Steel Portal Frame EC3

Design of Steel portal frame structures according to Eurocode 3

Elastic analysis, with allowance for second order effects. Gravity loads, snow loads, wind loads and imposed loads are considered. Analysis for seismic loads using lateral force method and modal superposition spectrum analysis. Verification of the members in ULS (strength and stability), deflection check SLS, all the load combinations. Detailed design of bolted connection, purlin system, lateral bracing system and concrete foundation. Parameters according to National Annex of Eurocode.

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1 Design Steel portal frame structures according to Eurocode 3
Steel Portal Frame EC3

Single-storey, one bay portal frames. Complete design according to Eurocode 3. All the loading conditions and load combinations according to Eurocode 0 and Eurocode 1. Seismic design according to Eurocode 8. Design of steel structure, according to Eurocode 3-1-1, steel joints according to Eurocode 3-1-8, lateral bracing system according to Eurocode 3-1, and the concrete foundation according to Eurocode 2-1 and Eurocode 7-1. Detailed drawings of the structure and the connections.

2 Concept design

- Elastic linear analysis, with allowance for second order effects. (Eurocode 3-1-1)
- Gravity loads, imposed loads, snow loads, wind loads (Eurocode 1-1, 1-3, 1-4).
- Seismic loads (Eurocode 8-1).
- All the load combinations (Eurocode 0)
- Analysis for seismic loads using lateral force method and modal superposition spectrum analysis. (Eurocode 8-1)
- Verification of the members (rafters, columns, haunch) in ultimate limit state (ULS) cross-section resistance and member flexural and lateral stability (Eurocode 3-1-1, 3-1-3, 3-1-5)
- Deflection checks in SLS, (Eurocode 3-1).
- Detailed design of bolted eave, apex and base connections. (Eurocode 3-1-8)
- Design of base anchoring (Eurocode 3-1-1, CEN/TS 1992-4-1)
- Design of purlins (Eurocode 3-1).
- Design of vertical and horizontal lateral bracing system (Eurocode 3-1).
- Design of concrete foundation. (Eurocode 2-1, Eurocode 7-1)
- Detailed drawings of the structure and the connections.
3 Program features

- Automatic production of structure geometry with minimum data entering. All necessary data on one screen.
- Analysis and design of the structure simultaneously solution with data changes. Error messages for inadequate design in a specialized window. Design parts are marked OK or error.
- Selection of National Annex, snow, wind and earthquake region.
- Material and code parameters can be modified.
- Tools for evaluating snow load according to EN1991-1-3, wind load according to EN1991-1-4 and earthquake load according to EN1998-1-1 from environmental data.
- All the load combination for Ultimate limit state ULS (EQU, STR), serviceability limit state SLS, and analysis for seismic loading according to EN1990-1-1.
- Full library with steel section profiles. Welded (fabricated) profiles can be used. Editor for properties of welded (fabricated) profiles.
- Linear elastic finite element analysis with modified element stiffness for the haunch effect.
- Imperfections with equivalent loads. Second order effects using $\alpha_{cr}$ and amplification factors. EN1993-1-1 §5.2
- Complete design verification according to EN1993-1-1 for section classification, cross-section resistance and member in plane, out-of plane and lateral torsional buckling.
- Design of bolted connections for Apex and Eave, and base according to EN1993-1-8.
- Design of column base joint according to EN1993-1-8. Anchoring system to resist uplift forces according to CEN/TS 1992-4. Base connection can be pinned or rigid.
- Design of concrete foundation, according to EN1997-1-1 and EN1992-1-1.
- Design for seismic loading using both Lateral force method, and Modal superposition spectrum analysis according to EN1998-1-1.
- Design of purlins. Continuous or simply supported purlins, lateral restrained or not. The degree of restrain due to sheeting is evaluated.
- Design of vertical and horizontal lateral bracing system.
- Detailed report with diagrams of internal forces, connection drawings. References to Eurocode paragraphs, report of analytical formulas and calculations. Table of contents.
- PDF and DOC export of the report.
- Report contents and design parts can be selected.
- Detailed drawing of the structure and the connection details,
- CAD tools to preview and adjust the drawings, with dxf, pdf and wmf export.

4 Eurocodes used in SteelPortalFrameEC3

EN1990:2002, Eurocode 0 Basis of Structural Design
EN1991-1-1:2002, Eurocode 1-1 Actions on structures
EN1991-1-3:2003, Eurocode 1-3 Snow loads
EN1991-1-4:2005, Eurocode 1-4 Wind actions
EN1993-1-1:2005, Eurocode 3 1-1 Design of Steel structures
EN1993-1-3:2005, Eurocode 3 1-3 Cold-formed members
EN1993-1-5:2006, Eurocode 3 1-5 Plated structural elements
EN1993-1-8:2005, Eurocode 3 1-8 Design of Joints
EN1997-1-1:2004, Eurocode 7 Geotechnical design
5 Main screen

5.1 Main window fields:

- **Top main menu, with basic commands:**
  - **File,** file handling, read and save data,
  - **Parameters,** design codes, national annex, snow wind and seismic initial values.
  - **Steel sections,** Library with standard and welded (fabricated) steel profiles.
  - **Computations,** Computations, selection of design parts.
  - **Setup,** for basic program options, selection (language etc.),
  - **Help,** help and manuals
  - **Update,** for automatic program update

- **Bottom Bar**
  - **Computation** performs all computations and design checks.
  - **Auto compute,** if checked the computations are performed as the data changed.
  - **Drawing** for CAD drawing of the structure and the connection details.
  - **Report** to show (preview) the report.
  - **Report contents** Adjust the contents of the report

- **Window with wire drawing of the structure**
  The sketch of the structure appears and adjusted, as you enter the data.

- **Window with design overview**
  Basic design parts are checked if the design is verified or not.

- **Structure data and loads:**
  All the structural data, materials, sections, loads and load data are shown in the main window. When you change data values and the **Auto compute** is checked, the computations are performed simultaneously.

5.2 Structure data and load data

- **National Annex**
- **Building category**

- **Structure dimensions, lengths, heights, frame spacing.**
- **Support conditions pinned of fixed base.**
- **Haunch size, L/20, L/10, L/8, L/6.6 or 0 for frames without haunch.**
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- Roofing dimensions cladding and purlins
- Continuous or simply supported purlins
- Spacing of lateral bracing for columns
- Spacing for lateral torsional constraints for rafters

- Steel grade
- Steel sections for columns rafter and bracing. Selection from full library of profiles.
- Standard or Welded (fabricated) profiles for columns and rafters

- Snow load. Can be selected from snow region and altitude.
- Wind loading. May be selected from wind region, altitude and terrain configuration.
- Wind internal pressure
- Roof covering and ceiling load under.
- Seismic loading. May be selected from seismic region and ground type.

- Connection data, plate thickness and steel grade, bolt characteristics.
- Anchor bolt characteristics

- Concrete footing dimensions and material.
- Properties of foundation soil.
- Horizontal forces can be resisted with steel tie at column base or passive earth pressure.

6  **10 steps - How to work with the program**

1. To avoid the computations being slow, uncheck Auto computation on the left of button line. If it is checked, the computations are performed at the same moment you change some of the data, and your computer might be slow when it is turned on. When the computations are completed, the full design of the structure is done. If the computer is not very fast it may be a small delay when you entering data if the Auto computation is checked. So until you enter all the basic data for the structure and loads keep Auto computations unchecked.

2. Check the National Annex to be appropriate on the top right of the window. If not, reset from Parameters/National Annex or click on Eucode EN  

3. Check snow, wind and earthquake regions. If the regions are not right, reset from Parameters or click on the corresponding fields.

4. Enter the basic structure dimensions and loads. If the structure is flat enter first H1 and then H. Select pinned or rigid base connection. Specify the haunch size as ratio of total length. 0 when there is no haunch.

5. Select Standard or welded (fabricated) steel profiles for column or rafter sections. Specify steel sections. Click to pre estimate the section sizes.

6. Click Computations. If an error window appears with messages try to refine the model by changing the cross-sections.

7. Check the window with design overview if all design parts are OK.

8. Preview the Drawing of the structure and details.

9. Click Report to preview the design report. You can print the report from the preview.

10. Check Auto computation. Refine the design.
7 Files

New, Open, Reopen, Save, Save As

A standard windows dialog is displayed, where you should select a file name. Reopen, Keep a list of the five (5) more recent files, to open them directly. All the data of a project are saved in file *.SteelPortalFrameEC3. After you opened an old or new file the changes are saved automatically. In the folder /examples you will find examples of ready frame structures.

8 Parameters

Basic program parameters for materials, design parameters and regions for snow, wind and earthquake loading.

8.1 National Annex

Select the National Annex of the country you want to work. To do this first click Locked to unlock. The various design parameters (load factors, material factors etc.) are set according to the National annex. This does don affect the regions for snow, wind and earthquake, which have to be selected from the next menu lines of the parameter menu.

8.2 Materials

Structural steel, Concrete, Reinforcing steel and Soils for the foundation. You can change (edit) material properties. In order to avoid accidental material changes the edit capabilities are locked. To edit, click first to unlock the edit capabilities. With you add or delete lines from the property tables, with the original program values are loaded.
8.3 Design Parameters
The National Annex parameters are set according to the National Annex you select. You may although want to change some of them, or specify some design considerations not mentioned in the national Annex.

8.3.1 NAD parameters

**Action coefficients for Ultimate limit states EQU and STR.**
According to Eurocode 0 Table A1.2A and Table A1.2B. Click Reset to reset to National Annex values.

**Load Combination coefficients** according to Eurocode0 Table A1.1. Click Reset to reset to National Annex values.

**Material factors for Steel** according to Eurocode 3 §6.1

**Material factors for Reinforced concrete** according to Eurocode 2 §2.4.2.4., used for the reinforced concrete in the foundation.

**Material factors for Soil** according to Eurocode 7 Annex A. Used for the foundation design.

**Eurocode 3, design parameters.**
Lateral torsional buckling computations base on Eurocode 3 Eq. 6.56, and Tables T 6.3, and T 6.4. (most common)

Lateral torsional buckling computations base on Eurocode 3 Eq. 6.57, and Table T 6.5.

Method for Bending and compression. Method 1 Annex A or method 2 Annex B (most common)
8.3.2 Parameters for Portal frames

Specify some parameters that are not covered from national annex. Such as:

1. Deflection limits for Serviceability limit state (SLS)

   The limits for these deflections are usually defined in the National Annex. EN1993-1-1 § 7.2 and EN 1990 Annex A1.4 According to EN1993-1-1 these limits may be specified for each project and agree with the client. Usual values: vertical deflection L/200, horizontal deflection H/150, vertical deflection due to bending L/200.

2. Design parameters for buckling control

   **Columns**
   (1): (most reasonable default)
   - In plane buckling, critical buckling length Lcr = system length points of axis.
   - Out of plane buckling and torsional buckling and lateral torsional buckling, critical buckling Lcr the column height up to the haunch, or the distance of lateral restraints Lm1, if is specified smaller than the column length.

   (2): (conservatively)
   - In plane buckling Lcr = system length points of axis.
   - Out of plane buckling and torsional buckling and lateral torsional buckling, Lcr the system length or the distance of lateral restraints Lm1.

   **Rafters**
   (1) (most reasonable default)
   - In plane buckling Lcr = system length. This is computed from the total span L and the first buckling mode.
   - Lateral buckling length at span the purlin space, torsional buckling the distance between torsional restraints Lm2

   (2) (conservatively)
   - In plane buckling Lcr = system length
   - Lateral and torsional buckling length, the distance between torsional restraints Lm2.
8.4 Snow load on the ground
Default region and snow zone. Click and select the snow region of your area. The snow zone and the amplitude, and the characteristic snow load value on the ground $\mathbf{s}_k$ is set according to Eurocode EN1991-1-3:2003.

8.5 Basic wind velocity
Select wind region and wind zone. The default basic wind velocity is set.

8.6 Seismic zone
Default seismic region and seismic zone. The ground acceleration $a=a_{gr}/g$ is set.
9 Setup

9.1 Language setup
Sets program language to Native language or English.

Set current data as Default-Initial values. Saves the current structure data. When you start the program next time, these values will be loaded. If you, instead of [Save], click [Reset] the Initial values from the program are loaded.

10 Computations

Click to perform all the computations, if checked the computations are performed at the same time the data are changed. This may sometimes (if slow computer) delay the changing of input data. It is advised to uncheck Auto computation when you form the model and when you make a lot of input data adjustments.

If the sections, plate thickness or bolt diameters, are not adequate, an error window appears with appropriate error messages for the verifications that are not verified. In addition if you preview the report you will see in red extended error messages at the place the calculations or verifications are performed.

In the design overview window it is displayed which designs are verified.

The program automatically increases plate thicknesses, bolt diameters or foundation width to achieve design verification.

11 Report

Click and the full design report with detailed analysis, drawings and references to Eurocodes is displayed.

Warning message, in red colour, appears in the report for the design parts for which the verifications fail.

The report is organized in numbered paragraphs. Some basic chapters start on a new page. From Report/Report setup you can select to start every chapter on a new page.

In the end of the report an extended table of contents is included.

You go front and back pages in the report or jump to a specific page with .

From the preview you can print all or part of the report, and export to PDF and Word file.
In order to select a range of pages to be printed click .

The appearance, top or bottom logo, font, margins etc., is adjusted from Compute-Report/Report setup. It is advisable to don't change the font used in the report. The font already selected is courier new and it supports certain characters (Greek, mathematical symbols) and it is fixed pitch font so the various formulas and tables are lined correctly.

The contents of the report are adjusted with .

You can select the drawings and the chapters that are included in the report.
By checking full, medium or short report you can fast select report configurations.
Options:

**Structure drawing** is the first wired diagram of the structure, with the basic shape and dimensions.

**Finite element analysis details** gives detailed description and output of the finite element model and matrices, and better not to be checked/marked.

**CAD structural drawing**, **CAD Drawing of structure** and **CAD Drawing of details**, are drawing in scale at the end of the report.

**Visible layers in drawing as in CAD**, if checked, the visible layers in the drawings in the end of the report are the same as the ones checked in the CAD drawing, otherwise all the layers are visible.

**Table of Contents.** If checked, a full table of contents is included in the end of the report.

The last five(5) options **Design of Purlins**, **Design of connections**, **Seismic design**, **Design of concrete footing**, **Design of lateral bracing system**, are design parts which you can choose to be included or not. This is only to include or not include these design parts in the report. If you don't want to perform these design parts you have to uncheck them from Active design parts.
11.1 Report menu

Compute Perform all the design computations.
Report Preview-print the report.
Report contents You can select the drawings and the chapters to appear in the report.
Report setup, font settings, captions, footnotes, etc., for report
Printer Standard dialog to select printer, and printer properties
Drawing opens the CAD drawing window.

11.2 Report setup

Report, Adjust the appearance and contents of header, footer report margins and font.
Page setup, Select the Paper size, printing on both sides.
Paragraphs: Adjust the distance between the report lines, (usually for best appearance 4mm.)
You can choose to have each chapter to start on a new page.
The errors appear in red or other colour.
12 CAD Drawings

By clicking you obtain the CAD drawing of the structure and the structural details for the connections.

With the CAD tools you can adjust the appearance of the drawings, print drawing in various forms and paper sizes, export to DXF, PDF, WMF.

Select the kind of drawing to be included:
- Structure and details
- Only structure
- Eave connection detail
- Apex connection detail
- Base connection detail

Visible layers are checked in the layer window. The colour and thickness of the line, font size and colour, colour of DXF layer are adjusted in the property window.

Click on screen. When the hand appears as cursor, you can drag and move the drawing up, down, left, right, by pressing the mouse.

- Scale 1:200 Scale of details 1:25 adjust scale of drawing or details.

- move drawing, enable drag. Drag is enabled by clicking on the main drawing.
- cursor options and measuring distances.
13 Input Data

13.1 Materials
Select the steel grade from the steel materials available. Most of the used steel grades are included in the program, and are loaded according to the national Annex you select. You can add steel grades, or change properties for steel grades in the menu Parameters/materials/Structural Steel. The program automatically sets the respective steel properties (fyk, fuk, Es etc.) The material partial factors γM0, γM1, γM2, are set according to the national Annex selected.

13.2 Steel grades included in the program

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<td>EN 10210-1</td>
<td>460</td>
<td>560</td>
</tr>
<tr>
<td>S 460 NH/NLH</td>
<td>EN 10210-1</td>
<td>460</td>
<td>560</td>
</tr>
</tbody>
</table>
13.3 Cross-sections

Specify the cross section for the columns, the rafters, purlins and transverse bracing.

All the standard hot-rolled or cold-format cross sections are included. Click , and the library with the standard section will open. You select the section type on the left tree and at the same time all the sections of this group with their geometric properties are displayed on the right window together with the section drawing in scale. Section geometric properties are calculated precisely including fillets. The notation is shown at the drawing at the low left window.

13.3.1 Estimate of member sizes.

Click and you get a rough estimate of member sizes for the structural elements of the structure with the dimensions you have specified. You can start with this estimate to continue for better design.

13.3.2 Standard types of cross section profiles included in the program

**[Image of cross-section profiles]**

**Steel Portal Frame EC3**

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13.3.3 Welded (fabricated) cross sections

If you specify (check) welded cross sections for the columns and rafters, the library with the cross sections defined from the user appears to select cross section. This library is updated from the menu Steel-sections/Welded sections.

Click at Edit to update or change the properties. to add or remove sections. In the window that appears, enter the name of the profile and the values for total height h in mm, total width b in mm, web thickness tw in mm, flange thickness tf in mm, and weld seam a in mm.
13.4 Structure data

13.4.1 Basic structure dimensions

Bay width L [m], the distance between column axes. Total height H [m] and column height H1 [m] at axis points. If the frame is flat then H=H1. In this case specify first H1 and the H equal to H1. Total transverse length B [m]. Is needed to evaluate the loading on the lateral bracing system, from wind or seismic loading. Spacing s [m] of frames, transverse distance of column axis. Is uses as free span for purlins. For n frames B=(n-1)s.

Type of support. Pinned or fixed. Most common is the pinned support. The base connection and anchoring is simpler and the foundation smaller. In case of fixed support the base bending moment can be quite large for the base anchoring system or the fundament.

The size of the haunch is specified by selecting one of the ratios (1/20, 1/10, 1/8, 1/6.6). This represents the horizontal size of the haunch measured from the axis of the column to the start point (h=raft height). The height of the haunch at the point of the junction with the column flange is always set to 2 times the rafter height (2xh). If you don’t want to specify haunch (as in flat frames) select the last option 0xL.

The cladding is supported on purlins. The thickness of the sheeting tw [mm] and the profile height hw [mm] are used for estimating the degree of lateral restrain of the purlins. The spacing of purlins is the distance between the purlin axes. The section of purlins must be a symmetric section. If you select purlin laterally unrestrained then the possible restraining of the purlin due to sheeting is disregarded. If you select purlin laterally restrained then the restraining due to sheeting is evaluated and used for wind pressure (sagging), and for the purlin is considered laterally unrestrained for wind uplift (hogging). For the evaluation of the dimensioning bending moments and shear forces you may choose Simply supported purlin or Continuous purlin. In the second case the purlin is considered continuous over many spans.

The spacing of the lateral bracing for columns and torsional bracing for rafters is used for the lateral-torsional buckling design. Check the way they applied in parameters/design parameters.
13.5 Loads

The program automatically forms and evaluates all the load combinations in ultimate limit state ULS (EQU,STR), and serviceability limit state SLS. The partial factors for loading and load combination factors are taken according to Eurocode 0 and National Annex. The basic loads are:

### 13.5.1 Permanent loads

- **Load of roof covering** [kN/m²] It includes the weight of the sheeting, purlins and insulation materials.
- **Load of ceiling under the roof** [kN/m²]
- **Self weight** of frame elements, calculated by the program from the element cross sections with Unit mass $\rho = 7850$ Kg/m³

### 13.5.2 Variable loads

- **Imposed load** according to EN1990-1-1 Tab 6.1, calculated by the program according to the selected National Annex
- **Snow load** according to Eurocode 1-3:2004

The characteristic snow load on the ground $sk$ is specified in kN/m².

Click and a special dialog window appear. In this window you set the snow zone and the height above the sea level. The characteristic snow load on the ground is computed according to Eurocode 1-3:2004, and the National Annex. The snow region can be selected from Parameters/snow load on the ground. The snow load on the roof is computed according to Eurocode 1-3:2003.

- **Wind load**, according to Eurocode 1-4:2005

The wind pressure on vertical surface is specified in kN/m². Click and in this window you compute the wind pressure from the wind velocity and the topography of the region according to Eurocode 1-4:2005.

The wind load is computed for various places at the roof and the vertical walls according to Eurocode 1-4:2005 §7.2.5 and Tab 7.4a and Tab. 7.1. The wind region, which specifies the wind velocity, is selected from Parameters/Basic wind velocity.

Wind internal pressure $wi$ in kN/m². This is internal pressure and it acts from inside outwards on the walls and roof. It is subtracted directly (without further multiplication by pressure coefficients) from any uplift wind pressure on the outside surfaces.
13.5.3 Seismic load Eurocode 8-1:2004

The program performs a verification of the structure under seismic loading, using both Lateral force method, and Modal superposition spectrum analysis. Basic value used in the seismic design is the ratio of horizontal seismic acceleration. Click and a special dialog window appears where you may in detail specify all the necessary seismic parameters (soil factors, spectra periods, behaviour factors, etc..) for the design spectrum, according to Eurocode 8-1:2004.

13.6 Connections

Apex and eave bolt-connections with end plate are designed to resist moment and shear forces. For the apex and eave connection the end plate (thickness and steel grade) and bolts (diameter, grade) are the same. The thickness of Apex and eave end plate should be at least as thick as the flange thickness of the rafter and column section. At the base of the haunch, a stiffener is designed to resist the increased compressive forces.

Base plate bolt-connection is designed for the column over the concrete foundation. The anchor bolts are designed to resist shear and pullout forces due to uplift wind or seismic forces. CEN/TS 1992-4-1:1992 and CEN/TS 1992-4-2:1992 are used for the design of the fastenings in concrete.

The holding down anchor bolts of the base plate are extended with anchors. The anchor system can be (simple hook, bended hook or washer plate). The hook type anchoring (first two choices) cannot be selected for bolt grade with fy>300N/mm2 (M>5.6), according to Eurocode 1993-1-8:2005, 6.2.6.12 (6).

The program will, if it is necessary, increase the diameter of the bolts or the thickness of the connection plate to satisfy the design checks. Connections are designed according to EN1993-1-8.

13.7 Foundation

The concrete footing has to be designed to resist soil pressure for maximum vertical load, and it must have enough weight to resist uplift (from wind or seismic forces).

- Reinforced concrete properties

Click and select concrete and steel class. Click to select concrete cover Cnom [mm]

- Fundament dimensions Specify the dimensions of the short column above the fundament cross-section dimensions cx and cy and height ch, and next the diameter of the column main reinforcing bars for the CAD drawing.
The dimensions of the fundament Bx width lengthwise, By width in transverse direction, Bh the height of the fundament, and the size of the reinforcing bars of the fundament. The program may change the footing dimensions chosen by the user to fulfil the design criteria for the foundation design. If you don’t want a footing dimension to be changed then check the box next to the dimension.

- **Soil properties**, soil bearing capacity $q_u$ [N/mm²], soil unit weight $\gamma$ KN/m³, and soil angle of internal friction $\varphi$, can be selected by click .

- **Foundation depth** $h_f$ is the depth of the bottom of the fundament. This depth is used for the computation of the passive earth resistance.

The high horizontal forces acting at the base are acting outwards as a result of bending in the columns due to vertical loading on the roof. This is resisted in two ways.

- **Steel tie at column base** A tie cast into the floor slab connected to the base of the columns. This should be considered more safe method to resist the horizontal forces at the base of the columns.

- **Passive earth pressure on the side of the foundation**.
  In this case the earth filling and compacting on the side of the foundation must be performed carefully, so that the passive earth pressure is not reduced. The fundament transverse width By and the height Bh are used to compute the active area for passive earth pressure.

It is advisable to check the desired fundament height Bh on the side and let the dimensions Bx and By to be adjusted by the program. Bx and By are adjusted so the fundament weight has enough weight to resist uplift, (the foundation is also an important factor). By is adjusted also for adequate passive earth force to resist the horizontal base force outwards.

### 13.7.1 Foundation bearing resistance

The basis for the design of foundations is the bearing resistance of the soil. The design bearing resistance may be calculated using analytical or semi-empirical methods. Annex D of Eurocode 7 EN1997-2004 describes a method of obtaining the design bearing strength of the soil.

The methods of Annex D for drained and undrained conditions are implemented in the program. The Design bearing strength of the soil is estimated for EQU, STR and GEO conditions. The computation of design bearing strength is for drained and undrained soil conditions. For drain soil conditions the important soil property is the angle of shearing resistance $\varphi_k$ [$^\circ$] and the cohesion intercept $c_k$ [kPA]. For undrained soil conditions the important soil property is the undrained strength $c_u$ [kPA]. For the computation of design bearing strength other parameters are the dimensions and foundation depth of the footing, as well as the loading and the load eccentricities.
In the foundation design of the program for the soil strength we use the soil bearing pressure $q_{uk}$ (N/mm²). This is corresponding soil strength to the soil allowable pressure. In the foundation design we use as design bearing soil pressure $q_{ud} = q_{uk} / \gamma_{qu}$ where $\gamma_{qu}$ is the partial factor for unconfined strength. (Eurocode 7, Annex A). So to be consistent in order to convert the design strength estimated from Annex D of Eurocode 7 to the soil bearing pressure used in the program the design value have to be multiplied by $\gamma_{qu}$, $q_{uk} = q_{ud} \cdot \gamma_{qu}$. 

$\gamma_{qu} = 1.40$ for EQU and 1.00 and 1.4 for STR-GEO.

Click ![image](image.png) in the design of fundaments, and you get into a calculation window for design bearing resistance. There you have an estimate of the soil bearing resistance $q_{uk}$ which you may use in the program, from the soil and fundament parameters. If there you check to include the calculations in the report, then the design bearing resistance will be set to the minimum estimated and the calculations will be included in the report of the footing design (remember that if you alter the dimensions or loading you have to reevaluate $q_{uk}$).
14 Design Considerations

Active parts of the design.

- Design of members (always active)
- Design of purlins
- Design of connections
- Seismic design
- Design of concrete foundation
- Design of lateral bracing system

On the design overview you can see the various parts of the design. A green check OK shows that this part of design is verified, a red cross shows inadequate design. If there are no marks then this design part is not active. Active design parts are selected by click at or from the report contents.

15 Error messages

When the verification checks are not satisfied, error messages appear in red in the report and in a special window that appears on the main screen. These errors are:

- $\text{acr} = \frac{F_{cr}}{F_{ed}} < 3$, Change cross-sections, or perform second-order analysis §5.2.2.1
- Second order effects are significant in dynamic analysis EC8 §4.4.2.2(2), $\theta > 0.2$ and second order P-D affects must be taken into account with a second order analysis. If $\theta < 0.2$ the program uses the multiplier $1/(1-\theta)$ to take into account the second order effects.
- Limit for Vertical deflection is exceeded. (SLS serviceability limit state EC3 §7.2.1). The limit value can be set in menu Parameters/design parameters
- Limit for Horizontal deflection (SLS serviceability limit state (EC3 §7.2.2). The limit value can be set in menu Parameters/design parameters
- verification of cross section resistance $N_{ed} < N_{rd}$, $V_{ed} < V_{rd}$, $M_{ed} < M_{rd}$ are not satisfied, (EC3 §6.2.4, §6.2.5, §6.2.6) and combined $N_{ed} + V_{ed} + M_{ed}$ (EC3 §6.2.9, §6.2.10) If not satisfy you must change sections for column or rafter
- verification of Buckling check compression, $N_{c,ed} < N_{b,rd}$ (EC3 §6.3.1)
- verification of Buckling check bending, $M_{y,ed} < M_{r,rd}$ (EC3 §6.3.2)
- verification of Lateral torsional buckling equations 6.61 and 6.62, EC3 §6.3.2. If the buckling checks are not satisfied you must select stiffer cross-sections for column or rafter or you must reduce the spacing of lateral restraints
16 Short theoretical overview

16.1 Design Loads EN1991:2005:

16.1.1 Permanent loads EN1991-1:2005
Weight of the roof system (sheeting+purlins+insulation)
Weight of the ceiling structure (if any)
Self-weight of the portal frame elements (calculated by the program)

16.1.2 Imposed loads EN1991-1:2005
A distributed imposed load qk according to Eurocode 1 EN1991-1-1 Tab 6.1 is considered on top of the roof.

16.1.3 Snow load EN1991-3:2003
Snow load is computed according to Eurocode 1-3 EN1991-3:2003, from the characteristic snow load on the ground and the roof slope.

\[ s = \mu_i C_e C_t s_k \] (EN1991-3:2003 §5.2) [kN/m²]

The three characteristic load arrangements of EN1991-3:2003 §5.3.3 are considered in the load cases. If the frame is flat (\( \alpha = 0^\circ \)) one load arrangement is considered \( s = 0.80 C_e C_t s_k \).

The characteristic snow load on the ground \( s_k \) can be defined directly by selecting the snow region, snow zone and the altitude, according to EN1991-3:2003 Annex C.

16.1.4 Wind load of EN1991-4:2005
Wind load is computed according to of EN1991-4:2005 §7.2.5 from the wind peak velocity pressure \( q(z) \).

Wind pressure on surfaces \( w_e = q(z) \cdot Cpe \) [kN/m²]

The wind pressure coefficients \( Cpe \) are computed from EN1991-4:2005 Tab.74a for roof surfaces and EN1991-4:2005 Tab 7.1 for the vertical wall surfaces.

The wind peak velocity pressure \( q(z) \), can be defined directly from the wind velocity the terrain roughness and the orography. According to EN1991-4:2005 §4.5 and Annex A.

The wind pressure or underpressure on roof and wall surface are computed according to Eurocode 1-4. For roof slopes (\( \alpha < 8^\circ \)) one load arrangement is considered. For higher slope values two wind load cases are considered according to the pressure coefficients of Table 7.4a of Eurocode 1-4.

The specified internal pressure is always added (increase underpressure) to the external wind pressure situation.

16.1.5 Earthquake loading EN1998-1:2004
The earthquake loading is defined from the ground acceleration and the design spectrum according to Eurocode 8 EN1998-1:2004.

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16.2 Design load combinations EN1990:2002

All the necessary load combinations defined in Eurocode0 EN1990:2002 are considered and the resulting design forces are checked in the strength verifications.

16.2.1 Load combination factors (EN1990 Tab.A1.1)

- **Category H (roofs)**
  - Snow loads on buildings: $Q_s \psi_0 = 0.50, \psi_1 = 0.20, \psi_2 = 0.00$

- **Wind loads on buildings**
  - Snow loads on buildings: $Q_s \psi_0 = 0.60, \psi_1 = 0.20, \psi_2 = 0.00$

16.2.2 Ultimate Limit State (ULS) (EQU)

\[ Ed = \gamma_G Gk + \gamma_Q Qk1 + \gamma_Q \psi_0 \cdot Qk2 \]  
(Eq. 6.10)

- $\gamma_G, sup = 1.10$ (Unfavourable)
- $\gamma_Q, inf = 0.90$ (Favourable)
- $\gamma_Q = 1.50$ (Unfavourable)
- $\gamma_Q = 0.00$ (Favourable)

Load combinations (ULS)(EQU), Permanent load $Gk$, Imposed load $Qk$, Snow load $Qs1, Qs2, Qs3$, Wind load $Qw1, Qw2$

- **L.C. 101**: $1.10Gk + 1.50Qk$  
  (Eq. 6.10)
- **L.C. 102**: $1.10Gk + 1.50Qs1$  
  (Eq. 6.10)
- **L.C. 103**: $1.10Gk + 1.50Qs2$  
  (Eq. 6.10)
- **L.C. 104**: $1.10Gk + 1.50Qs3$  
  (Eq. 6.10)
- **L.C. 105**: $1.10Gk + 1.50Qw1$  
  (Eq. 6.10)
- **L.C. 106**: $1.10Gk + 1.50Qw2$  
  (Eq. 6.10)
- **L.C. 111**: $0.90Gk + 1.50Qw1$  
  (Eq. 6.10)
- **L.C. 121**: $1.10Gk + 1.50Qs1 + 0.60x1.50Qw1 = 1.10xGk + 1.50Qs1 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 122**: $1.10Gk + 1.50Qs1 + 0.50x1.50Qw2 = 1.10xGk + 1.50Qs1 + 0.75Qw2$  
  (Eq. 6.10)
- **L.C. 123**: $1.10Gk + 1.50Qs2 + 0.60x1.50Qw1 = 1.10xGk + 1.50Qs2 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 124**: $1.10Gk + 1.50Qs2 + 0.50x1.50Qw2 = 1.10xGk + 1.50Qs2 + 0.75Qw2$  
  (Eq. 6.10)
- **L.C. 125**: $1.10Gk + 1.50Qs3 + 0.60x1.50Qw1 = 1.10xGk + 1.50Qs3 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 126**: $1.10Gk + 1.50Qs3 + 0.50x1.50Qw2 = 1.10xGk + 1.50Qs3 + 0.75Qw2$  
  (Eq. 6.10)
- **L.C. 127**: $1.10Gk + 1.50Qw1 + 0.50x1.50Qs1 = 1.10xGk + 1.50Qw1 + 0.75Qs1$  
  (Eq. 6.10)
- **L.C. 128**: $1.10Gk + 1.50Qw1 + 0.50x1.50Qs2 = 1.10xGk + 1.50Qw1 + 0.75Qs2$  
  (Eq. 6.10)
- **L.C. 129**: $1.10Gk + 1.50Qw1 + 0.50x1.50Qs3 = 1.10xGk + 1.50Qw1 + 0.75Qs3$  
  (Eq. 6.10)
- **L.C. 130**: $1.10Gk + 1.50Qw2 + 0.50x1.50Qs1 = 1.10xGk + 1.50Qw2 + 0.75Qs1$  
  (Eq. 6.10)
- **L.C. 131**: $1.10Gk + 1.50Qw2 + 0.50x1.50Qs2 = 1.10xGk + 1.50Qw2 + 0.75Qs2$  
  (Eq. 6.10)
- **L.C. 132**: $1.10Gk + 1.50Qw2 + 0.50x1.50Qs3 = 1.10xGk + 1.50Qw2 + 0.75Qs3$  
  (Eq. 6.10)

16.2.3 Ultimate Limit State (ULS) (STR)

\[ Ed = \gamma_G Gk + \gamma_Q Qk1 + \gamma_Q \psi_0 \cdot Qk2 \]  
(Eq. 6.10a)

\[ Ed = \gamma_G Gk + \gamma_Q \psi_0 \cdot Qk1 + \gamma_Q \psi_0 \cdot Qk2 \]  
(Eq. 6.10b)

- $\gamma_G, sup = 1.35$ (Unfavourable)
- $\gamma_Q, inf = 1.00$ (Favourable)
- $\gamma_Q = 1.50$ (Unfavourable)
- $\gamma_Q = 0.00$ (Favourable)

Load combinations (ULS)(STR), Permanent load $Gk$, Imposed load $Qk$, Snow load $Qs1, Qs2, Qs3$, Wind load $Qw1, Qw2$

- **L.C. 201**: $1.35Gk + 1.50Qk$  
  (Eq. 6.10)
- **L.C. 202**: $1.35Gk + 1.50Qs1$  
  (Eq. 6.10)
- **L.C. 203**: $1.35Gk + 1.50Qs2$  
  (Eq. 6.10)
- **L.C. 204**: $1.35Gk + 1.50Qs3$  
  (Eq. 6.10)
- **L.C. 205**: $1.35Gk + 1.50Qw1$  
  (Eq. 6.10)
- **L.C. 206**: $1.35Gk + 1.50Qw2$  
  (Eq. 6.10)
- **L.C. 211**: $1.35Gk + 1.50Qs1 + 0.60x1.50Qw1 = 1.35xGk + 1.50Qs1 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 212**: $1.35Gk + 1.50Qs1 + 0.60x1.50Qw2 = 1.35xGk + 1.50Qs1 + 0.90Qw2$  
  (Eq. 6.10)
- **L.C. 213**: $1.35Gk + 1.50Qs2 + 0.60x1.50Qw1 = 1.35xGk + 1.50Qs2 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 214**: $1.35Gk + 1.50Qs2 + 0.60x1.50Qw2 = 1.35xGk + 1.50Qs2 + 0.90Qw2$  
  (Eq. 6.10)
- **L.C. 215**: $1.35Gk + 1.50Qs3 + 0.60x1.50Qw1 = 1.35xGk + 1.50Qs3 + 0.90Qw1$  
  (Eq. 6.10)
- **L.C. 216**: $1.35Gk + 1.50Qs3 + 0.60x1.50Qw2 = 1.35xGk + 1.50Qs3 + 0.90Qw2$  
  (Eq. 6.10)
- **L.C. 217**: $1.35Gk + 1.50Qw1 + 0.50x1.50Qs1 = 1.35xGk + 1.50Qw1 + 0.75Qs1$  
  (Eq. 6.10)
- **L.C. 218**: $1.35Gk + 1.50Qw1 + 0.50x1.50Qs2 = 1.35xGk + 1.50Qw1 + 0.75Qs2$  
  (Eq. 6.10)
- **L.C. 219**: $1.35Gk + 1.50Qw1 + 0.50x1.50Qs3 = 1.35xGk + 1.50Qw1 + 0.75Qs3$  
  (Eq. 6.10)
L.C. 220: 1.35Gk+1.50Qw2+0.50x1.50Qs1= 1.35xGk+1.50Qw2+0.75Qs1  (Eq.6.10)
L.C. 221: 1.35Gk+1.50Qw2+0.50x1.50Qs2= 1.35xGk+1.50Qw2+0.75Qs2  (Eq.6.10)
L.C. 222: 1.35Gk+1.50Qw2+0.50x1.50Qs3= 1.35xGk+1.50Qw2+0.75Qs3  (Eq.6.10)
L.C. 223: 1.35Gk+1.50Qw1+1.50x0.60Qw1= 1.35xGk+0.75Qs1+0.90Qw1  (Eq.6.10)
L.C. 224: 1.35Gk+1.50Qw1+1.50x0.60Qw2= 1.35xGk+0.75Qs2+0.90Qw2  (Eq.6.10)
L.C. 225: 1.35Gk+1.50Qw1+1.50x0.60Qw3= 1.35xGk+0.75Qs3+0.90Qw3  (Eq.6.10)

L.C. 231: 1.35Gk+1.50Qs1+1.50x0.60Qw1= 1.35xG+0.75Qs1+0.90Qw1  (Eq.6.10a)
L.C. 232: 1.35Gk+1.50Qs1+1.50x0.60Qw2= 1.35xG+0.75Qs2+0.90Qw2  (Eq.6.10a)
L.C. 233: 1.35Gk+1.50Qs1+1.50x0.60Qw3= 1.35xG+0.75Qs3+0.90Qw3  (Eq.6.10a)

16.2.4 Serviceability Limit State (SLS)

\[ E_d = G_k + Q_{k1} + \psi_1\cdot Q_{k2} + \psi_2\cdot Q_{k3} \]  (Characteristic combination)   (Eq.6.14b)
\[ E_d = G_k + \psi_1\cdot Q_{k1} + \psi_2\cdot Q_{k2} + \psi_2\cdot Q_{k3} \]  (Frequent combination)   (Eq.6.15b)
\[ E_d = G_k + \psi_2\cdot Q_{k1} + \psi_2\cdot Q_{k2} + \psi_2\cdot Q_{k3} \]  (Quasi-permanent combination)   (Eq.6.16b)

Load combinations (SLS)

Permanent load Gk, Imposed load Qk, Snow load Qs1,Qs2,Qs3, Wind load Qw1,Qw2
L.C. 301: Gk+Qk  (Eq.6.14a)
L.C. 302: Gk+Qs1  (Eq.6.14a)
L.C. 303: Gk+Qs2  (Eq.6.14a)
L.C. 304: Gk+Qs3  (Eq.6.14a)
L.C. 305: Gk+Qw1  (Eq.6.14a)
L.C. 306: Gk+Qw2  (Eq.6.14a)
L.C. 311: G + Qs1 + 0.60Qw1  (Eq.6.14a)
L.C. 312: G + Qs2 + 0.60Qw2  (Eq.6.14a)
L.C. 313: G + Qs3 + 0.60Qw3  (Eq.6.14a)
L.C. 314: G + Qs2 + 0.60Qw2  (Eq.6.14a)
L.C. 315: G + Qs3 + 0.60Qw3  (Eq.6.14a)
L.C. 316: G + Qs3 + 0.60Qw3  (Eq.6.14a)
L.C. 317: G + Qw1 + 0.50Qs1  (Eq.6.14a)
L.C. 318: G + Qw1 + 0.50Qs2  (Eq.6.14a)
L.C. 319: G + Qw1 + 0.50Qs3  (Eq.6.14a)
L.C. 320: G + Qw2 + 0.50Qs1  (Eq.6.14a)
L.C. 321: G + Qw2 + 0.50Qs2  (Eq.6.14a)
L.C. 322: G + Qw2 + 0.50Qs3  (Eq.6.14a)
L.C. 331: G + 0.50Qs1 + 0.30Qw1  (Eq.6.15a)
L.C. 332: G + 0.50Qs1 + 0.30Qw2  (Eq.6.15a)
L.C. 333: G + 0.50Qs2 + 0.30Qw1  (Eq.6.15a)
L.C. 334: G + 0.50Qs2 + 0.30Qw2  (Eq.6.15a)
L.C. 335: G + 0.50Qs3 + 0.30Qw1  (Eq.6.15a)
L.C. 336: G + 0.50Qs3 + 0.30Qw2  (Eq.6.15a)
L.C. 337: G + 0.20Qw1 + 0.00Qs1  (Eq.6.15a)
L.C. 338: G + 0.20Qw1 + 0.00Qs2  (Eq.6.15a)
L.C. 339: G + 0.20Qw1 + 0.00Qs3  (Eq.6.15a)
L.C. 340: G + 0.20Qw2 + 0.00Qs1  (Eq.6.15a)
L.C. 341: G + 0.20Qw2 + 0.00Qs2  (Eq.6.15a)
L.C. 342: G + 0.20Qw2 + 0.00Qs3  (Eq.6.15a)
L.C. 351: G + 0.00Qs1 + 0.30Qw1  (Eq.6.16a)
L.C. 352: G + 0.00Qs1 + 0.30Qw2  (Eq.6.16a)
L.C. 353: G + 0.00Qs2 + 0.30Qw1  (Eq.6.16a)
L.C. 354: G + 0.00Qs2 + 0.30Qw2  (Eq.6.16a)
L.C. 355: G + 0.00Qs3 + 0.30Qw1  (Eq.6.16a)
L.C. 356: G + 0.00Qs3 + 0.30Qw2  (Eq.6.16a)

16.2.5 Ultimate Limit State (ULS)Seismic situation
Steel Portal Frame EC3

\[ Ed = Gk + Aed + \psi_2 Qk1 + \psi_2 Qk2 + \psi_2 Qk3 \quad (\text{Eq.6.12b}) \]

**Snow load Qs, Wind load Qw, Seismic load Aed**

\[ L.C. 601: Gk + 0.3Qs1 + Aed \quad (\text{Eq.6.14a}) \]

### 16.3 Finite element model

The structure displacements and the internal forces and moments in the structure are calculated with the finite element program FRAME2Dexpress® (©RUNET).

The Finite element model uses 2-dimensional beam elements. The axes of the elements are passing from the centroid of the cross-sections of the beams and the columns. The effective span of the portal frame is the distance between the center lines of the columns.

The increase of the stiffness of the rafter elements due to the haunches is taken into account by modifying the element stiffness matrix of the rafter elements.

Linear static and dynamic elastic analysis is performed.

The eave and apex connections are modelled as stiff connections.

The base connection is considered pin or fixed connection according to the selection of the user. The horizontal force acting outwards is resisted either by the passive earth force or by a steel tie placed into the floor slab.

### 16.4 Materials EN 1993-1-1:2005 § 3.2

The steel grades listed in Eurocode EN 1993-1-1 Table 3.1 and EN 1993-1-3 are included in the program.

The steel properties (yield strength \(f_y\) and ultimate strength \(f_u\)) can be changed from Parameters/Material.

Design values for: Modulus of elasticity \(E=210000 \text{ N/mm}^2\), Poisson ratio \(\nu=0.30\), Unit mass \(\rho= 7850 \text{ Kg/m}^3\)

#### Steel grades

- **S 235** EN 10025-2 \(f_y:235\) \(f_u:360\)
- **S 275** EN 10025-2 \(f_y:275\) \(f_u:430\)
- **S 355** EN 10025-2 \(f_y:355\) \(f_u:510\)
- **S 450** EN 10025-2 \(f_y:440\) \(f_u:550\)
- **S 275 N/NL** EN 10025-3 \(f_y:275\) \(f_u:390\)
- **S 355 N/NL** EN 10025-3 \(f_y:355\) \(f_u:490\)
- **S 420 N/NL** EN 10025-3 \(f_y:420\) \(f_u:520\)
- **S 460 N/NL** EN 10025-3 \(f_y:460\) \(f_u:540\)
- **S 275 M/ML** EN 10025-4 \(f_y:275\) \(f_u:370\)
- **S 355 M/ML** EN 10025-4 \(f_y:355\) \(f_u:470\)
- **S 420 M/ML** EN 10025-4 \(f_y:420\) \(f_u:520\)
- **S 460 M/ML'** EN 10025-4 \(f_y:460\) \(f_u:540\)
- **S 235 W** EN 10025-5 \(f_y:235\) \(f_u:360\)
- **S 355 W** EN 10025-5 \(f_y:355\) \(f_u:510\)
- **S 460 Q/QL** EN 10025-6 \(f_y:460\) \(f_u:570\)
- **S 235 H** EN 10210-1 \(f_y:235\) \(f_u:360\)
- **S 275 H** EN 10210-1 \(f_y:275\) \(f_u:430\)
- **S 355 H** EN 10210-1 \(f_y:355\) \(f_u:510\)
- **S 275 NH/NLH** EN 10210-1 \(f_y:275\) \(f_u:390\)
- **S 355 NH/NLH** EN 10210-1 \(f_y:355\) \(f_u:490\)
- **S 420 NH/NLH** EN 10210-1 \(f_y:420\) \(f_u:540\)
- **S 460 NH/NLH** EN 10210-1 \(f_y:460\) \(f_u:560\)
- **S 460 NH/NLH** EN 10210-1 \(f_y:460\) \(f_u:560\)
- **S 460 NH/NLH** EN 10210-1 \(f_y:460\) \(f_u:560\)

### 16.5 Partial factors EN 1993-1-1:2005 § 6.1

The partial factors \(\gamma_M\) are applied to various characteristics resistance values. The partial factors are defined in the program from the selected National Annex., and can be overwritten in Parameters/National Annex parameters.

Usual values for steel structures \(\gamma_M = 1.00\)
γ_M1 = 1.00
γ_M2 = 1.25
Usual values for concrete structures (EN1992-1-1 Tab. 2.1N)
γ_c = 1.50 (concrete)
γ_s = 1.15 (reinforcing steel)

16.6 Second order effects EN1993-1-1 §5.2.1

The material behaviour is considered linear elastic. The second order effects are geometrical (P-Δ and P-δ) effects. The practical consequence of (P-Δ)-effects is to reduce the stiffness of the frame, with a result the increase of the deflections and the internal forces beyond the ones calculated from first-order analysis.

The effects of the deformed geometry are quantified using the factor acr EN1993-1-1 §5.2.1

acr = Fcr/Fed  EN1993-1-1 Eq. (5.1)

Fed: is the design loading of the structure
Fcr : is the elastic critical buckling load for global instability mode based on initial elastic stiffness.

The frame is considered sufficiently stiff and second order effects may be ignored in a first order analysis if acr ≥ 10

For portal frames with shallow slopes according to EN1993-1-1 §5.2.1 (4) acr can be estimated as

acr = \left( \frac{H_{Ed}}{V_{Ed}} \right) \frac{h}{\delta_{H,Ed}}  \text{ EN1993-1-1 Eq (5.2)}

H_{Ed} : total design the total design horizontal load
V_{Ed} : total design vertical load
\delta_{hed} : is the horizontal displacement at the top of the columns
h : is the column height

Axial force in the rafters may be assumed to be significant if

\lambda < 0.5 \sqrt{\frac{A_{fr}}{N_{Ed}}}  \text{ EN1993-1-1 Eq (5.3)}

According to EN1993-1-1 §5.2.2 (5), single story portal frames designed based on elastic analysis the global analysis second order effects due to vertical load may be calculated by increasing the horizontal loads Hed by equivalent loads φ Ved due to imperfections and other possible sway effects according to the first order theory by an amplification factor

\frac{1}{1 - \frac{1}{acr}}  \text{ provided that acr ≥ 3 EN1993-1-1 Eq (5.4)}

If acr < 3, second order analysis is necessary

16.7 Imperfections EN1993-1-1 §5.3.1

Global initial sway imperfection: φ = φ_0 • α_h • φ_m
φ_0: Initial value = 1/200
α_h: Reduction factor for column height = 2/\sqrt{h} \ (2/3 ≤ α_h ≤ 1) \ (h: structure height)
φ_m: Reduction factor for number of columns in a row α_m = \sqrt{0.5 \left( 1 + \frac{1}{m} \right)}
16.8 Classification of cross sections EN 1993-1-1:2005 § 5.5

The design of steel elements can be done with elastic or plastic analysis depending on the class of the cross section. The design of sections of classes 1 and 2 is based on the plastic resistance, the design of cross-sections of class 3 is based on elastic resistance, and the design of cross-sections of class 4 is based on elastic resistance and effective cross section properties. The classification of cross sections in 1, 2, 3 and 4 classes depends on the ratios of thickness to width of the parts of the cross-section which are in compression according to tables 5.2 of EN 1993-1-1:2005.

Table 5.2 EN 1993-1-1:2005 – Internal compression parts

<table>
<thead>
<tr>
<th>Class</th>
<th>Part subject to bending</th>
<th>Part subject to compression</th>
<th>Part subject to bending and compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{c}{t} \leq 72 \varepsilon )</td>
<td>( \frac{c}{t} \leq 33 \varepsilon )</td>
<td>when ( \alpha &gt; 0.5 ): ( \frac{c}{t} \leq \frac{396 \varepsilon}{13 \alpha - 1} )</td>
</tr>
<tr>
<td>2</td>
<td>( \frac{c}{t} \leq 83 \varepsilon )</td>
<td>( \frac{c}{t} \leq 38 \varepsilon )</td>
<td>when ( \alpha &gt; 0.5 ): ( \frac{c}{t} \leq \frac{456 \varepsilon}{13 \alpha - 1} )</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{c}{t} \leq 124 \varepsilon )</td>
<td>( \frac{c}{t} \leq 42 \varepsilon )</td>
<td>when ( \psi &gt; -1 ): ( \frac{c}{t} \leq \frac{42 \varepsilon}{0.67 + 0.33 \psi} )</td>
</tr>
</tbody>
</table>

\[ \varepsilon = \sqrt{\frac{235}{f_y}} \]

<table>
<thead>
<tr>
<th>( f_y )</th>
<th>( t )</th>
<th>( c )</th>
<th>( \alpha )</th>
<th>( \psi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>235</td>
<td>1.00</td>
<td>0.92</td>
<td>0.81</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Table 5.2 EN 1993-1-1:2005 – Outstanding flanges

<table>
<thead>
<tr>
<th>Class</th>
<th>Part subject to compression</th>
<th>Part subject to bending and compression</th>
<th>Tip in compression</th>
<th>Tip in tension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td>c / t ≤ 9e</td>
<td>c / t ≥ 9e / α</td>
</tr>
<tr>
<td>2</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
<td>c / t ≤ 10e / α</td>
<td>c / t ≤ 10e / α</td>
</tr>
<tr>
<td>3</td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
<td>c / t ≤ 2.1Fe / kx</td>
<td></td>
</tr>
</tbody>
</table>

\[ \varepsilon = \sqrt{\frac{235}{f_y}} \]

Class 1:
- \[ f_c = 235, \quad \varepsilon = 1.00, \quad \varepsilon^2 = 1.00 \]
- \[ f_c = 275, \quad \varepsilon = 0.92, \quad \varepsilon^2 = 0.85 \]
- \[ f_c = 355, \quad \varepsilon = 0.81, \quad \varepsilon^2 = 0.66 \]
- \[ f_c = 420, \quad \varepsilon = 0.75, \quad \varepsilon^2 = 0.56 \]
- \[ f_c = 460, \quad \varepsilon = 0.71, \quad \varepsilon^2 = 0.51 \]

Table 5.2 EN 1993-1-1:2005 - Angles

Refer also to “Outstanding flanges” (see sheet 2 of 3)

<table>
<thead>
<tr>
<th>Class</th>
<th>Section in compression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><img src="image7" alt="Diagram" /></td>
</tr>
</tbody>
</table>

\[ h / t ≤ 15e : \frac{b + h}{2t} ≤ 11.5e \]

Class 3:
- \[ h / t ≤ 15e : \frac{b + h}{2t} ≤ 11.5e \]

Tubular sections

<table>
<thead>
<tr>
<th>Class</th>
<th>Section in bending and/or compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>d / t ≤ 50e^2</td>
</tr>
<tr>
<td>2</td>
<td>d / t ≤ 70e^2</td>
</tr>
<tr>
<td>3</td>
<td>d / t ≤ 90e^2</td>
</tr>
</tbody>
</table>

**NOTE** For d / t > 90e^2 see EN 1993-1-6.
16.9 Design for SLS  EN1993-1-1 § 7.2

The analysis for Serviceability Limit State (SLS), is performed by checking the deflections for all the SLS load cases after a first-order analysis.

Load combinations (SLS)

\[ \begin{align*}
    Ed &= Gk + Qk1 + \psi_0 \cdot Qk2 + \psi_0 \cdot Qk3 \quad \text{(Characteristic combination)} \\
    Ed &= Gk + \psi_1 \cdot Qk1 + \psi_2 \cdot Qk2 + \psi_2 \cdot Qk3 \quad \text{(Frequent combination)} \\
    Ed &= Gk + \psi_2 \cdot Qk1 + \psi_2 \cdot Qk2 + \psi_2 \cdot Qk3 \quad \text{(Quasi-permanent combination)}
\end{align*} \] (Eq.6.14b)

The basic deflection checks are for the maximum vertical deflection in the apex and the maximum horizontal deflection at the top of the columns. The limits for these deflections are usually defined in the National Annex. EN1993-1-1 § 7.2 and EN 1990 Annex A1.4

According to EN1993-1-1 these limits may be specified for each project and agree with the client.

The limits for deflections in the program can be specified in Parameters/Design parameters. Usual values: vertical deflection L/200, horizontal deflection H/150, vertical deflection due to bending L/200.

16.10 Ultimate limit states EN 1993-1-1:2005 § 6.2

16.10.1 Tension EN 1993-1-1:2005 § 6.2.3

\[ \frac{N_{Ed}}{N_{f,Rd}} \leq 1 \] (EN 1993-1-1, 6.5)

Design plastic resistance of the cross-section.

\[ N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} \] (EN 1993-1-1, 6.6)

Design ultimate resistance of net cross-section at holes for fasteners.

\[ N_{u,Rd} = \frac{0.9 A_{net} \cdot f_u}{\gamma_{M2}} \] (EN 1993-1-1, 6.7)

\[
\begin{align*}
    A & \quad \text{area of cross-section} \\
    A_{net} & \quad \text{area of net cross-section (minus holes)} \\
    f_y & \quad \text{yield strength of steel} \\
    f_u & \quad \text{ultimate strength of steel} \\
    \gamma_{M0} & \quad \gamma_{M2} \quad \text{partial factors for material}
\end{align*}
\]

16.10.2 Compression EN 1993-1-1:2005 § 6.2.4

\[ \frac{N_{Ed}}{N_{c,Rd}} \leq 1 \] (EN 1993-1-1, 6.9)

\[ N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} \quad \text{for class 1, 2, 3 cross-sections} \] (EN 1993-1-1, 6.10)
\[ N_{c,Rd} = \frac{A_{eff} \cdot f_y}{\gamma_{M0}} \text{ for class 4 cross-sections} \] (EN 1993-1-1, 6.11)

- \( A \) area of cross-section
- \( A_{eff} \) effective area of cross-section
- \( f_y \) yield strength of steel
- \( \gamma_{M0} \) partial factors for material

In case the design value of shear is \( V_{Ed} > 0.50 V_{pl,Rd} \) the reduced yield strength is used.

\[
(1 - \rho) f_y, \text{ where } \rho = \left(\frac{2V_{Ed}}{V_{pl,Rd} - 1}\right)^2 
\] (EN 1993-1-1, 6.29)

### 16.10.3 Bending moment EN 1993-1-1:2005 § 6.2.5

\[
\frac{M_{Ed}}{M_{c,Rd}} \leq 1 
\] (EN 1993-1-1, 6.12)

Design resistance of cross section for bending about the principal (y-y) or secondary (z-z) axis.

- \( M_{y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} \) for class 1, 2 cross-sections (EN 1993-1-1, 6.13)
- \( M_{z,Rd} = M_{pl,z,Rd} = \frac{W_{pl,z} \cdot f_y}{\gamma_{M0}} \) for class 1, 2 cross-sections
- \( M_{y,Rd} = M_{el,y,Rd} = \frac{W_{el,y} \cdot f_y}{\gamma_{M0}} \) for class 3 cross-sections (EN 1993-1-1, 6.14)
- \( M_{z,Rd} = M_{el,z,Rd} = \frac{W_{el,z} \cdot f_y}{\gamma_{M0}} \) for class 3 cross-sections
- \( M_{y,Rd} = M_{c,y,Rd} = \frac{W_{eff,y} \cdot f_y}{\gamma_{M0}} \) for class 4 cross-sections (EN 1993-1-1, 6.15)
- \( M_{z,Rd} = M_{c,z,Rd} = \frac{W_{eff,z} \cdot f_y}{\gamma_{M0}} \) for class 4 cross-sections

- \( W_{pl,y} \) plastic section modulus about principal and secondary axis,
- \( W_{el,y} \) elastic section modulus about principal and secondary axis,
- \( W_{eff,y} \) effective section modulus about principal and secondary axis,
- \( f_y \) yield strength of steel
- \( \gamma_{M0} \) partial factors for material

When bending moment acts together with axial force design check is performed according to:
\[
\frac{M_{Ed}}{M_{N,Rd}} \leq 1 \quad \text{(EN 1993-1-1, 6.31)}
\]
\[
M_{N,Rd} = M_{pl,Rd} \left[ 1 - \left( \frac{N_{Ed}}{N_{pl,Rd}} \right)^2 \right] \quad \text{(EN 1993-1-1, 6.32)}
\]

In case the design value of shear is \( V_{Ed} > 0.50 V_{pl,Rd} \), the reduced yield strength is used.

\[
(1 - \rho)f_y, \text{ where } \rho = \left( \frac{2V_{Ed}}{V_{pl,Rd}} - 1 \right)^2 \quad \text{(EN 1993-1-1, 6.29)}
\]

**16.10.4 **Bi-axial bending EN 1993-1-1:2005 § 6.2.9

\[
\left( \frac{M_{y,Ed}}{M_{y,Rd}} \right)^\alpha + \left( \frac{M_{z,Ed}}{M_{z,Rd}} \right)^\beta \leq 1 \quad \text{(EN 1993-1-1, 6.41)}
\]

For I and H sections: \( \alpha=2, \beta=5n, \beta \geq 1 \) (\( n=N_{Ed}/N_{pl,Rd} \))

For circular hollow sections: \( \alpha=2, \beta=2 \)

For rectangular hollow sections \( \alpha=\beta=1.66/(1-1.13n^2) \)

**16.10.5 **Shear EN 1993-1-1:2005 § 6.2.6

\[
\frac{V_{Ed}}{V_{c,Rd}} \leq 1 \quad \text{(EN 1993-1-1, 6.17)}
\]

Plastic shear resistance parallel to the cross-section web.

\[
V_{z,Rd} = V_{pl,z,Rd} = \frac{A_{yz} \cdot f_y}{\sqrt{3} \gamma_{M0}} \quad \text{(EN 1993-1-1, 6.18)}
\]

Plastic shear resistance parallel to the cross-section flanges.

\[
V_{y,Rd} = V_{pl,y,Rd} = \frac{A_{yz} \cdot f_y}{\sqrt{3} \gamma_{M0}} \quad \text{(EN 1993-1-1, 6.18)}
\]

\( A_{yz} \), \( A_{yz} \) shear areas parallel to the cross-section web or flanges,

\( f_y \) yield strength of steel

\( \gamma_{M0} \) partial factors for material
16.10.6 Buckling resistance of uniform members in compression

EN 1993-1-1:2005 § 6.3.1

Buckling resistance due to compression.

\[
\frac{N_{Ed}}{N_{b,Rd}} \leq 1 \quad \text{(EN 1993-1-1, 6.46)}
\]

\[
N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} \quad \text{for class 1, 2, 3 cross-sections} \quad \text{(EN 1993-1-1, 6.47)}
\]

\[
N_{b,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}} \quad \text{for class 4 cross-sections} \quad \text{(EN 1993-1-1, 6.48)}
\]

The reduction factor \( \chi \) is determined from the non-dimensional slenderness \( \overline{\lambda} \)

\[
\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \overline{\lambda}^2}} \leq 1 \quad \text{(EN 1993-1-1, 6.49)}
\]

\[
\Phi = 0.5 \left[ 1 + \alpha (2 - 0.2 + \overline{\lambda}^2) \right]
\]

\[
\overline{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}}; \quad N_{cr} = \frac{\pi^2 E A}{\overline{\lambda}^2}; \quad \overline{\lambda} = \frac{I_{eff}}{i}; \quad i = \sqrt{\frac{I}{A}}
\]

\( \overline{\lambda} \) non-dimensional slenderness,
\( N_{cr} \) elastic critical buckling load,
\( L_{cr} \) equivalent buckling length,
\( \lambda \) slenderness,
\( i \) radius of gyration.

The imperfection factor \( \alpha \) that corresponds to the appropriate buckling curve \( a, a, b, c, d \) should be obtained from Table 6.2 of Eurocode 3, EN 1993-1-1:2005:

<table>
<thead>
<tr>
<th>Buckling curve</th>
<th>( a_0 )</th>
<th>a</th>
<th>b</th>
<th>C</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperfection factor ( \alpha )</td>
<td>0.13</td>
<td>0.21</td>
<td>0.34</td>
<td>0.49</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Equivalent buckling lengths \( L_{cr}/L \)
### Table 6.2 EN 1993-1-1:2005 Selection of buckling curve of a cross-section

<table>
<thead>
<tr>
<th>Cross section</th>
<th>Limits</th>
<th>Buckling about axis</th>
<th>$S_{235}$</th>
<th>$S_{275}$</th>
<th>$S_{355}$</th>
<th>$S_{420}$</th>
<th>$S_{460}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled sections</td>
<td>$t_{f} \leq 40$ mm</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td>$a$</td>
<td>$b$</td>
<td>$a_0$</td>
<td>$a_0$</td>
</tr>
<tr>
<td></td>
<td>$h_{b} &gt; 1.2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$40 \text{ mm} &lt; t_{f} \leq 100$</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td>$b$</td>
<td>$a$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h_{b} \leq 1.2$</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td>$b$</td>
<td>$a$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$t_{f} &gt; 100$ mm</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td>$d$</td>
<td></td>
<td>$c$</td>
<td></td>
</tr>
<tr>
<td>Welded I-sections</td>
<td>$t_{f} \leq 40$ mm</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td>$b$</td>
<td></td>
<td>$b$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$t_{f} &gt; 40$ mm</td>
<td>$y-y$</td>
<td>$z-z$</td>
<td></td>
<td>$c$</td>
<td></td>
<td>$c$</td>
</tr>
<tr>
<td>Hollow sections</td>
<td>hot finished</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$a$</td>
<td>$a_0$</td>
</tr>
<tr>
<td></td>
<td>cold formed</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$c$</td>
<td>$c$</td>
</tr>
<tr>
<td>Welded box sections</td>
<td>generally (except as below)</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$b$</td>
<td>$b$</td>
</tr>
<tr>
<td></td>
<td>thick welds: $a &gt; 0.5 t_{f}$</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$c$</td>
<td>$c$</td>
</tr>
<tr>
<td></td>
<td>$b/t_{f} &lt; 30$</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$c$</td>
<td>$c$</td>
</tr>
<tr>
<td></td>
<td>$h/t_{w} &lt; 30$</td>
<td></td>
<td></td>
<td></td>
<td>any</td>
<td>$c$</td>
<td>$c$</td>
</tr>
<tr>
<td>L-, T- and solid sections</td>
<td></td>
<td>any</td>
<td>$c$</td>
<td>$c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-sections</td>
<td></td>
<td>any</td>
<td>$b$</td>
<td>$b$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 16.10.7 Lateral torsional buckling for uniform members

EN 1993-1-1:2005 § 6.3.2

Lateral torsional buckling of uniform members in bending.

\[
\frac{M_{Ed}}{M_{b,Rd}} \leq 1 \quad \text{(EN 1993-1-1, 6.54)}
\]

\[
M_{b,Rd} = \frac{z_{LT} W_y f_y}{\gamma_{Ml}} \quad \text{(EN 1993-1-1, 6.55)}
\]

\[W_y = W_{pl,y} \quad \text{for class 1, 2 cross-sections,}
\]

\[W_y = W_{el,y} \quad \text{for class 3 cross-sections,}
\]

\[W_y = W_{eff,y} \quad \text{for class 4 cross-sections.}
\]

The reduction factor \(z_{LT}\) is determined from the non-dimensional slenderness \(\bar{z}_{LT}\)

\[
z_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{z}_{LT}^2}} \leq 1 \quad \text{(EN 1993-1-1, 6.56)}
\]

\[\Phi_{LT} = 0.5 \left[1 + \alpha_{LT} \left(\bar{z}_{LT} - 0.2\right) + \bar{z}_{LT}^2\right]
\]

\[\bar{z}_{LT} = \frac{W_y f_y}{M_{cr}}
\]

The imperfection factor \(\alpha\) which corresponds to the appropriate buckling curve a,b,c,d:

<table>
<thead>
<tr>
<th>Buckling curve</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperfection factor (\alpha_{LT})</td>
<td>0.21</td>
<td>0.34</td>
<td>0.49</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Recommended values for torsional buckling curves:
- Rolled Sections  h/b<2 buckling curve a, h/b>2 buckling curve b
- Welded sections  h/b<2 buckling curve c, h/b>2 buckling curve d

The critical elastic moment for lateral torsional buckling is computed according to Annex F of Eurocode 3-1-1 (1992).

\[
M_{cr} = C_1 \frac{\pi^2 E I_z}{(kL)^2} \left[ \frac{k}{k_w} \frac{I_w}{I_z} + \frac{(kL)^2 G I_z}{\pi^2 E I_z} + \left(C_2 Z_g - C_3 Z_j\right)^2 - \left(C_2 Z_g - C_3 Z_j\right) \right]
\]

\(C_1, C_2, C_3\), coefficients depending on the loading conditions and support conditions, for a beam with uniform bending moment diagram \(C_1=1.000, C_2=0.000, C_3=1.000\) for a beam with parabolic bending moment diagram \(C_1=1.132, C_2=0.459, C_3=0.525\)

\(I_i\)  St. Venant torsional constant,

\(I_w\)  warping constant,

\(I_z\)  second moment of inertia about the weak axis,

\(L\)  beam length between the support points,

\(k, k_w\)  coefficients depending on the support conditions,

\(Z_g\)  distance of shear center from point of load application
16.10.8 Uniform members in bending and compression EN 1993-1-1:2005 § 6.3.4

\[
\frac{N_{Ed}}{x_y N_{Rk} / \gamma_{M1}} + k_{yy} \frac{M_{Y,Ed}}{\chi_{LT} M_{y,Rk} / \gamma_{M1}} + k_{yz} \frac{M_{z,Ed}}{M_{z,Rk} / \gamma_{M1}} \leq 1
\]

(EN 1993-1-1, 6.61)

\[
\frac{N_{Ed}}{x_z N_{Rk} / \gamma_{M1}} + k_{zy} \frac{M_{Y,Ed}}{\chi_{LT} M_{y,Rk} / \gamma_{M1}} + k_{zz} \frac{M_{z,Ed}}{M_{z,Rk} / \gamma_{M1}} \leq 1
\]

(EN 1993-1-1, 6.62)

\[
N_{Rk} = Af_y
\]

\[
M_{y,Rk} = W_{pl,y} f_y \quad \text{for class 1, 2 cross-sections}
\]

\[
M_{y,Rk} = W_{el,y} f_y \quad \text{for class 3 cross-sections,}
\]

\[
M_{y,Rk} = W_{ef,y} f_y \quad \text{for class 4 cross-sections,}
\]

\[
M_{z,Rk} = W_{pl,z} f_y \quad \text{for class 1, 2 cross-sections}
\]

\[
M_{z,Rk} = W_{el,z} f_y \quad \text{for class 3 cross-sections,}
\]

\[
M_{z,Rk} = W_{ef,z} f_y \quad \text{for class 4 cross-sections.}
\]

The interaction coefficients \( k_{yy}, k_{yz}, k_{zy}, k_{zz} \) are determined from tables B.1 and B.2

**Table B.1 interaction coefficients \( k_{yy}, k_{yz}, k_{zy}, k_{zz} \)**

<table>
<thead>
<tr>
<th>Interaction factors</th>
<th>Type of sections</th>
<th>Design assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>elastic cross-sectional properties class 3, class 4</td>
</tr>
<tr>
<td>( k_{yy} )</td>
<td>I-sections RHS-sections</td>
<td>( C = 1 + 0.6 \bar{x}<em>y \frac{N</em>{Ed}}{x_y N_{Rk} / \gamma_{M1}} ) \leq C = 1 + 0.6 \bar{x}<em>y \frac{N</em>{Ed}}{x_y N_{Rk} / \gamma_{M1}}</td>
</tr>
<tr>
<td>( k_{yz} )</td>
<td>I-sections RHS-sections</td>
<td>( k_{yz} )</td>
</tr>
<tr>
<td>( k_{zy} )</td>
<td>I-sections RHS-sections</td>
<td>0.8 ( k_{yy} )</td>
</tr>
<tr>
<td>( k_{zz} )</td>
<td>I-sections RHS-sections</td>
<td>( C = 1 + 0.6 \bar{x}<em>z \frac{N</em>{Ed}}{x_z N_{Rk} / \gamma_{M1}} ) \leq C = 1 + 0.6 \bar{x}<em>z \frac{N</em>{Ed}}{x_z N_{Rk} / \gamma_{M1}}</td>
</tr>
<tr>
<td>( k_{zz} )</td>
<td>RHS-sections</td>
<td>( C = 1 + 1.4 \frac{N_{Ed}}{x_z N_{Rk} / \gamma_{M1}} )</td>
</tr>
</tbody>
</table>

For I- and H-sections and rectangular hollow sections under axial compression and uniaxial bending \( M_{r,Ed} \) the coefficient \( k_{zz} \) may be \( k_{zz} = 0 \).
Table B.2

<table>
<thead>
<tr>
<th>Interaction factors</th>
<th>Design assumptions</th>
<th>elastic cross-sectional properties</th>
<th>plastic cross-sectional properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>class 3, class 4</td>
<td>class 1, class 2</td>
</tr>
<tr>
<td>$k_{ey}$</td>
<td>$k_{ey}$ from Table B.1</td>
<td>$k_{ey}$ from Table B.1</td>
<td></td>
</tr>
<tr>
<td>$k_{ez}$</td>
<td>$k_{ez}$ from Table B.1</td>
<td>$k_{ez}$ from Table B.1</td>
<td></td>
</tr>
</tbody>
</table>

$$
\begin{align*}
    k_{ey} &= \left[ 1 - \frac{0.05 \bar{\lambda}_z}{(C_{eLT} - 0.25) \chi_z \frac{N_{Ed}}{\gamma_{M1}}} \right] \\
    &\geq \left[ 1 - \frac{0.05}{(C_{eLT} - 0.25) \chi_z \frac{N_{Ed}}{\gamma_{M1}}} \right] \\
    k_{ez} &= k_{ez} \text{ from Table B.1}
\end{align*}
$$

for $\bar{\lambda}_z < 0.4$:

$$
k_{ey} = 0.6 + \bar{\lambda}_z \leq 1 - \frac{0.1 \bar{\lambda}_z}{(C_{eLT} - 0.25) \chi_z \frac{N_{Ed}}{\gamma_{M1}}}
$$

Table B.3

<table>
<thead>
<tr>
<th>Moment Diagram</th>
<th>Range</th>
<th>$C_{my}, C_{ez} \neq C_{eLT}$ under loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>$-1 \leq \psi \leq 1$</td>
<td>$0.6 + 0.4 \psi \geq 0.4$</td>
</tr>
<tr>
<td>$-M_h$</td>
<td>$0 \leq \alpha_5 \leq 1$</td>
<td>$0.2 + 0.8 \alpha_5 \geq 0.4$</td>
</tr>
<tr>
<td>$+M_h$</td>
<td>$-1 \leq \psi \leq 0$</td>
<td>$0.1 - 0.8 \alpha_5 \geq 0.4$</td>
</tr>
<tr>
<td>$\alpha_5 = M_h / M_h$</td>
<td>$-1 \leq \psi &lt; 0$</td>
<td>$0.1(1 - \psi) - 0.8 \alpha_5 \geq 0.4$</td>
</tr>
<tr>
<td>$+M_h$</td>
<td>$0 \leq \alpha_h \leq 1$</td>
<td>$0.95 + 0.05 \alpha_h$</td>
</tr>
<tr>
<td>$-M_h$</td>
<td>$-1 \leq \psi \leq 0$</td>
<td>$0.95 + 0.05 \alpha_h$</td>
</tr>
<tr>
<td>$\alpha_h = M_h / M_h$</td>
<td>$-1 \leq \psi &lt; 0$</td>
<td>$0.95 + 0.05 \alpha_h (1 + 2\psi)$</td>
</tr>
</tbody>
</table>
16.11 Connections Eurocode 3-1-8:2005

The three connections designed are eave, apex and base connection. The connections are designed based on Eurocode 3 1-8 Design of Joints. The eave and apex connections are designed with end plates and bolts. All the checks for moment and shear resistance are performed. The base connection is a plate bearing connection and considered pinned or fixed connection to the footing. The anchor bolts are designed to resist shear and uplift forces (wind and seismic uplift forces). In the case of rigid (fixed) base connection the anchor bolts are designed to resist the tension upwards forces due to bending. The anchoring system is designed according to Eurocode 3-1-8 §6.2.6.12 and CEN/TS 1992-4-1:2009, Design of fastenings in concrete, General and CEN/TS 1992-4-2:2009, Design of fastenings, Headed Fasteners. The concrete of the base is designed to resist the compression forces according to Eurocode 3-1-8 §6.2.5(7) and Eurocode 2-1-1:2004.

\[ F_{C,Rd} = f_{sd} \cdot b_{eff} \cdot l_{eff} \]
\[ f_{sd} = \beta_j \cdot F_{Re,y} / (b_{eff} \cdot l_{eff}) \]
\[ \beta_j = \frac{2}{3} \]
\[ f_{cd} = \alpha_{cc} f_{ck} / \gamma_c \]
\[ \alpha_{cc} = 1.0, \quad \gamma_c = 1.5 \text{ defined in National annex} \]

16.12 Bracing system

Bracing systems are required to resist transverse actions, due to wind and earthquake. For this, two bracing systems are provided. Vertical bracing system in the sidewalls between the columns. This system transmits the horizontal transverse loads from the roof to the ground and temporary stability during the erection. Horizontal roof bracing system. On the roof to transmit the transverse loads from the roof to the vertical bracing and to provide temporary stability during the erection.

If you select a light profile L for the bracing system then it may result in many braced frames along the building than if you select a heavier profile.
16.13 Foundation

The horizontal reaction acting outwards is resisted in two ways.
1. Passive earth pressure on the side of the foundation. In this case the earth filling and compacting on the side of the foundation must be performed carefully, so that the passive earth pressure is not reduced.
2. A tie cast into the floor slab connected to the base of the columns. This should be considered more safe method to resist the horizontal forces at the base of the columns.

The fundament is designed according to Eurocode 7 EN1997-1-1:2004, Eurocode 7 Geotechnical design, for stability in vertical download forces as well as uplift forces due to wind or seismic load.

The reinforced concrete design is according to EN1992-1-1:2004, Eurocode 2 Reinforced concrete.

16.13.1 Design of footing

According to Eurocode 7 §6.5.2. The bearing resistance of the footing \( R_d \) must be greater than the design load \( V_d \), \( R_d > V_d \). The bearing resistance \( R_d = q_u A' / \gamma_q \), where \( q_u \) is bearing capacity of soil and the \( A' \) is the effective design area of footing as defined in Annex D of Eurocode 7. The partial factor for soil properties \( \gamma_q \) is used for the design values of geotechnical parameters according to Eurocode 7 Annex A. EQUI STR and GEO limit states, and can be modified in Parameters/Design parameters/NAD parameters/material factors.

Only vertical load \( A' = B x L \)

Vertical load \( N \) and moment \( M \), \( A' = B x L' \). \( L' = \text{effective foundation length} \)

16.13.2 Passive earth pressure

Passive earth pressure is the resultant pressure developed by a granular material against some surface, when the latter shifts over a small distance towards the material. The basic assumptions for lateral earth-pressure, using a simplified wedge theory, are set by Coulomb (1736-1806).
17 Standards and Bibliography

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Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads
Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions
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Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions
Eurocode 1 - Actions on structures Part 1-6: General actions - Actions during execution
EN 1991-1-7:2006/AC:2010
Eurocode 1 - Actions on structures - Part 1-7: General actions - Accidental actions
Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges
Eurocode 1 - Actions on structures - Part 3: Actions induced by cranes and machinery
Eurocode 1 - Actions on structures - Part 4: Silos and tanks
EN 1992-1:2004
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Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings
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Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design
Eurocode 3 - Design of steel structures - Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting
EN 1993-1-4:2006
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Eurocode 3 - Design of steel structures - Part 1-6: Strength and Stability of Shell Structures
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Eurocode 3: Design of steel structures - Part 1-8: Design of joints
Eurocode 3: Design of steel structures - Part 1-9: Fatigue
Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties

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Eurocode 3 - Design of steel structures - Part 1-11: Design of structures with tension components

Eurocode 3 - Design of steel structures - Part 1-12: Additional rules for the extension of EN 1993 up to steel grades S 700

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