **Horizontal deflections for portal frames**

![Definition of horizontal deflection](image)

*Figure 2.1 Definition of horizontal deflection*
### Deflection limits for single storey buildings

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure</th>
<th>Deflection limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Portal frames without gantry cranes</td>
<td>H/150</td>
<td>The values to the left are given in the French National Annex to EN 1993-1-1 and should be used if nothing else is agreed with the client. The values of the deflections calculated from the characteristic combinations should be compared to these limits.</td>
</tr>
<tr>
<td>France</td>
<td>Buildings with no particular requirements regarding the deflection:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Deflection at the top of the columns</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Difference of deflection between two consecutive portal frames</td>
<td>B/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Member supporting metal cladding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Post</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Rail</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Other single storey buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Buildings with particular requirements regarding the deflection (little walls, appearances...).</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Deflection at the top of the columns</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Difference of deflection between two consecutive portal frames</td>
<td>B/200</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td>There are no national deflection limits. The limits should be taken from manufacturers’ instructions (technical approvals) or should be agreed with the client.</td>
</tr>
<tr>
<td>Spain</td>
<td>Portal frames (without fragile elements susceptible to failure in the envelopes, façade and roof)</td>
<td>H/150</td>
<td>The values to the left are given in the national technical document for steel structures [3] and in the Technical Building Code [4] and should be used i</td>
</tr>
<tr>
<td>Spain</td>
<td>Single storey buildings with horizontal roofs (without fragile elements susceptible to failure in the envelopes, façade and roof)</td>
<td>H/300</td>
<td></td>
</tr>
</tbody>
</table>

### Deflection limits for single storey buildings

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure</th>
<th>Deflection limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>Portal frames without gantry cranes, with walls of :</td>
<td></td>
<td>There are no national deflection limits. The figures to the left are recommended in industry guidance [6].</td>
</tr>
<tr>
<td></td>
<td>Steel sheeting</td>
<td>H/100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- deflection at top of column</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fibre reinforced sheeting</td>
<td>H/300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- deflection at top of column</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brickwork</td>
<td>H/300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- deflection at top of column</td>
<td>H/150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Differential deflection between two consecutive portal frames</td>
<td>( \frac{H^2 + B^2}{660} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hollow concrete brickwork</td>
<td>H/200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- deflection at top of column</td>
<td>H/200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Differential between two consecutive portal frames</td>
<td>( \frac{H^2 + B^2}{500} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precast concrete units</td>
<td>H/200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- deflection at top of column</td>
<td>H/200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Differential deflection between two consecutive portal frames</td>
<td>( \frac{H^2 + B^2}{330} )</td>
<td></td>
</tr>
</tbody>
</table>
### Deflection limits for single storey buildings

**Table 2.1 Limiting horizontal deflection**

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure</th>
<th>Deflection limits ( u )</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Portal frames without gantry cranes</td>
<td>H/150</td>
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</tr>
<tr>
<td></td>
<td>Buildings with no particular requirements regarding the deflection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deflection at the top of the columns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difference of deflection between two consecutive portal frames</td>
<td>( B/150 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Member supporting metal cladding</td>
<td>( H/150 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>( H/150 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>( B/150 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other single storey buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buildings with particular requirements regarding the deflection (brick walls, appearance...)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deflection at the top of the columns</td>
<td>( H/150 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difference of deflection between two consecutive portal frames</td>
<td>( B/200 )</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
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<td></td>
<td>Single storey buildings with horizontal roofs (without fragile elements susceptible to failure in the envelopes, façade and roof)</td>
<td>H/300</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Portal frames without gantry cranes, with walls of:</td>
<td></td>
<td>There are no national deflection limits. The figures to the left are recommended in industry guidance [6].</td>
</tr>
<tr>
<td></td>
<td>Steel sheeting</td>
<td>H/100</td>
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</tr>
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<td></td>
<td>- deflection at top of column</td>
<td>H/150</td>
<td></td>
</tr>
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<tr>
<td></td>
<td>Brickwork</td>
<td>H/300</td>
<td></td>
</tr>
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<td>- deflection at top of column</td>
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<td></td>
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<td>Differential deflection between two consecutive portal frames</td>
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<td></td>
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<td>Differential deflection between two consecutive portal frames</td>
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<td></td>
</tr>
</tbody>
</table>
3. Vertical deflections for portal frames

![Diagram of a portal frame with deflections marked]

Figure 3.1 Definitions of vertical deflection of apex of portal frame

Recommended limiting values for vertical deflection are given in Table 3.1

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure Description</th>
<th>Deflection Limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Roofs in general</td>
<td>L/200 L/250</td>
<td>The values to the left are given in the National Annex to EN 1993-1-1 and should be used if nothing else is agreed with the client. The values of the deflections calculated from the characteristic combinations should be compared to these limits.</td>
</tr>
<tr>
<td></td>
<td>Roofs frequently carrying personnel other than for maintenance</td>
<td>L/200 L/100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roofs supporting plaster or other brittle toppings or non-flexible parts</td>
<td>L/250 L/350</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td>There are no national deflection limits. The limits should be taken from manufacturers instructions (technical approvals) or should be agreed with the client.</td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td>There are no national deflection limits.</td>
</tr>
<tr>
<td>UK</td>
<td>Portal frames without gantry cranes, with rafter slopes 3°</td>
<td></td>
<td>There are no national deflection limits. These figures are recommended in industry guidance [6].</td>
</tr>
</tbody>
</table>

Differential deflection relative to adjacent frame
- Metal sheeting and fibre reinforced sheeting: B 100
- Felted metal decking on purlins: B 100
- Felted metal supported on rafters: B 200
3. Vertical deflections for portal frames

![Diagram of portal frame with deflection limits](image)

**Figure 3.1** Definitions of vertical deflection of apex of portal frame

Recommended limiting values for vertical deflection are given in Table 3.1

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure Description</th>
<th>Deflection Limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Roofs in general</td>
<td>$W_{\text{max}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roofs frequently carrying personnel other than for maintenance</td>
<td>$W_{\text{max}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roofs supporting plaster or other brittle toppings or non-flexible parts</td>
<td>$W_{\text{max}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$W_{1}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$W_{2}$</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td>The values to the left are given in the National Annex to EN 1993-1-1 and should be used if nothing else is agreed with the client. The values of the deflections calculated from the characteristic combinations should be compared to these limits.</td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td>There are no national deflection limits. The limits should be taken from manufacturers’ instructions (technical approvals) or should be agreed with the client.</td>
</tr>
<tr>
<td>UK</td>
<td>Portal frames without gantry cranes, with rafter slopes $3'1'$</td>
<td></td>
<td>There are no national deflection limits. These figures are recommended in industry guidance [6].</td>
</tr>
</tbody>
</table>

Differential deflection relative to adjacent frame:
- Metal sheeting and fibre reinforced sheeting: $B_{100}$
- Felted metal decking on purlins: $B_{100}$
- Felted metal supported on rafters: $B_{200}$
4. Vertical deflections for horizontal roof members

4.1 Serviceability limit states

Guidance for the deflection limits are given in Table 4.1 for a selection of countries. Definition of vertical deflection in Annex A to EN 1990 is shown in Figure 4.1

\[ W_{\text{def}} = W_1 + W_2 + W_3 \]

\[ W_{\text{max}} \]: Remaining total deflection taking into account the precamber

**Table 4.1 Recommended limiting values for vertical deflections**

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure</th>
<th>Deflection limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Roofs in general</td>
<td>( W_{\text{max}} ): L/200</td>
<td>The values to the left are given in the National Annex to EN 1993-1-1 and should be used if nothing else is agreed with the client.</td>
</tr>
<tr>
<td></td>
<td>Roofs frequently carrying personnel other than for maintenance</td>
<td>( W_1 ): L/250</td>
<td>The values of the deflections calculated from the characteristic combinations should be compared to these limits.</td>
</tr>
<tr>
<td></td>
<td>Roofs supporting plaster or other brittle toppings or non-flexible parts</td>
<td>( W_2 ): L/300</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>Roofs in general</td>
<td>( W_{\text{max}} ): L/300(*)</td>
<td>The values to the left are given in the national technical document for steel structures [4] and in the Technical Building Code [5] and should be used if nothing else is agreed with the client.</td>
</tr>
<tr>
<td></td>
<td>Roofs with access only for maintenance</td>
<td>( W_1 ): L/250(*)</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Roofs with access for maintenance</td>
<td>( W_2 ): L/200</td>
<td>There are no national deflection limits. The figures presented are taken from industry guidance [6].</td>
</tr>
<tr>
<td></td>
<td>Roofs accessible to personnel other than for maintenance</td>
<td>( W_3 ): L/360</td>
<td></td>
</tr>
</tbody>
</table>

(*) This values refers to \( W_2 + W_3 \) but \( W_2 = 0 \) for steel structures.
4. Vertical deflections for horizontal roof members

4.1 Serviceability limit states

Guidance for the deflection limits are given in Table 4.1 for a selection of countries. Definition of vertical deflection in Annex A to EN 1990 is shown in Figure 4.1

\[ W_{\text{def}} = W_1 + W_2 + W_3 \]

- \( W_1 \): precamber in the unloaded structural member
- \( W_2 \): Initial part of the deflection under permanent loads of the relevant combination of actions
- \( W_3 \): Long-term part of the deflection under permanent loads, not to be considered for single storey steel buildings,
- \( W_{\text{max}} \): Additional part of the deflection due to the variable actions of the relevant combination of actions

\[ W_{\text{def}} = W_1 + W_2 + W_3 \]

\( W_{\text{max}} \): Remaining total deflection taking into account the precamber

---

### Table 4.1 Recommended limiting values for vertical deflections

<table>
<thead>
<tr>
<th>Country</th>
<th>Structure</th>
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<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Roofs in general</td>
<td>( L/200 )</td>
<td>The values to the left are given in the National Annex to EN 1993-1-1 and should be used if nothing else is agreed with the client. The values of the deflections calculated from the characteristic combinations should be compared to these limits.</td>
</tr>
<tr>
<td></td>
<td>Roofs frequently carrying personnel other than for maintenance</td>
<td>( L/250 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roofs supporting plaster or other brittle toppings or non-flexible parts</td>
<td>( L/300 )</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>There are no national deflection limits. The limits should be taken from manufacturers' instructions (technical approvals) or should be agreed with the client.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>Roofs in general</td>
<td>( L/300(*) )</td>
<td>The values to the left are given in the national technical document for steel structures [4] and in the Technical Building Code [5] and should be used if nothing else is agreed with the client.</td>
</tr>
<tr>
<td></td>
<td>Roofs with access only for maintenance</td>
<td>( L/250(*) )</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>There are no binding restrictions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Roofs with access for maintenance</td>
<td>-</td>
<td>There are no national deflection limits. The figures presented are taken from industry guidance [6].</td>
</tr>
<tr>
<td></td>
<td>Roofs accessible to personnel other than for maintenance</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

(*) This values refers to \( w_2 + w_3 \) but \( w_2 = 0 \) for steel structures.
4.2 Ultimate limit state: Ponding

Where the roof slope is less than 5%, additional calculations should be made to check that collapse cannot occur due to the weight of water:

- either collected in pools which may be formed due to the deflection of structural members or roofing material,
- or retained by snow.

These additional checks should be based on the combinations at the Ultimate Limit States.

Precambering of beams may reduce the likelihood of rainwater collecting in pools, provided that rainwater outlets are appropriately located.

Examples

- Determination of loads on building envelope
- Plastic design of single bay portal frame – class 1 rolled sections
- Plastic design of single bay portal frame – class 2&3 rolled sections
- Elastic design of a portal frame – class 4 sections
- Truss and post single bay, low pitch roof
- Portal frame eaves connection – end plate and haunch
- Portal frame pinned base connection
- Truss/post end connection
- Bracing/wind frame connections
- Rolled section purlin
- Design of gable wind posts
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