Eurocode 8
Part 4 - Silos, tanks and pipelines
Part 6 – Towers, masts and chimneys

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EN 1998-4 – Silos, tanks and pipelines

1 - General

2 - General principles and application rules

3 - Specific principles and application rules for silos

4 - Specific principles and application rules for tanks

5 - Specific principles and application rules for above-ground pipelines

6 - Specific principles and application rules for buried pipelines

Annex A - Seismic analysis procedures for tanks

Annex B - Buried pipelines

General aspects to be considered in design

- the nature and amount of the contents and associated potential danger
- the functional requirements during and after the seismic event
- the environmental conditions.

Safety requirements

Ultimate limit state:

Structural failure

or

State prior to failure when consequences are severe
(controlled release of contents should be ensured)

This requirement should be met for a **reference seismic action** with 10 % probability of exceedance in 50 years (recommended value) i.e. with **475 years Return Period**

Safety requirements

Damage limitation state (satisfy one or two performance levels):

- **Integrity** (remain fully serviceable and leak proof)
- **Minimum operating level** (operation can be restored to a predefined level after the event)

This requirement should be met for a **seismic action** with 10 % probability of exceedance in 10 years (recommended value) i.e. with **95 years Return Period**

Reliability differentiation (as in EN 1998-1)

Target reliability of requirement depending on consequences of failure

Classify the structures into 4 importance classes

Assign a higher or lower return period to the design seismic action

*Multiply the **reference seismic action** by the **importance factor** γ_I*

System vs element reliability

*Assign **higher importance class** to **critical elements***

Importance classes for buildings

Importance Class	Silos, tanks and pipelines
I	Risk to life is low and the economic and social consequences of failure are small or negligible.
II	Medium risk to life and local economic or social consequences of failure.
III	High risk to life and large economic and social consequences of failure.
IV	Exceptional risk to life and extreme economic and social consequences of failure.

***Importance factors** (recommended values):*

γ_I ***= 0,8; 1,0; 1,2 and 1,6***

Seismic action

Basic representation: Elastic response spectrum (as in EN 1998-1)

Additional rules for spatial variation (buried pipelines)

Reduction factor ν for DLS (as in EN 1998-1)

Analysis

Basic methods as in EN 1998-1

- Lateral forces
- Modal response spectrum
- Nonlinear (pushover)
- Nonlinear (time history)

Behaviour factors

$q = 1{,}0$ for DLS

$q = 1{,}5$ for ULS in general

$q > 1{,}5$ for ULS if energy dissipation sources are explicitly identified and detailing allows it exploitation

$q = 1{,}5$ in case of base isolation

but

$q = 1{,}0$ for

- design of substructure
- convective part of liquid response (sloshing forces)
- design of isolators

Specific principles and application rules for **silos**

Distinction between

- Silos **supported on the ground**
- **Elevated** silos

Response of the particulate solid

- Additional (positive or negative) pressure on the wall
- Pressure depending on the acceleration along the height

Behaviour factor

- $q = 1{,}5$ for silos **supported on the ground**
- $q > 1{,}5$ for **elevated silos** (values for inverted pendulum structures or reduced by 0,7 for other cases)

Specific principles and application rules for **tanks**

DLS

Integrity

- **Leak tightness**
- **Adequate freeboard (prevent damage to roof or spilling)**
- **Hydraulic system able to accommodate stresses and distortion**

Minimum operating level

- **Local buckling does not trigger collapse and is reversible**

ULS

- **Overall stability (sliding and overturning)**
- **Inelastic behaviour restricted to well defined parts**
- **Buckling controlled**
- **Hydraulic system able to prevent loss of contents**

Specific principles and application rules for **tanks**

Analysis

Account for the hydrodynamic response of the contained liquid (Informative Annex A):

- **Convective and impulsive components of the motion of the liquid**
- **Deformation of the tank wall and interaction with the impulsive component**
- **Deformability of foundation**
- **Effect of floating roof (if relevant)**

Specific principles and application rules for **tanks**

Behaviour factor

q = 1,0 to 1,5 in general (q = 1,0 for the sloshing component of liquid motion)

$q > 1,5$ for tanks supported on the ground if:

- **designed for uplift and sliding**
- **no plastic deformation at shell wall and base plate**

then:

q = 2,0 for unanchored tanks

q = 2,5 for anchored tanks with specially designed ductile anchors (allowing R/200 increase of anchor length without rupture)

Specific principles and application rules for **above-ground pipelines**

Distinction between

- **Single lines**
- **Redundant networks**

DLS

- **Maintain the supplying capability**
- **Active equipment (valves, pumps, etc) within operating range**

ULS

- **Pipeline rupture**
- **Consider remoteness of location and exposure of population**
- **Consider damage to environment**

Specific principles and application rules for **above ground pipelines**

Seismic action

- **Inertia forces**
- **Differential movement of supports**
- **Spatial variability of ground motion for L > 600m**

Modelling

- **Flexibility of foundation**
- **Mass of fluid**
- **Dynamic response of supports**
- **Connections between pipeline and supports**
- **Joints along pipeline**

Specific principles and application rules for **above ground pipelines**

Behaviour factor

Energy dissipation only in supports and/or in welded pipelines (hence, in general, q depends on the type and detailing of the supporting structure)

For welded steel pipelines

$q = 3{,}0$ *if* $r/t \leq 50$ (**$q = 2$ for supports**)

$q = 2{,}0$ *if* $r/t \leq 100$ (**$q = 1{,}5$ for supports**)

$q = 1{,}5$ *if* $r/t > 100$ (**$q = 1{,}25$ for supports**)

Specific principles and application rules for **buried pipelines**

Seismic action

a) **Seismic waves propagating on firm ground** (spatial soil deformation)

b) **Permanent deformations** (seismic fault displacement, landslides, ground displacement due to liquefaction)

Inertia forces may be neglected
In most cases b) is the dominant issue in a network
Check with EN 1998-5 for the possibility of occurrence

Modelling of seismic waves

- **Body waves (Shear and Dilatational – short distances)**
- **Surface waves (Love and Rayleigh – long distances)**

Simple wave passage model in Annex B

Specific principles and application rules for buried pipelines

Simple wave passage (sinusoidal) model (Annex B):

$$u(x,t) = d \sin \omega (t - x/c)$$

d – displacement

c – apparent wave velocity

Longitudinal particle motion:

Max Strain: $\varepsilon_{\max} = v/c$

with v = peak soil velocity

Transverse particle motion:

Max Curvature: $\chi_{\max} = a/c^2$

with a = peak soil acceleration

Specific principles and application rules for **buried pipelines**

Design measures for fault crossing:

- Choose orientation of pipe to favour tensile deformation
- Increase thickness of pipe in the vicinity of the crossing
- Decrease friction between pipe and soil (smooth coating)
- Apply loose backfill over 50 m on each side of the fault
- Place locally the pipeline above ground (with deformable supports allowing relative movement)