DETERMINATION OF THE EFFORTS AND DEFINE NECESSARY SECTION OF INTERMEDIATE WIND GIRDERS IN CYLINDRICAL VERTICAL TANKS

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It is necessary to put intermediate stiffening rings in the tanks with bigger volumes. The stiffening rings give the possibility for decreasing of thickness of the upper course when the stability in the radial direction is assured and the geometrical wall form is unchangeable.

1. Number and position of the intermediate stiffening rings

The maximal height of wall which is not stiffening and which will not lose stability in radial direction according to [2] must be calculated by the following formula:

$$H_1 = 9{,}47.t.\sqrt{\left(\frac{t}{D}\right)^3} \text{ , where:}$$

H_1 – maximal height of the unstiffened shell, m
t – thickness of the upper course of the tank, mm
D – nominal diameter of the tank, m

This formula is valid for wind velocity equal to 160 km/h. For the values different from 160 km/h the value for H_1 must be reduced with coefficient K_v, determined by formula:

$$k_v = \left(\frac{160}{v_w}\right)^2 \text{ , where:}$$

V_w - the real velocity of the wind for the specified wind region, km/h. Then for H_1 the following formula will be valid:

$$H_1 = 9{,}47.t.Kv.\sqrt{\left(\frac{t}{D}\right)^3}$$

The following equation change the real height H_1 of every coarse from one wall to the other, reduced height regarding height, which thickness of the sheets is equal with this one of the upper (thinner) course.

$$H_{ir} = H_i.\sqrt{\left(\frac{t_{\min}}{t_i}\right)^5} \text{ , where}$$

H_{er} – reduced height of the i–th course in the shell with thickness t_i ;
H_i – real height of i-th course in the wall with thickness t_i ;
t_{min} - thickness of the shell of the tank in the upper course;
t_1 – current thickness in the tank in i-th course of the shell ;
The transformed height of the tank shell is determined according to the following formula:

$$H_r = \sum_{i=1}^{n} H_{ir}$$

If the height H_1 calculated according to the above mentioned formula is equal or bigger than H_r the construction of the intermediate stiffing ring is not necessary. If the height H_1 is less than transformed height of tank H_r there are two possible solutions:

a) increase of thickness of courses t_i in order to increase H_1
b) to put intermediate wind girders, designed for its own wind loading.

For equal stability of the shell under and above stiffening ring, the ring itself must be put at a half of the transformed height H_r. If the $H_1 < Hr/2$ then an intermediate stiffening ring must put in order to decrease the height of the shell which is not stiffened to value less than H_1. Then for equal stiffening of the shell the stiffening rings must be put at every third part of the height H_r.

It is recommended in [2] that minimal section modulus of the intermediate girders W_1 can be calculated according to the formula:

$$W_1 \geq \frac{1}{k_v} \cdot \frac{D^2.H_1}{17}$$

Open top tanks have to have top wind girder with minimum section modulus according to:

$$W_G \geq \frac{1}{k_v} \cdot \frac{D^2.H}{17}, \text{ where:}$$

H – height of the tank

When the tank have fixed roof with smallest section modulus of top angle the calculation according to the above mentioned formula can be done in advance but it is recommended to have in mind stiffening action of roof.

2. Determination of the efforts of the intermediate stiffening girders.

As consequence of the wind the efforts appear in the intermediate girders which according to [1] can be determined by the following formulas:

$$M_{wi} = k_1.w_{eq}.\gamma_{fw}.b_i.r^2$$
$$Q_{wi} = k_2.w_{eq}.\gamma_{fw}.b_i.r$$
$$N_{wi} = k_3.w_{eq}.\gamma_{fw}.b_i.r,$$

where:

k_1, k_2, k_3 – coefficients, which for different values of the centre angles and relation H/D are reported by Annex IX of [1];

w_{eq} – normative equivalent wind pressure on the shell of the tank. This wind pressure is evenly distributed upon the height and has the same as recommended height distribution influence on the tank;

γ_{fw} – coefficient of the wind pressure;

b_i – helping largeness of loading surface by wind. The wind pressure is transmitted to the wind resistant ring.

R – radius of the tank

When the tank has fixed roof the vacuum inside is very important. The above mentioned formula will be transformed in the following equation.

$$M_{w,pi} = k_1.w_{eq}.\gamma_{fw}.b_i.r^2$$
$$Q_{w,pi} = k_2.w_{eq}.\gamma_{fw}.b_i.r$$
$$N_{w,pi} = (k_3.w_{eq}.\gamma_{fw} - p_v.\ \gamma_{fv}).b_i.r:$$

where

p_v – vacuum inside tank

γ_{fv} – coefficient of overloading of vacuum pressure

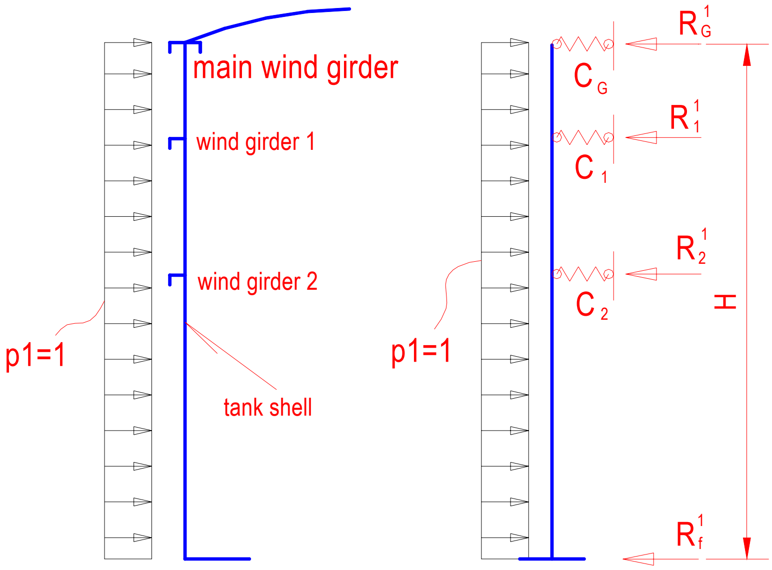
When the wind velocity **v** m/s for height of the 10 m above the site is known, the velocity pressure of the wind **q**, one of the elements which determine w_{eq}, can be calculated by formula:

$$q_o = \frac{v^2}{16}, daN/m^2$$

2.1 Attempt for 2D solution

For determination of b_i, the tank is pressured with conditional evenly distributed pressure p = 1 .

1. If the shell has variable thickness along his height the real thickness of the sheets must be accepted in model.



Two dimensioned model where the different geometrical features of the wind rings are reported

The new distribution of the efforts in the intermediate rings here is calculated according their stiffness.

$$R_G^1 = p_1.b_G \;\rightarrow\; R_G^1 = b_G$$

$$R_1^1 = p_1.b_1 \;\rightarrow\; R_1^1 = b_1$$

$$R_2^1 = p_1.b_2 \;\rightarrow\; R_2^1 = b_2$$

$$R_f^1 = p_1.b_f \;\rightarrow\; R_f^1 = b_f$$

$$R_G^1 + R_1^1 + R_2^1 + R_f^1 = p_1.H$$

$$b_G + b_1 + b_2 + b_f = H$$

where:

C_G,C_1,C_2 – spring constants of the wind girders according to their geometrical features and the thickness of the shell below them. The problem of their determination is result of the complicated character of the wind pressure. The wind girders are formed as a girder in elastic foundation. The spring constants of the foundation (the shell of the tank) will be calculated by formula:

$$k_{wi} = \frac{E.t_{wi}}{r^2}$$

where:

k_{wi} – spring constant of cylindrical shell;
E – model of the elasticity of the shell;
t_{wi} – thickness of the shell;
r – radius of the tank.

It is accepted that the bottom is indefinitely stiff in its plane.
The results of several attempts for two dimensioned solution of this problem with different stiffness of the girders and real thickness of the shell show that the relation between calculated reaction R_i remained approximately the same although the changes in the spring constants. Every time it turned out that the intermediate wind girders must bear the pressure many times bigger in comparison with top angle. The distance between supports is valid for R_i and not their stiffness.
The solutions of the problem are different when the shell thickness is increased. Then the values of $\mathbf{C_i}$ have bigger influence and the resistant reactions of $\mathbf{R_i}$ began to depend on their stiffness.

2.2 Solution of the 3D problem

The main purpose is to find the solution closest to the reality and because of it the problem accepted the following values of the volumes for models of 3D tanks: 2000m^3, 3000m^3, 5000m^3, 10000m^3, with fixed roofs, and with real thickness of the shell and real geometrical characteristics of supporting rings. The wind pressure is unevenly distributed according to [3]. The vacuum inside the tanks with fixed roof is evenly distributed.

p_w^n = 1,234kN/m^2 - normative pressure of the wind with speed v = 160 km/h;
p_v = 0,5 kN/m^2 – normative vacuum pressure in the tank;
γ_{fw} = 1,2 – coefficient of overpressure of wind according to [2];
γ_{fv} = 1,2 coefficient of over pressure of vacuum;

The calculated efforts in the rings depend on their inertia moment and are different between each other in times. The biggest effort is in top angle, which has the biggest inertia moment in the problem condition, and is additionally stiffened from the roof.
The intermediate wind girders for these 4 tanks are checked for the efforts inside them referring EN 1993 EUROCODE 3 Design of steel construction. The sections of the rings which are accepted for assuring minimal resistant moment were absolutely sufficient.

2. Design

Intermediate wind girders are checked for their stiffness of pressure and tension with corresponding bending moments.
After the design of their stiffness they must be checked for loss of stability according to [1], by the formula:

$$q_{cr} = \frac{3.E.J_m}{r_m^3} \geq q$$

where:
E – module for elasticity of the steel, kN/m^2
J_m –moment of inertia of wind resistant rings, m^4.
r_m – medium radius of resistant ring, m.
q – real pressure upon the wind ring kN/m^3

Conclusion

The working volumes of tank construction increase and it imposes the intermediate wind girders for stiffening as really important. This article is the first attempt to discover the methodology , through which to be determined real efforts in intermediate stiffening girders and rings measuring for this purpose. When we design follow only the constructive requirements mentioned in [2] it is not clear whether the accepted sections are sufficient.
It is possible also to calculate and accept big sections. But the initial profiles and position of the intermediate rings are accepted by the abovementioned methodology are good basement for creation of space model, checking and design.
The solutions that are searched in three dimensioned and two dimensioned conditions, are aiming the easier comparison of the results.

1. “Ръководство за проектиране на стоманени вертикални цилиндрични резервоари”, БРВ – КЗР, 1988 г.
2. API 650 – tenth edition, November 1998
3. “Норми за натоварване и въздействие върху сгради и съоръжения”, 1989 г.