УНИВЕРСИТЕТ ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ

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DESIGN PROBLEMS OF ANCHORING OF ABOVEGROUND STEEL TANKS

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Research area**:** *steel structures*

SUMMARY

Aboveground steel tanks are spatial sheet structures. The loads which impact on them are self-weight, snow, wind, earthquake, overpressure and vacuum. When the earthquake, overpressure and wind loads have high values, it is possible that the tank overturn or going to slide. To eliminate the threat from free moving, the steel facilities are often anchored to the foundation. This solution is not recommendable, and in standards [1] and [2] it is positioned on the last place.

Despite the standard's recommendations when the conditions of exploitation are strait and/or extreme, the steel vertical tanks must be anchored. Because of it, the developing of new specific details is needed on the purpose to minimize their unfavourable effects.

1. Introduction

The anchoring of steel tanks has a purpose to prevent their movements out of the position according to the project. In general this movement can be divided in the following main groups:

- Tank's uplifting;
- Tank's overturning;
- Horizontal movement (sliding) of the tank.

In the first two groups of movements the anchors bear tension forces. When the tank slides the anchors work against shearing.

The type of the effort determines how the anchor's chairs shall be constructed (Fig.1)

This type of the chair prevents the radial deflections of the shell. This leads to the change in the stress – strain state in the shell in the fields close to anchor's chairs.

The current research of the tanks in which anchor bolts, respectively chairs (Fig.2), must bear tension and shearing forces, has the following purpose:

- to check how the stress-strain state changes in the shell in the zones of anchor's chairs;
- to check whether the anchor bolts are bended when the tank is being filled and consecutive shell's deformation;
- what is the influence of the internal stiffening ring.

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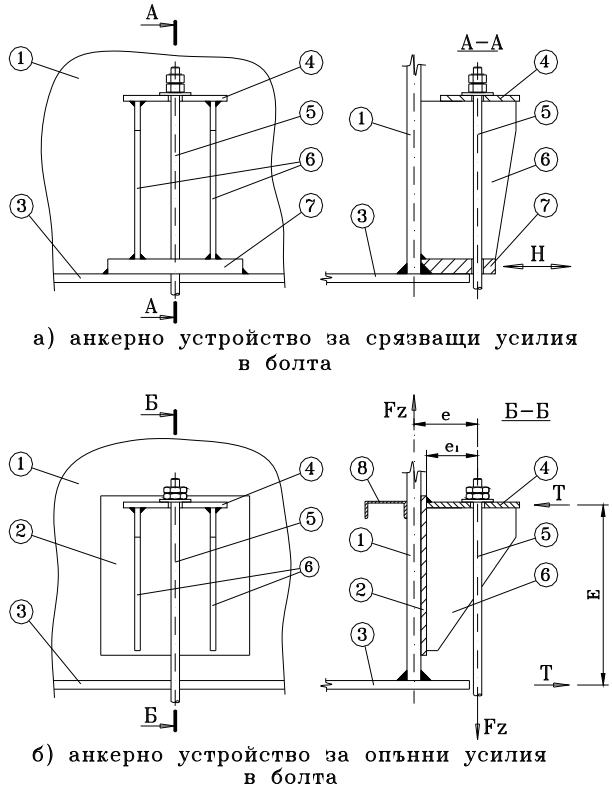


Fig. 1. Type of anchor's chair depending on forces in bolts

1. Tank's shell
2. Plate
3. Tank's bottom
4. Superior plate
5. Anchor bolt
6. Vertical ribs
7. Inferior plate
8. Stiffening ring

In some cases anchor bolts bear tension and shearing forces and this case imposes the relevant details of their chairs (Fig.2)

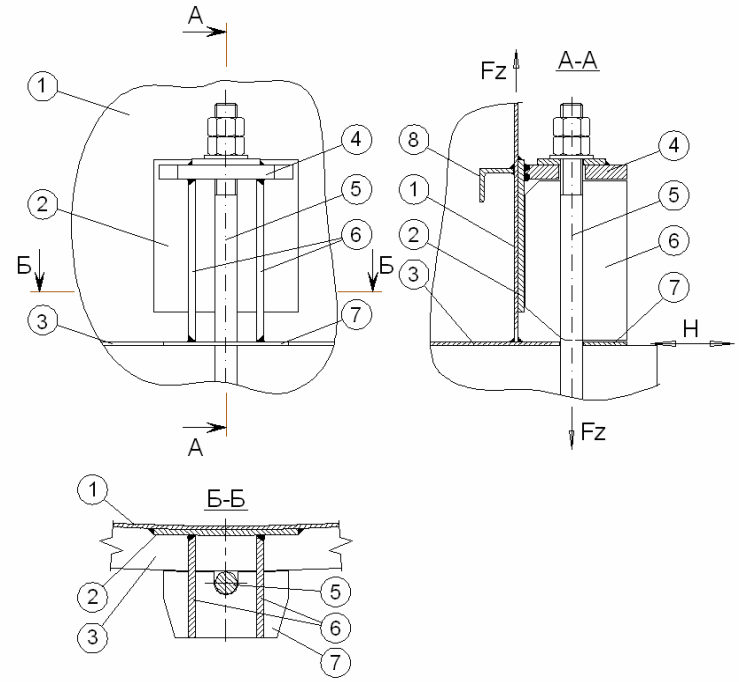


Fig. 2. Anchor bolts for tension and shearing forces, and their chair

1. Tank shell
2 Plate
3. Tank's bottom
4. Superior plate
5. Anchor bolt
6. Vertical ribs
7. Inferior plate
8. Stiffening ring

2. Research of the influence of anchor's chairs

The influence of the anchor's chairs shall be researched for the tank T003, in La Reunion. The tank have the following parameters (Table 1):

Table 1. Tank T003, in La Reunion

№	Index	Description
1	**Main dimensions**	
1.1	Nominal volume - **V**	V = 630 m^3
1.2	Internal diameter - ***D***	D = 8 000 mm
1.3	Shell height - $\boldsymbol{H_s}$	H = 12 600 mm
1.4	Roof - Type	Self-supporting cone
2	**Liquid (product)**	
2.1	Name	water
2.2	Density - ρ	1 000 kg/m^3
2.3	Temperature – $\boldsymbol{t}$ ^{0}C - minimum working - maximum working	 min $\boldsymbol{t}$ = +15 ^{0}C max $\boldsymbol{t}$ = + 60 ^{0}C
2.4	Overpressure - p_0^n	p_0^n = 1,00 kPa
2.5	Vacuum - p_v^n	p_v^n = 0,50kPa
2.6	Maximum level of the filling according to the project	H_t = 12 300 mm
3	**Conditions of the site**	
3.1	Snow - $\boldsymbol{S_n}$	no
3.2	Wind - $\boldsymbol{w_n}$	w_m = 34 m/s
3.3	Seismic zone - ***E***	VIII – th zone, k_c = 0,15
3.4	Geological soil structure	According to the geological report
4	**Additional data**	
4.1	Material used for bottom, shell and roof	S235J0 according to EN 10025
4.2	Anchoring	16 pieces M39
4.3	Mode of construction	Sheet by sheet
4.4	Production powder - $\mathbf{g_p}$	no
4.5	Thermal insulation - $\mathbf{g_t}$	no

A software product SAP 2000 Nonlinear was used for the analysis. It was used to create several 3D tank's models. Anchor's chairs which must bear tension and shearing forces in bolts are included also (Fig.3). In these models the bottom, shell, roof, anchor's chairs and stiffening rings on the shell were inserted as shell elements and anchor bolts are frame elements.

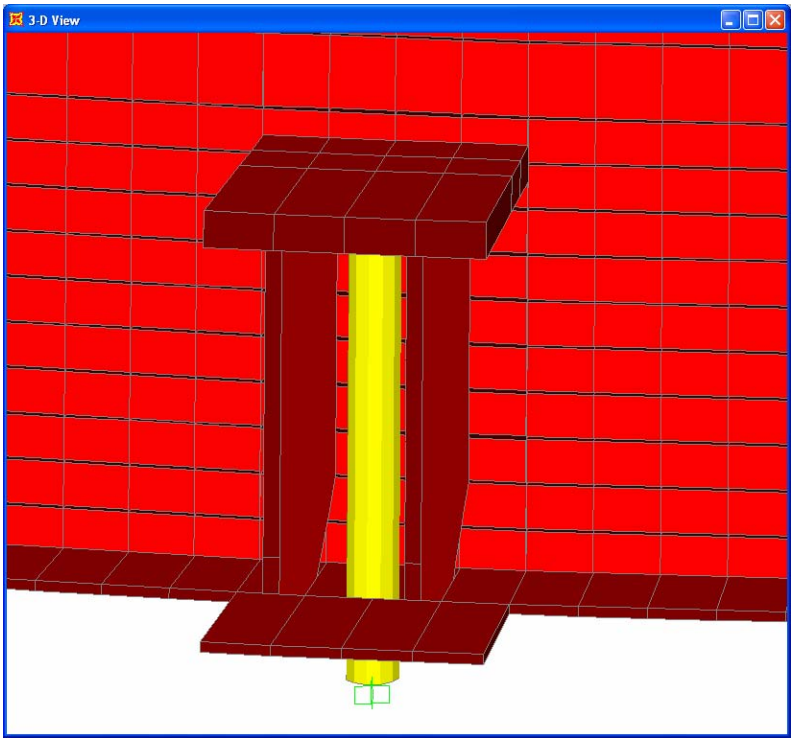


Fig. 3. Numerical 3D model

All the tank's parts are joined with their geometrical characteristic (thickness). All elements are made from structural steel S235 which mechanical characteristics are shown in standard EN 10025.

Whole bottom of the tank, included also the inferior plates on chairs protruded out as a console, is considered as plate on the elastic base with the bed's coefficient k_b = 200 MN/m^3 . It is assured that the bottom shall bear only pressure's forces.

The detachment of the bottom e.g. sliding and overturning of the tank shall be avoided by 16 anchors positioned at equal distance around the shell, thread M39, made from steel S355. All these anchor bolts have pin joints with the upper plate and are fixed to the foundation. Anchors shall not bear pressure's forces.

Several numerical models were created initially, in which anchor bolts were jointed to the bottom (fig.2) e.g. it is not possible for the bottom to expand or to shrink as a result of temperatures differences. In these models it is accepted that all steel elements are additionally loaded with heat. The difference in temperature is equal to $\Delta t = 25\ ^0C$. Design load combination is:

$$g_n \cdot \gamma_{Fg,sup} + T_n \cdot \gamma_{Ft} \qquad (1)$$

where:

g_n is the characteristic value of its self-weight;

T_n - resulted inside forces when it acts an additional temperate load $\Delta t = 25\ ^0C$;

$\gamma_{Fg,sup}$ = 1,35 – particular coefficient for loading from its self-weight;

γ_{Ft} = 1,5 – particular coefficient for loading from temporary loads.

Resulted shearing forces which are caused in the anchor bolts as a result from the upper loading combination (1) are shown on the Table 2:

Table 2. Shearing forces in the anchor bolts

Internal stiffening ring	Shearing forces in the anchor, kN
no	402,84
- 6x50	401,88
- 3x100	402,09
- 6x100	402,21

As result, shearing forces in the anchors caused by heat loads, exceed their bearing capacity. Because of it in the anchor's chair and / or in the bottom it is formed an oval opening which assures free expanding or shrinking of the bottom.

Later new research models were created according to which the anchor bolts are not connected to the bottom. The bottom can freely slide from the temperature differences. These new models have only one

difference between them and it is the presence and measures of the stiffening ring in the internal side of the shell.

The imposed loads in the 3D models are:
G – its self-weight of the steel construction;
W_a – loading by stored product in the tank;
P – over pressure;
V – under pressure (vacuum);
W_i – wind pressure on the tank.

3. Results

Deformations in the tank's shell (Fig. 4) are a sure sign that the anchor's chairs, constructed on this way, which shall bear tension and shearing forces are an obstacle for the free moving of the tank. This leads to the change in stress – strain state e in the tank (Fig. 5).

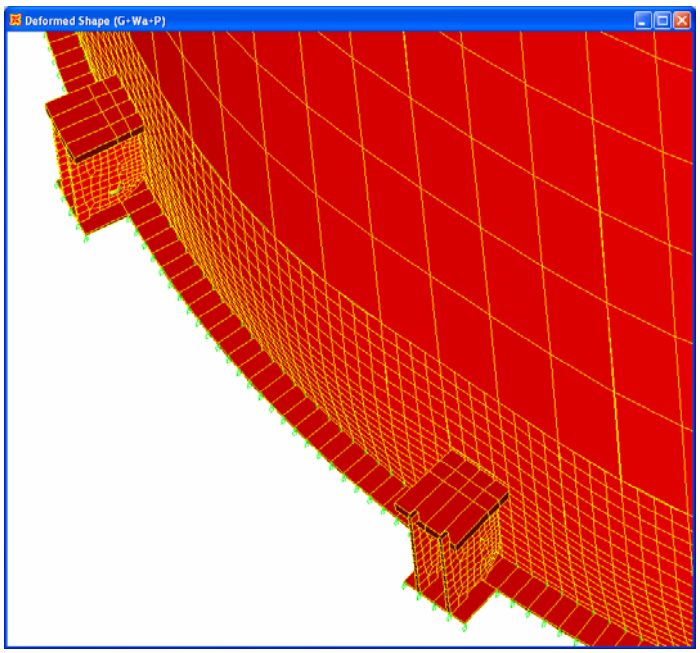
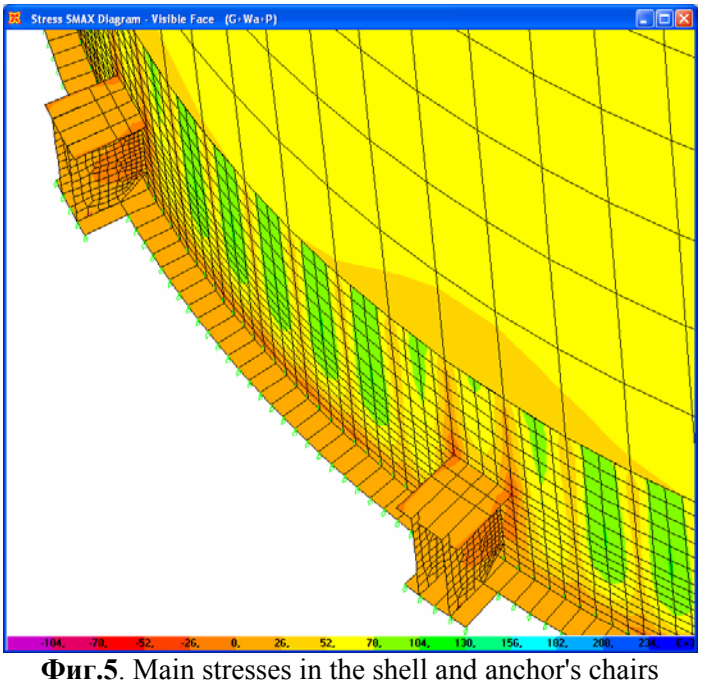


Fig. 4. Deformation in the tank's shell



Фиг.5. Main stresses in the shell and anchor's chairs

Radial deflection of the shell and its main stresses are reported in the 3D research models for one and the same point in the tank.

Table 3. Radial deflection of the shell, mm

ring	Between the chairs			In the chairs		
	$G + W_a + P$	$G + V$	$G + W_i + P$	$G + W_a + P$	$G + V$	$G + W_i + P$
no	1,94	0,16	-1,16	0,14	-0,23	1,1
- 6x50	1,57	0,1	-0,83	0,4	-0,15	0,67
- 3x100	1,32	0,01	-0,46	0,61	-0,09	0,39
- 6x100	1,19	0,01	-0,34	0,6	-0,07	0,27

Deflection „+“ it is on the outside direction
Deflection „-“ e it is on the inside direction – toward the tank center

Table 4. Main stresses in the shell, kN/cm^2

ring	Between the chairs			In the chairs		
	$G + W_a + P$	$G + V$	$G + W_i + P$	$G + W_a + P$	$G + V$	$G + W_i + P$
no	10,83	0,187	0,62	2,78	0,09	2,12
- 6x50	9,94	0,124	0,88	2,5	0,04	3,24
- 3x100	9,88	0,056	0,97	2,86	0,43	4,41
- 6x100	9,49	-0,087	1,09	2,83	0,51	4,9

Table 5. Shearing forces in the anchor bolts

Ring	Bending moment ***M***, kN.m			Cutting efforts ***Q***, kN		
	$G + W_a + P$	$G + V$	$G + W_i + P$	$G + W_a + P$	$G + V$	$G + W_i + P$
no	0,27	0,16	0,84	4,7	2,1	17,27
- 6x50	0,4	0,11	0,58	3,95	1,82	16,77
- 3x100	0,49	0,08	0,43	3,24	1,64	16,5
- 6x100	0,49	0,061	0,48	3,37	1,57	16,39

4. Conclusion

The anchor’s chair constructed on this way does not permit the radial deflection in the shell. This leads to the changes in the stress - strain state in the shell and in the area of the anchor’s chair.

When the movement of the chair and the pick of the anchor bolts are one and the same, there are additional bending moments ***M*** and shearing forces ***Q*** in the bolts. Because of it anchors shall move freely in their upper end and for this purpose oval openings are done.

Important influences have also and the geometric characteristics of the stiffening rings put inside. The stiffening rings with bigger moment of inertia shall cause:

- Decrease of radial deflection and main stresses in the shell between the chairs;
- Increase of radial deflection and main stresses in the shell in the chairs area;
- Increase of the bending moment ***M*** in the anchor bolt by the loading combination $G + W_a + P$

LITERATURE

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