Second Generation of Eurocode 8

# WEBINAR 4: Silos, tanks, pipelines, towers masts and chimneys – Towers, masts and chimneys

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# OVERVIEW

- Scope of application
- Structure of the Standard
- Main changes cf. EN1998-6:2005
- Rules for towers, masts and chimneys EN1998-4: Ch.10
  - Bases of Design
  - Verification to Limit States
  - Specific rules for reinforced concrete chimneys
  - Specific rules for steel chimneys
  - Specific rules for steel towers

  (Annex F (Informative) number of degrees of freedom and of modes of vibration)

  (Annex G (Informative) masonry chimneys)

# SCOPE OF APPLICATION

- Ch.10 should be used for the design of tall slender steel towers, guyed masts and chimneys in addition to Eurocode 3 - Part 3: Towers, masts and chimneys, and in addition to EN 1992-1-1
- Ch.10 in EN1998-4 does not completely cover the design of structures for electrical power transmission and distribution, which is typically controlled by wind loads, often combined with ice loads or by unbalanced longitudinal wire loads; only ‘Tangent Towers’ are covered concerning structural modelling
- Ch.10 in EN1998-4 should not be applied to cooling towers and offshore structures.
- Towers supporting tanks are designed according to Chap. 6.7.
- Other ENs (beyond EN199x) referred throughout Ch.10:
    - EN 13084-2: Free-standing chimneys – Concrete chimneys.
    - EN 13084-7: Free-standing chimneys – Product specification of cylindrical steel fabrications for use in single-wall steel chimneys and steel liners.

# STRUCTURE OF THE STANDARD

- **Basis of Design**: addresses the basic rules for mass and stiffness modelling, for the structural analysis and for the maximum values for the components $q_R$ and $q_S$ of the behaviour factors
- **Limit States**: Damage Limitation (DL) criteria are given for chimneys, towers and masts; Fully Operational (OP) verifications are related to the equipment in risk defined by the intervenient parties in the Project
- **Specific rules** for dissipative behaviour and respective value of the component $q_D$ >1,0 of the behaviour factor to be used in design
  - Rules for reinforced concrete chimneys to achieve $q_D$ =1,3
  - Rules for steel chimneys to achieve $q_D$ defined in EN 1998-1-2
  - Rules for steel towers to achieve $q_D$ defined in EN 1998-1-2, with a limitation of $q_D$ =1,3 for trussed tubular towers

# MAIN CHANGES CF. EN1998-6:2005

Main changes introduced in the contents of EN1998-6:2005 when transposing and adapting it to the new prEN1998-4 are related to:

- Adopting the new structure common to the other chapters and parts
- Abandoning the definition of **rotational spectra**

From the scientific publications available it can be concluded that, although there is evidence that rotational components can contribute to additional seismic forces and horizontal displacements, mostly in soft soils and near-fault situations, **no reliable direct measurements of the rotational components are available and that such influence, when existing, is not exclusive of towers masts or chimneys**. The conclusion is that the influence of rotational spectra on tall towers, if any, is still not adequately investigated and **is not at a level to be included in the code**. Also, no quantitative assessment of the rotational components have been found that could justify the methodology adopted in EN1998-6:2005. Furthermore, if such spectra are to be defined in the code, it should be done in the Seismic Load Definition included in Part 1-1

# MAIN CHANGES CF. EN1998-6:2005

Main changes introduced in the contents of EN1998-6:2005 when transposing and adapting it to the new prEN1998-4 are related to:

- Adopting the new structure common to the other chapters and parts
- Abandoning the definition of **rotational spectra**
- Decreasing **behaviour factors,** specially those to be used for the design of concrete chimneys.

The studies published by Wilson (2003, 2009) analyze the inelastic response of ten reinforced concrete chimneys, ranging in height from 115 m to 301 m subject to earthquake excitation. It is concluded that the limited ductility design approach as specified in the 2001 CICIND code is recommended for the design of tall chimney structures. This method allows a 50% reduction in earthquake forces (q = 2) to account for ductility effects, provided some basic design guidelines are followed. Considering these results, an overall behavior factor q=1,95 is considered in EN1998-4

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Bases of Design - Modelling and structural analysis:

**Model should include:**

a) the rotational and translational stiffness of the foundation;

b) the stiffness of cables and guys;

c) sufficient degrees of freedom to determine the response of any significant structural element, equipment or appendage;

d) relative displacements of the supports of equipment or machinery (e.g. in chimneys);

e) piping interactions, externally applied structural restraints, hydrodynamic loads (e.g. in chimneys).

**Application of "rigid diaphragm"**

For the "rigid diaphragm" assumption to be applicable:

- to steel towers, a horizontal bracing system should be provided, with adequate in-plane stiffness and spacing between bracing levels.
- to steel chimneys, horizontal stiffening rings should be provided with adequate in-plane stiffness and spacing between stiffening rings.

If the conditions for the applicability of the "rigid diaphragm" assumption are not met, a three-dimensional dynamic analysis should be performed.

**Rules for structural modelling including stiffness and mass distribution are given**
**Annex F gives additional information about number of degrees of freedom and of modes of vibration**

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

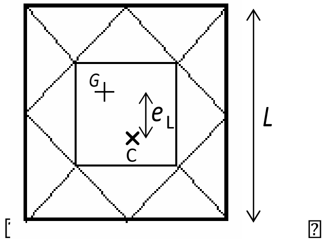
## Bases of Design

### Rules for Behaviour factors

Regular structures
The maximum value for the behaviour factor q is calculated using
$q_R = 1,0$
$q_S = 1,5$
$q_D$ defined in 10.4, 10.5 and 10.6, respectively for reinforced concrete chimneys, steel chimneys and steel towers.

Reduction due to irregularities (mass/stiffness)
q should be reduced by the modification factor $k_r$
When more than one of the irregularities are present, $k_r$ should be assumed to be equal to the lowest values of $k_r$ multiplied by 0,9.

$k_r$ factors according to existing irregularities

| **Description** | $k_r$ |
|---|---|
| Horizontal eccentricity ($e_L$) of the centre of mass ($G$) at a horizontal level with respect to the centroid of the stiffness ($C$) of the (vertical) elements at that level, exceeding 5 % of the parallel horizontal dimension ($L$) of the structure at same level   | 0,8 |
| Openings in the shaft or structural shell causing a 30 % or larger reduction of the moment of inertia of the cross-section | 0,8 |
| Concentrated mass within the top third of the height of the structure, contributing by 50 % or more to the overturning moment at the base | 0,7 |

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Verification to Limit States

## Significant Damage (SD) limit state

### Structural Verification:

structural elements and the structure as a whole should possess a capacity larger than the demand obtained from the structural analysis using one of the following design approaches:

a) Design for dissipative behaviour using a value of the behaviour factor q greater then 1,5 and applying the rules for energy dissipation capacity

b) Design the structure for low-dissipative behaviour in DC1 using a value of the behaviour factor q equal to 1,5.

Guyed masts should be designed using approach (b).

### Second order effects:

Second order theory should be considered in the analysis, unless the following condition is fulfilled:

$$\delta M / M_o < 0{,}10$$

$\delta M$ is the additional overturning moment at the base level due to second-order (P-$\Delta$) effect, where P is the vertical load in the seismic design situation and $\Delta$ is the displacement corresponding to the moment $M_0$ calculated with the first-order theory ($\delta M = P\,\Delta$);

$M_o$ is the first-order overturning moment at the base level.

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Verification to Limit States

## Significant Damage (SD) limit state

### Steel Connections:

For non-dissipative connections, the resistance should be determined according to EN 1993

The resistance of dissipative connections should be greater than the plastic resistance of the connected dissipative member based on the design yield stress taking into account the randomness material factor according to EN 1998-1-2.

### Stability:

The stability of structural elements may be considered to be verified if the rules relevant to stability verification in EN 1992 and EN 1993 are fulfilled.

In structural steel members, class 4 sections may be used if following conditions are fulfilled:

a) the specific rules concerning classification of cross-sections in EN 1993-1-1;
b) the value of the behaviour factor, q, is limited to 1,5;
c) the slenderness $l_s$ is not greater than:
– 120 in leg members;
– 180 in seismic primary bracing members;
– 250 in seismic secondary bracing members.

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Verification to Limit States

## Damage Limitation (DL) limit state

Unacceptable Damage

- to the structure itself and to ancillary elements should be prevented
- specific criteria can be agreed for a specific project by the relevant parties, in particular, if the operation of the structure is considered to be sensitive to deformations

.

Default criteria for towers and masts

The lateral displacement of the top of the structure calculated in accordance with EN 1998-1-1 6.4.2(2), does not exceed 0,5 % of the height of the structure

Default criteria for chimneys :

- Waste gas flues in chimneys should be verified for imposed deformations if they exceed 0,5 % of the height of the structure
- The relative deflection between different points of support of the liner $d_r$, should be limited as follows

a) $d_r \leq 0{,}012\ \Delta H$ in general

b) $d_r \leq 0{,}020\ \Delta H$ if provisions are taken to allow relative movement

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Verification to Limit States

## Fully Operational (OP) limit state

Unacceptable Damage

For a specific project, the relevant parties can specify all components of interest in the verification, together with a description of relevant damage states for each component and the associated requirements

No Default criteria in the code

Criteria applicable to the structure and associated equipment, in addition to EN 1998-1-1:20XX, 6.7.3(7), should be derived from the analysis of the components the operability of which is required as well as from the analysis of their supporting systems

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Specific rules for reinforced concrete chimneys

## Design for dissipative behaviour (q>1,5)

Concrete chimneys of annular (hollow circular) cross- section

- cross-section should be of a Concrete Class not lower than C20/25
- value of the behaviour factor component $q_D \leq 1{,}3$
- within the critical region:
  - A minimum value of the confining reinforcement should be provided as for DC3 in EN 1998-1-2
  - Ratio of the outer diameter to the wall thickness should not exceed 20
  - Avoid horizontal construction joints
  - Special provisions for lap and lap-splicing given in EN 1998-1-2 apply

Definition of critical region:

- from the base of the chimney to a height D above the base;
- from an abrupt change of section to a height D above the abrupt change of section;
- a height D above and below sections of chimney where more than one opening exists, where limits are defined by the openings' edges.

where D is the outer diameter of the chimney at the middle of the critical region

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Specific rules for reinforced concrete chimneys

## Design for dissipative behaviour (q>1,5)

### Minimum reinforcement (vertical or horizontal)

For D≥4,0m

- the vertical and horizontal reinforcement should be placed in two layers and the ratio of the horizontal reinforcement to the cross-sectional area ≥ 0,0025

For D<4,0m

- the vertical and horizontal reinforcement can be placed in one layer and the ratio of the reinforcement inneach direction to the cross-sectional area ≥ 0,003

Along one third of the height starting from the top of the chimney, the minimum vertical reinforcement ratio may be taken equal to that of the horizontal reinforcement

### Spacing of reinforcement:

The spacing of vertical bars should be not more than 250 mm and that of horizontal bars should not be more than 200 mm

Cross-ties between the outer and the inner layer of reinforcement should be provided at a horizontal and vertical spacing ≤ 600 mm

### Reinforcement around openings

The area of the additional horizontal and vertical reinforcement in each direction should not be less than that of the bars which are discontinued due to the presence of the opening.

vertical reinforcement ratio ≥ 0,0075

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Specific rules for steel chimneys

## Design for dissipative behaviour (q>1,5)

Steel chimneys of annular (hollow circular) cross-section

- Guyed steel chimneys or typical steel chimneys, seismic loads are usually not governing the design
- combined cycle power plants chimneys with large diameters (e.g. 8 m) and sizeable openings for inflowing gasses (up to 25 m high) in moderate to high seismicity class, seismic loads can govern the design. In this case, no plastic hinge can safely develop at the base of such chimneys without local buckling occurring first.

Steel frame or truss structures

which provide lateral support to flue gas ducts of chimneys may be designed for dissipative behaviour using behaviour factors according to EN 1998-1-2, 11.4.2.

# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

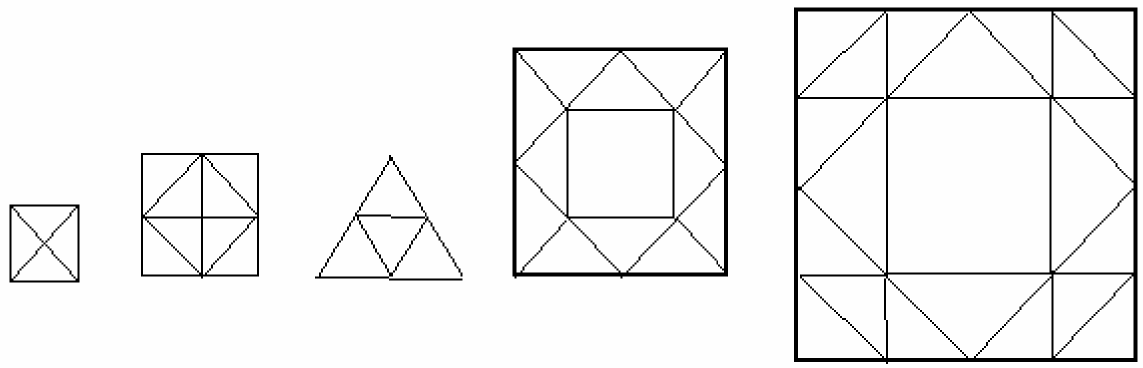
## Specific rules for steel towers

## Design for dissipative behaviour (q>1,5)

- Design of steel towers using moment resisting frames or eccentric braced frames should be designed in accordance with EN 1998-1-2
- The design of frames with concentric bracings should be in accordance with EN 1998-1-2 with additional rules

Rigid diaphragm

A horizontal bracing system capable of assuring the required rigid diaphragm action should be provided for systems designed with q greater or equal to 3,5.



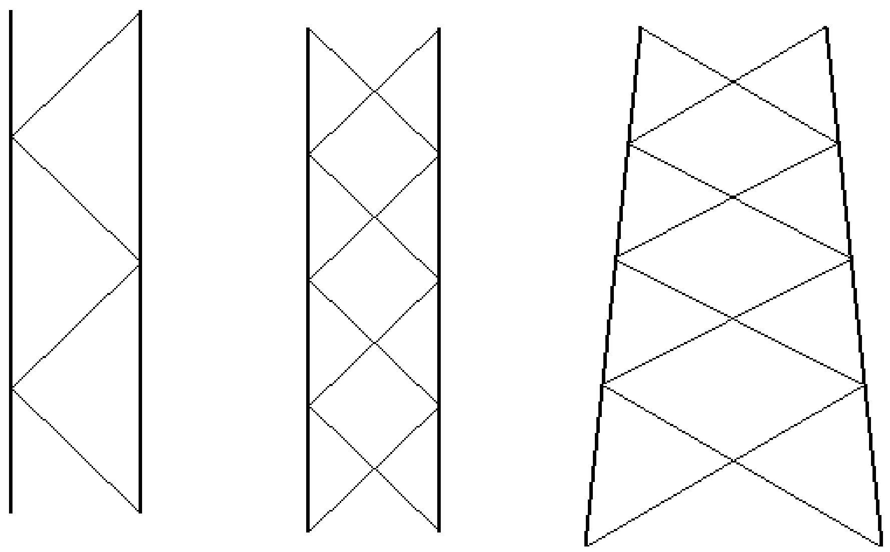
# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Specific rules for steel towers

### Design for dissipative behaviour (q>1,5)

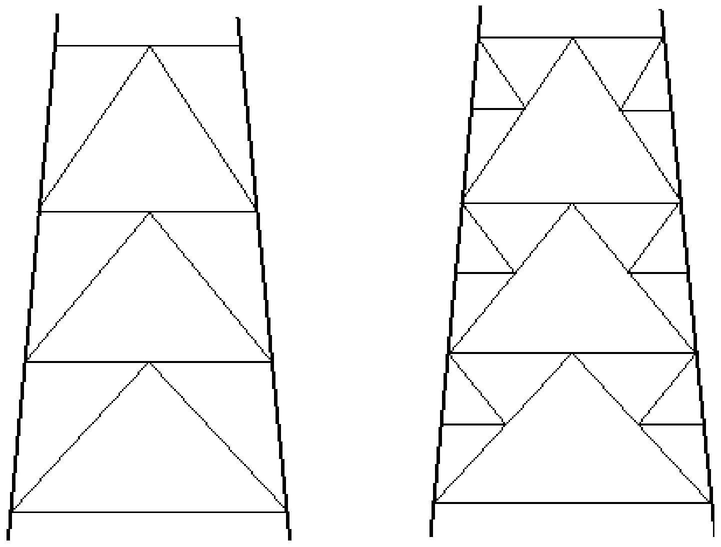
Additional rules for concentric braced towers

Frames in Figure belong to K types of bracings and should be designed in DC1 behaviour factor q=1,5.



Additional rules for concentric braced towers

The frames in Figure are similar to V-braced frames. Design for dissipative behaviour in accordance with EN 1998-1-2 11.10



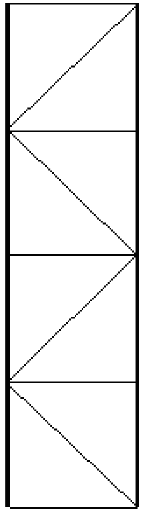
# RULES FOR TOWERS, MASTS AND CHIMNEYS EN1998-4: CH.10

## Specific rules for steel towers

### Design for dissipative behaviour (q>1,5)

Additional rules for concentric braced towers

Design of the frame in Figure in accordance with EN 1998-1-2, 11.10, pertaining to frames with diagonal bracings not positioned as X.



Additional rules for concentric braced towers

The X-braced frames in Figure may be considered as frames with X diagonal bracings designed in accordance with EN 1998-1-2 11.10.