Tanks and pipelines

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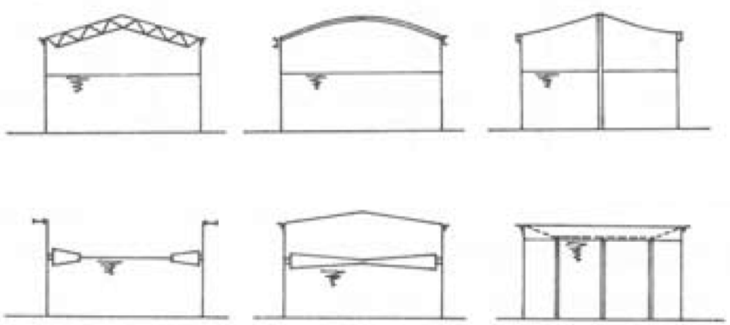
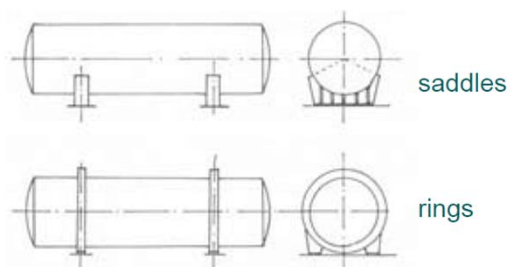
Tanks

- Tanks are commonly used to store oil products or water, stiffened as well as unstiffened.
- The principal structural element of these tanks is a vertical steel cylinder, or shell, which is made by welding together a series of rectangular plates and which restrains the hydrostatic pressures by hoop tension forces.
- The tank is normally provided with a flat steel plated bottom which sits on a prepared foundation, and with a fixed roof attached to the top of the shell wall.
- According to shape: cylindrical vertical, cylindrical horizontal, spherical, rectangular, other.
- According to internal pressure: low-pressure (up to 20 mbar = 2kPa), high-pressure.
- The tank is normally provided with a flat steel plated bottom which sits on a prepared foundation, and with a fixed roof attached to the top of the shell wall.

Types of cylindrical tanks



Horizontally placed cylinders



Spherical tank

Storage tank, dome roof

Storage tank, conical roof

Fuel storage tank, capacity approx 2,000,000 liters, fixed roof and internal floating roof

Irrigation Water Storage Tank

Analysis and design of tanks (EN 1993-4-2)

3 consequence Classes: Class 1, 2, 3

Class 1: Simple structures for agriculture or tanks containing water.

- membrane theory may be used, with simple formulas for boundary disturbance and asymmetric loading.

Checks for (roof, webs, for bottom use FEM):

- global stability and static equilibrium,
- strength of the structure and joints,
- stability (global and local – formulas given in Eurocode),
- cyclic plasticity,
- fatigue,
- SLS (deflections and vibrations).

Actions

Liquid induced loads: During operation, the load due to the contents should be the weight of the *product to be stored from maximum design liquid level* to empty.

Internal pressure loads: During operation, the internal pressure load should be the load due to the specified minimum and maximum values of the internal pressure.

Thermally induced loads: Stresses resulting from restraint of thermal expansion may be ignored if the number of load cycles due to thermal expansion is such that there is no risk of fatigue failure or cyclic plastic failure.

Dead loads: The dead loads on the tank should be considered as those resulting from the weight of all component parts of the tank and all components permanently attached to the tank.

Insulation loads: The insulation loads should be those resulting from the weight of the insulation.

Distributed live load, Concentrated live load

Snow: The loads should be taken from EN 1991-1-3.

Wind: The loads should be taken from EN 1991-1-4.

Suction due to inadequate venting: The loads should be taken from EN 1991-1-4.

Seismic loadings: The loads should be taken from EN 1998-4, which also sets out the requirements for seismic design.

Loads resulting from connections: Loads resulting from pipes, valves and other items connected to the tank and loads resulting from settlement of independent item supports relative to the tank foundation should be taken into account.

Loads resulting from uneven settlement: Settlement loads should be taken into account where uneven settlement can be expected during the lifetime of the tank.

Emergency loadings: The loads should be specified for the specific situation and can include loadings from events such as external blast, impact, adjacent external fire, explosion, leakage of inner tank, roll over, overfill of inner tank.

Wind Loads

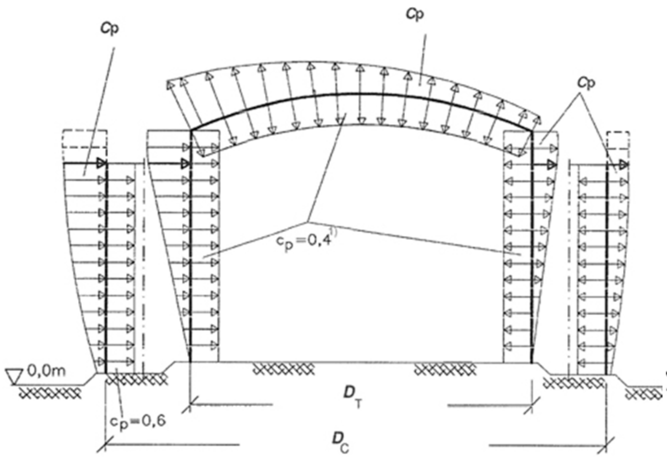
The loads should be taken from EN 1991-1-4. In addition, the following pressure coefficients may be used for circular cylindrical tanks, see figure:

a) internal pressure of open top tanks and open top catch basin: c_p = -0,6.

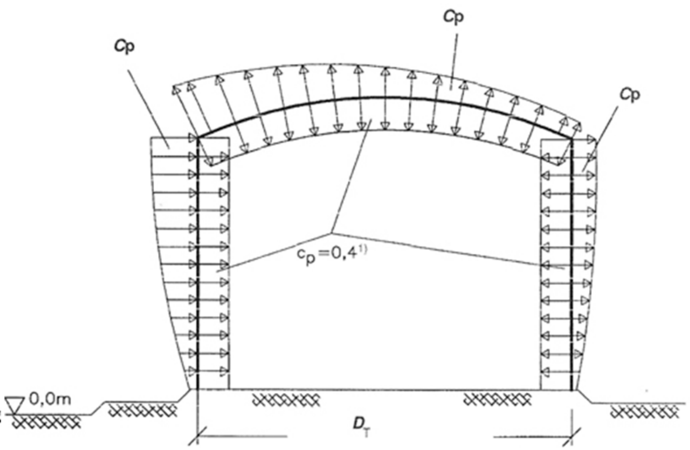
b) internal pressure of vented tanks with small openings: c_p = -0,4.

c) where there is a catch basin, the external pressure on the tank shell may be assumed to reduce linearly with height.

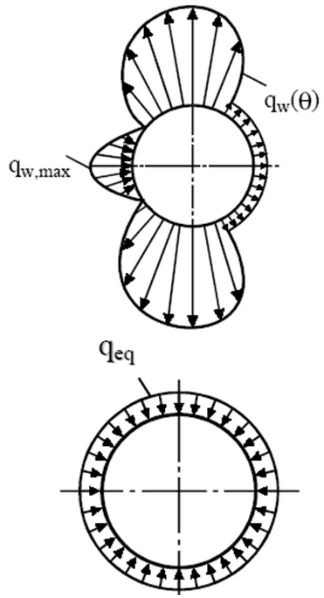
Due to their temporary character, reduced wind loads may be used for erection situations according to EN 1991-1-4.



Tank with catch basin



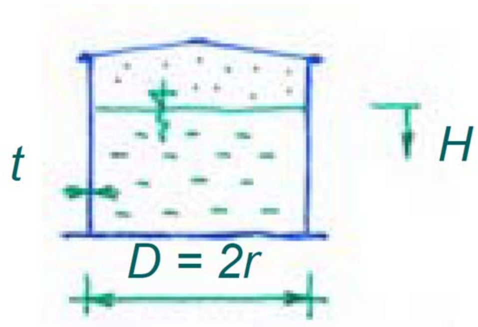
Tank without catch basin



Transformation of typical wind external pressure load distribution (for simplified design)

Design of shell - simplified relations

Required thickness of cylindrical tank web:



$$t = \frac{p_d\, r}{f_{yd}}$$

where design loading by liquid and overpressure, p_d is:

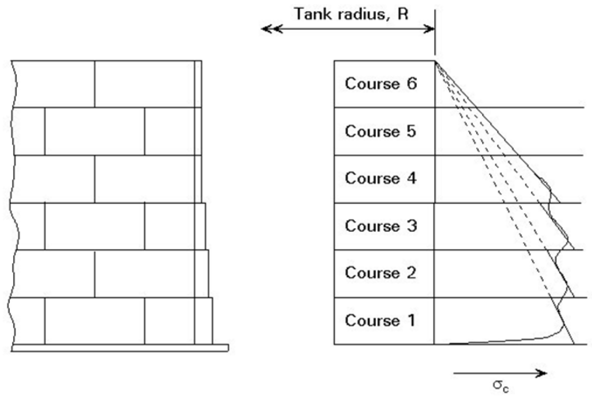
$$p_d = \gamma_F\, \gamma\, H + q_d$$

γ → unit weight

q_d → design overpressure above liquid level

For spherical tanks: $t = \dfrac{p\, r}{2\, f_{yd}}$ (one half in comparison to the above)

The lowest course of plates is fully welded to the bottom plate of the tank providing radial restraint to the bottom edge of the plate.
Similarly, the bottom edge of any course which sits on top of a thicker course is somewhat restrained because the thicker plate is stiffer.
The effect of this on the hoop stresses is illustrated in the figure



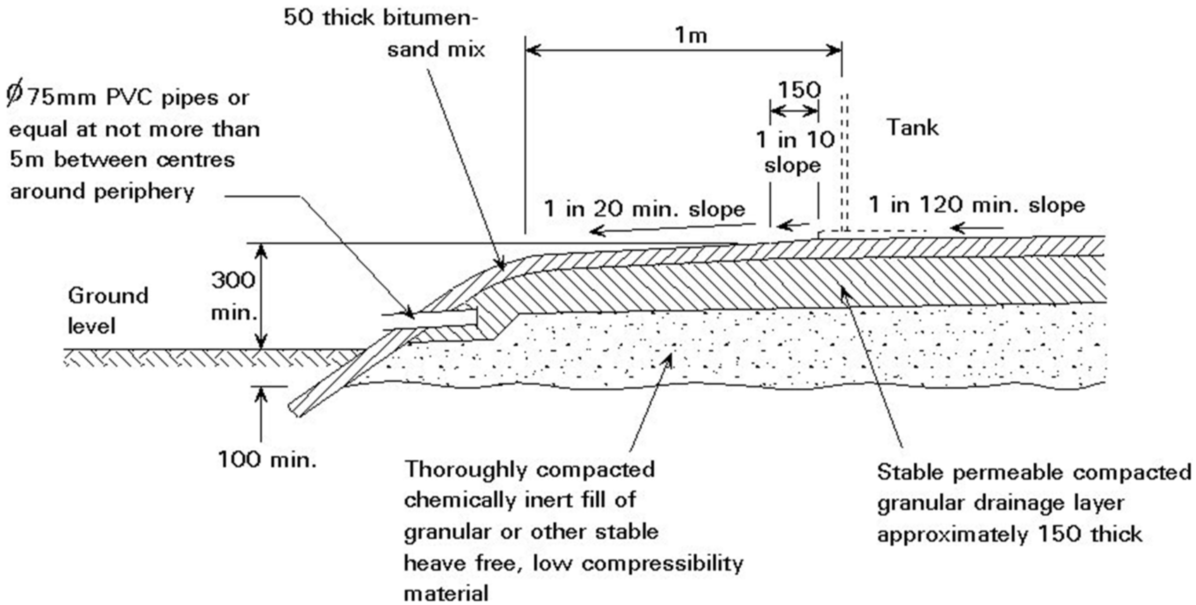
Variation of stress in shell wall

Bottom design

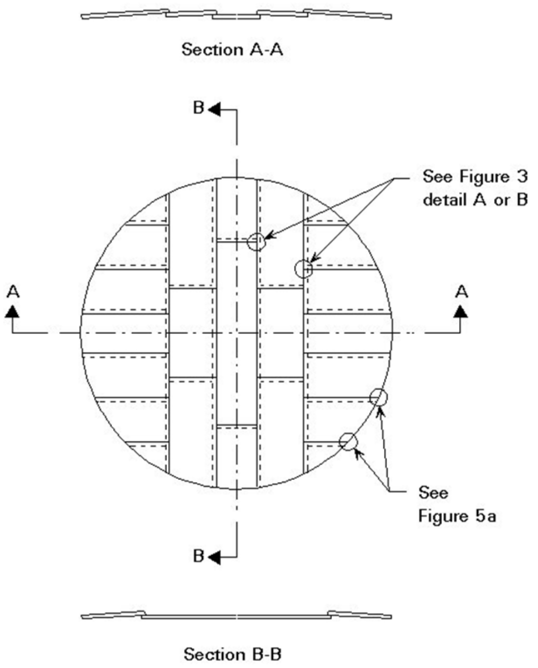
- The design of the bottom plate should take corrosion into account.
- Bottom plates should be lap welded or butt welded.
- The specified thickness of the bottom plates should not be less than specified in table below.

Minimum nominal bottom plate thickness

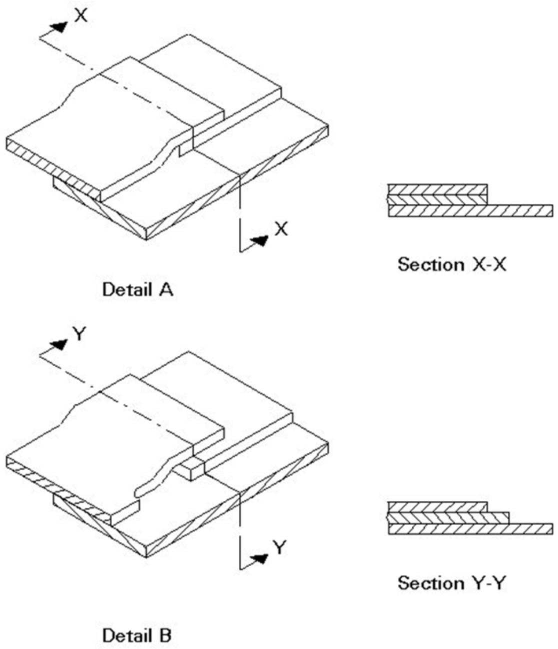
Material	Lap welded bottoms	Butt welded bottoms
Carbon steels	6 mm	5 mm
Stainless steels	5 mm	3 mm



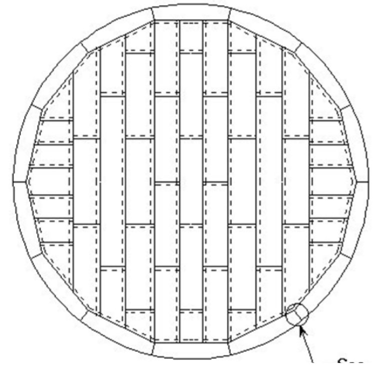
Typical tank foundation



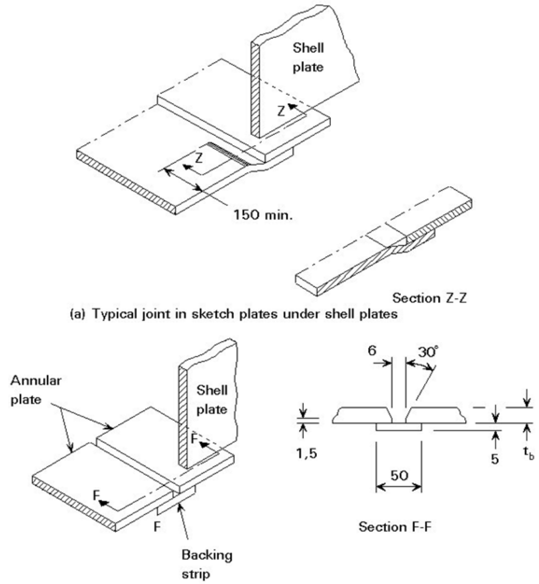
Typical bottom layout for tanks up to and including 12.5m diameter



Cross joints in bottom plates where three thicknesses occur



Typical bottom layout for tanks over 12.5 diameter



Joints in bottom plates bellow shell plates

Tank anchorage

- Tanks are usually not equipped with anchoring devices.

- Anchoring devices should be provided for fixed roof tanks, if any of the following conditions can cause the cylindrical shell wall and the bottom plate close to it to lift off its foundations:

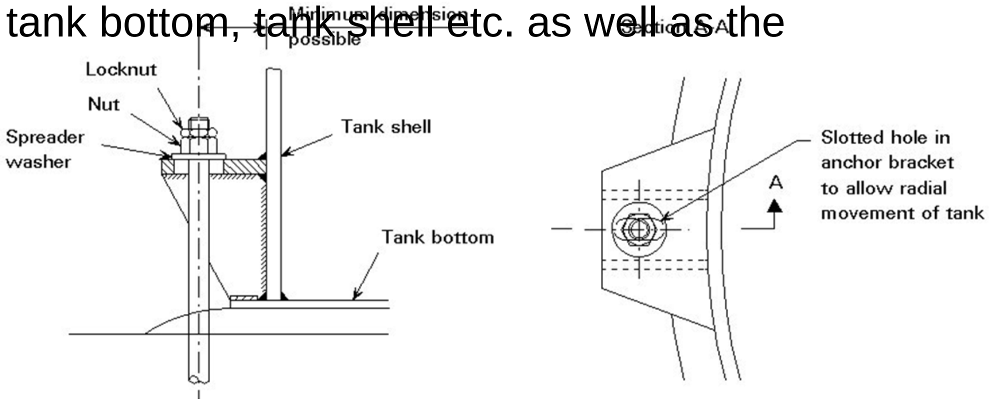
a) Uplift of an empty tank due to internal design pressure counteracted by the effective corroded weight of roof, shell and permanent attachments

b) Uplift due to internal design pressure in combination with wind loading counteracted by the effective corroded weight of roof, shell and permanent attachments plus the effective weight of the product always present in the tank

c) Uplift of an empty tank due to wind loading counteracted by the effective corroded weight of roof, shell and permanent attachments;

d) Uplift of an empty tank due to external liquid caused by flooding. In such cases it is necessary to consider the effects upon the tank bottom, tank shell etc. as well as the anchorage design.

e) Uplift of filled tank due to seismic action



Typical tank anchorage detail

Fixed roof design

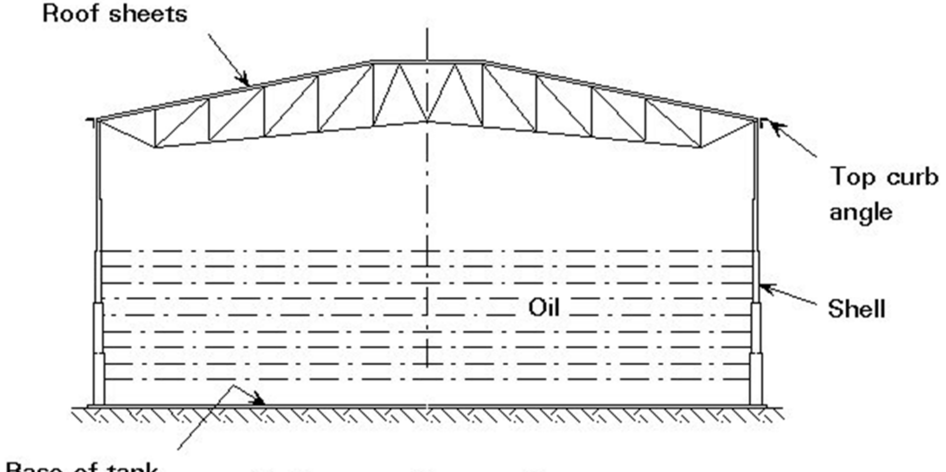
- Fixed roofs of cylindrical tanks are formed of steel plate and are of either conical or domed (spherically curved) configuration.
- The steel plates can be entirely self supporting (by 'membrane' action), or they may rest on top of some form of support structure.

Membrane Roofs

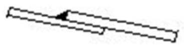
- In a membrane roof, the forces from dead and imposed loads are resisted by compressive radial stresses.
- For downward loads, the radial compression is complemented by ring tension.
- For upward loads, i.e. under internal pressure, the radial tension has to be complemented by a circumferential compression. This compression can only be provided by the junction section between roof and shell. This is expressed as a requirement for a minimum area of the effective section.

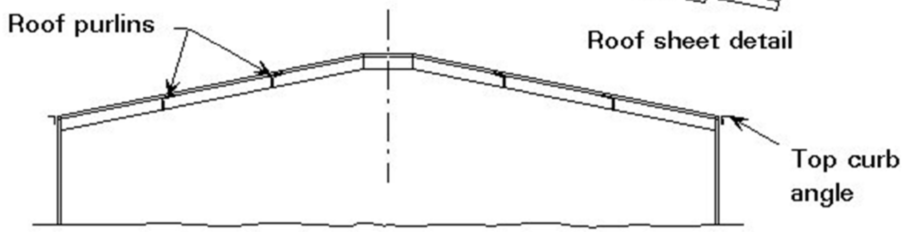
Supported Roofs

- Radial members supporting the roof plate permit the plate thickness to be kept to a minimum.
- Supported roofs are most commonly of conical shape, although spherical roofs can be used if the radial beams are curved.
- The roof support structure can either be self supporting or be supported on internal columns. Self supporting roofs are essential when there is an internal floating cover.

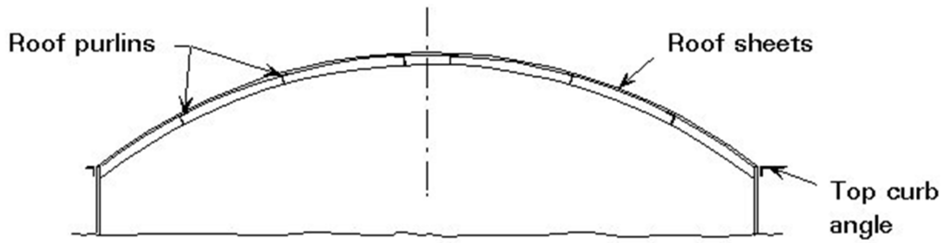


(a) Truss : self supporting

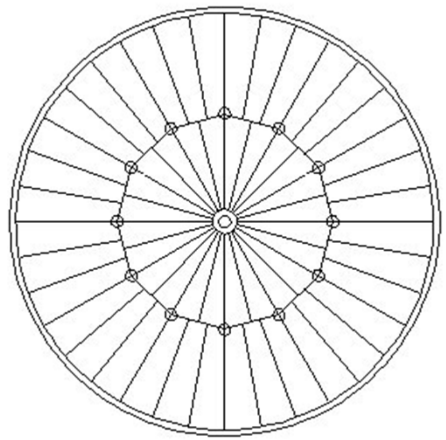




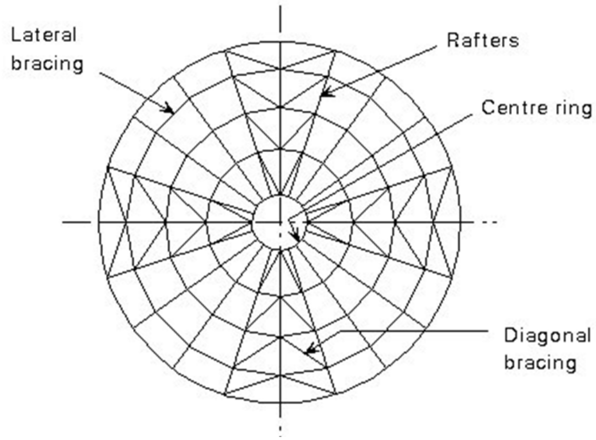
(b) Cone : self supporting



(c) Dome : self supporting



Column supports



Alternative support systems for roofs

Self-supporting fixed roofs

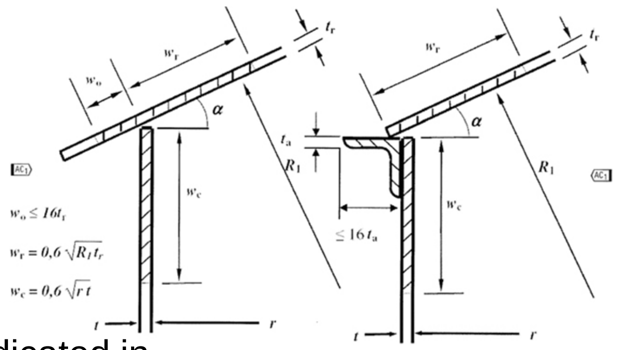
Edge ring at the shell to roof junction

- The force in the effective edge ring (area where the roof is connected to the shell) should be verified using:

$$\frac{N_{Ed}}{A_{eff}} \leq f_{y,d}$$

in which:

$$N_{Ed} = \frac{p_{v,Ed} r^2}{2 \tan \alpha}$$



where:

A_{eff}	is the effective area of the edge ring indicated in figure
α	is the slope of the roof to the horizontal at the junction;
$p_{v,Ed}$	is the maximum vertical component of the design distributed load including the dead weight of the supporting structure (downward positive).

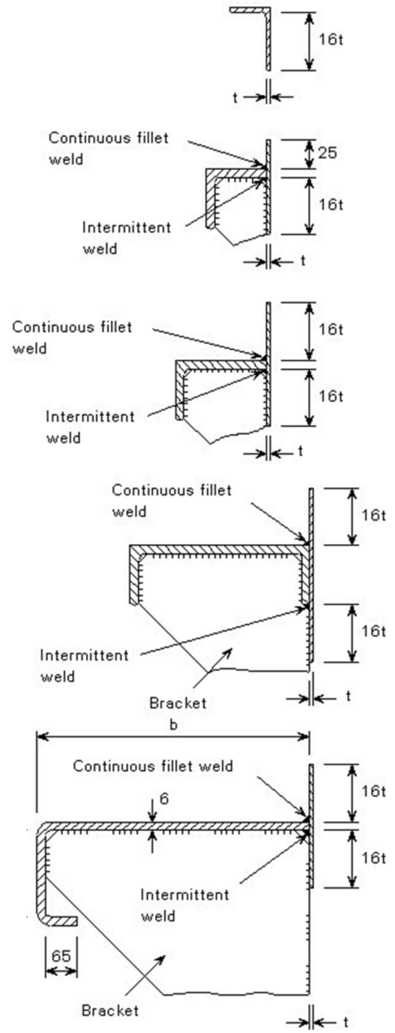
- The bending moments in the ring should be considered if rafter is located at a distance to the edge that exceeds 3,25m.

$$M_{s,Ed} = -\left(\frac{p_{v,Ed} r^3}{2 \tan \alpha}\right)\left(1 - \frac{\beta}{\tan \beta}\right)$$

At the connection of the rafter

$$M_{F,Ed} = -\left(\frac{p_{v,Ed} r^3}{2 \tan \alpha}\right)\left(\frac{\beta}{\sin \beta} - 1\right)$$

At half span between the rafters



Seismic design (EN 1998-4)

Seismic motion induces two main effects in tanks:

- The rocking motion, accompanied by an uplifting of the rim of the annular plate or the bottom plate, is induced by the overturning moment due to the horizontal inertia force. In this case, particular attention should be paid to the design of the bottom corner of the tank
- On the other hand the rocking motion in the liquefied gas storage tank caused by the overturning moment induces pulling forces in anchor straps or anchor bolts in place of uplifting the annular plate. In this case, the stretch of the anchor straps or anchor bolts which are provided at the bottom course of the tank, should be the subject of careful design.

Pulled out of anchor bolt

Cut off of anchor bolt

Pulled out of earthing wire

Elephant foot bulge type buckling of tank wall

Diamond pattern buckling of tank wall

Tank damage mode at Hanshin-Awaji Earthquake

Pipelines

- Design is done according to EN 1993-4-2: Eurocode 3 - Design of steel structures - Part 4-3: Pipelines
- Fundamental requirements
  - The pipeline shall be designed and constructed in such a way that:
    - With acceptable probability, it will remain fit for the use for which it is required, having due regard to its intended life and its cost;
    - With appropriate degrees of reliability, it will sustain all actions and other influences likely to occur during the execution and use and have adequate durability in relation to maintenance costs;
    - It will not be damaged by events like explosions, impact or consequences of human errors, to an extend disproportionate to the original cause.
  - The potential damage of pipelines shall be limited or avoided by appropriate choice of one or more of the following:
    - Avoiding, eliminating or reducing the hazards which the structure is to sustain.
    - Selecting a structural form that has low sensitivity to the hazards considered.

Actions to be considered in design

The following actions should be considered, where appropriate:
- Internal pressure;
- External pressure;
- Self weight of the pipeline;
- Self weight of the contents of the pipeline
- Soil loads;
- Traffic loads;
- Temperature variations;
- Construction loads;
- Imposed deformation: due to differential settlements, mining subsidence and landslides;
- Earthquake loads (reference should be made to Eurocode 8).

Pipelines for dusty material

Pipeline bridge - general view

Pipeline - detail

Oil pipelines

This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by Prof. Josef Macháček (CTU) and Michal Jandera, PhD. (CTU).

Adaptations brought by Florea Dinu, PhD (UPT) for 2nd Edition of SUSCOS

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