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

E C Carvalho, Chairman TC250/SC8
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 $\gamma_I$

System vs element reliability

Assign higher importance class to critical elements
**Importance classes for buildings**

<table>
<thead>
<tr>
<th>Importance Class</th>
<th>Silos, tanks and pipelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Risk to life is low and the economic and social consequences of failure are small or negligible.</td>
</tr>
<tr>
<td>II</td>
<td>Medium risk to life and local economic or social consequences of failure.</td>
</tr>
<tr>
<td>III</td>
<td>High risk to life and large economic and social consequences of failure.</td>
</tr>
<tr>
<td>IV</td>
<td>Exceptional risk to life and extreme economic and social consequences of failure.</td>
</tr>
</tbody>
</table>

**Importance factors (recommended values):**

\[ \gamma_I = 0,8; 1,0; 1,2 \text{ and } 1,6 \]
Seismic action

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

Additional rules for spatial variation (buried pipelines)
Reduction factor $\nu$ 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

\[ q = 1,0 \text{ for DLS} \]
\[ q = 1,5 \text{ for ULS in general} \]
\[ q > 1,5 \text{ for ULS if energy dissipation sources are explicitly identified and detailing allows its exploitation} \]
\[ q = 1,5 \text{ in case of base isolation} \]

but

\[ q = 1,0 \text{ for} \]

- 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**

\[ q = 1.0 \text{ to } 1.5 \text{ in general} \quad (q = 1.0 \text{ for the sloshing component of liquid motion}) \]

\[ q > 1.5 \text{ for tanks supported on the ground if:} \]

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

then:

\[ q = 2.0 \text{ for unanchored tanks} \]

\[ q = 2.5 \text{ for anchored tanks with specially designed ductile anchors} \text{ (allowing R/200 increase of anchor length without rupture)} \]
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

\[ q = 3.0 \text{ if } r/t \leq 50 \] \[ q = 2.0 \text{ if } r/t \leq 100 \] \[ q = 1.5 \text{ if } r/t > 100 \]

\( q = 2 \) for supports
\( q = 1.5 \) for supports
\( q = 1.25 \) 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:
\[ \varepsilon_{\text{max}} = \nu/c \]
with \( \nu \) = peak soil velocity

**Transverse particle motion:**

Max Curvature:
\[ \kappa_{\text{max}} = a/c^2 \]
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)