

DOME ROOF OF ABOVEGROUND STEEL TANK WITH $V=70000 \text{ m}^3$ CAPACITY

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Abstract: *Dome roofs are the lightest structure to cover cylindrical tanks. When they are steel made they could not be used to cover serious spans, respectively big tanks.*

Author has checked the possibilities to use steel dome roof as cover of aboveground cylindrical tank with $V=70000 \text{ m}^3$ capacity and diameter $D=64 \text{ m}$. The investigation was made with appropriate 3D software. It is used nonlinear solution, accounting large displacements of steel structure for more accuracy.

Most serious problem is vagueness of snow distribution and combination of wind and snow loads.

Key words: *dome roof, radial girders, load combinations, nonlinear solution*

Under one and the same conditions of use it is possible to design and use different kind of roofs – spherical, cone shaped, self-supporting or supported. The quantity of used material and the price of facility are different for every constructive solution.

Dome roofs are the lightest steel fixed roofs with girder's construction. They can be used when the internal pressure is higher, do not have problems with mounting of an internal floating roof. Supplementary foundations are not necessary for dome roofs. In other words always when it is possible the dome roofs are recommended.

The limited use of dome roofs can be mentioned as their disadvantage. It is considered that they cannot cover large diameters, i.e. to cover tanks with big volume. Recently the biggest tanks with dome steel roof in Europe have the volume of $V = 40\,000 \text{ m}^3$.

During his activity as a designer the author was requested to check the possibility whether the tank with capacity $V = 70000 \text{ m}^3$ can be covered with dome steel roof. The tank is for molasses storage and will be constructed in Czech Republic.

This task was a real challenge. If the result is positive it would extend boundaries of use of this type of roof.

1. General geometrical tank's specification:

- diameter of the shell – $D = 64,0 \text{ m}$;
- height of the shell – $H_s = 22,0 \text{ m}$;
- maximum filling level of product – $H_t = 21,5 \text{ m}$;
- nominal volume of the tank $V = 69165 \text{ m}^3$;
- radius of the spherical dome – $R_r = 80,0 \text{ m} < R_{r,max} = 1,5.D = 96,0 \text{ m}$;
- highness of the roof – $f = 6,68 \text{ m}$;
- number of the covering shields / radial girders – $n = 90$ бр.

2. Pressure upon the spherical dome

- snow – $S_n = 0,7 \text{ kN/m}^2$;
- over pressure – $p_0^n = 1,0 \text{ kPa}$;
- vacuum – $p_v^n = 0,5 \text{ kPa}$;
- maximum wind speed – $v = 45 \text{ m/s}$;

The wind pressure must be calculated according to the following:

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$$(1) \quad w_m = \frac{v^2}{16} = 126,6 \text{ dN} = 1,266 \text{ kPa}$$

$$(2) \quad w_n = w_m \cdot k_z \cdot c = 1,0403 \text{ kPa},$$

where:

$k_z = 1,37$ is a coefficient, related to the change of the pressure according to heights;

$c = 0,6$ – coefficient, related to the form of surface.

3. The measurement of the parts of the roof

3.1. Roof cover plates

When it is known that the number of the girders is $n = 90 \rightarrow \hat{L} = \frac{\pi \cdot D}{n} = 2,234 \text{ m}$, where \hat{L} is a distance

between the girders by shell circumference.

a) loading combination for measurement of the roof cover plates

- loading – perpendicular to plates load combination from the top to the bottom:

$$(3) \quad q_1 \downarrow = g_r \cdot \cos \alpha + \psi \cdot (S \cdot \cos \alpha + p_v)$$

- loading - perpendicular to plates load combination from the bottom to the top:

$$(4) \quad q_2 \uparrow = -g'_r \cdot \cos \alpha + \psi \cdot (w + p_0),$$

where:

$g_r = t_r \cdot \rho \cdot \gamma_f = 0,006.78,5.1,1 = 0,518 \text{ kN/m}^2$ - design loading of self weight of the roof plates, when the thickness is $t_r = 6 \text{ mm}$;

$g'_r = t_r \cdot \rho \cdot \gamma'_f = 0,006.78,5.0,9 = 0,424 \text{ kN/m}^2$ - design loading of self weight of the roof plates, when the load is favorable;

$S = S_n \cdot \gamma_f = 0,7.1,4 = 0,98 \text{ kN/m}^2$ - favorable loading from snow;

$p_0 = p_0^n \cdot \gamma_f = 1,0.1,2 = 1,2 \text{ kN/m}^2$ - design loading of internal pressure;

$p_v = p_v^n \cdot \gamma_f = 0,5.1,2 = 0,6 \text{ kN/m}^2$ - design loading vacuum;

$w = w_n \cdot \gamma_f = 1,0403.1,4 = 1,456 \text{ kN/m}^2$ - design loading of wind;

$\psi = 0,8$ - coefficient of combination of two short term loads;

α – angle between the horizontal plain and tangential to the roof in the examined point.

When the cover plates is accepted as single span girder for vertical loading, the bending moments in it is determined according to the following :

$$(5) \quad M_1 = \frac{1}{8} \cdot q_1 \cdot L^2 = \frac{1}{8} \cdot 1,673 \cdot 2,2^2 = 1,012 \text{ kNm}$$

$$(6) \quad M_2 = \frac{1}{8} \cdot q_2 \cdot L^2 = \frac{1}{8} \cdot 1,736 \cdot 2,2^2 = 1,05 \text{ kNm}$$

The bending moments in (5) and (6) are determined for point of plates between the shell and the roof, where $\alpha = 23,578^\circ$.

The minimal thickness of the joint must be determined according to the:

$$(7) \quad t_r \geq \sqrt{\frac{6 \cdot M_{\max}}{\gamma_c \cdot R_y}} = \sqrt{\frac{6 \cdot 1,05}{1 \cdot 21,5}} = 0,54 \text{ cm}$$

The thickness of the roof steel joint S235 is accepted in the following order:

- $t_r = 6 \text{ mm}$ when the distance between two neighboring radial girders $L = 1,8 \div 2,2 \text{ m}$;

- $t_r = 5 \text{ mm}$ when the distance between two neighboring radial girders $L \leq 1,8 \text{ m}$.

3.2. Roof construction

With appropriate program have been created 3D model of the roof's dome and the last two courses of the shell (fig. 1). The top angle (TA), which has been made from a thick steel sheet in this case, is put on the place of joint between the roof and the dome. The roof plates are connected to TA with uninterrupted joint.

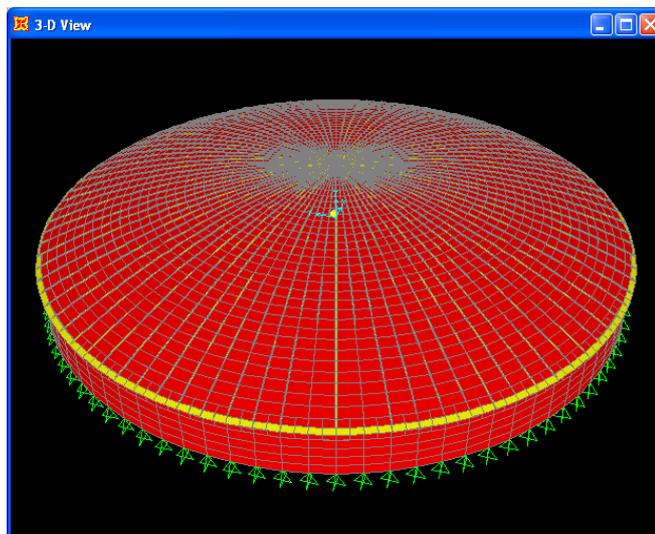


fig. 1 Computer model

The sections of the roof structure are examined when the efforts in the elements have been controlled, the $p-\Delta$ effects and the geometrical not linear behavior of the construction have been taken into account. The pressure is done step by step and effects of the previous loadings are reported.

3.2.1. Design of the dome roof in exploitation condition.

The position of the loadings on the roof is still unclear matter. In Bulgarian standards [2] the way of distribution of the loads on the spherical domes is not considered. The author has made supplementary researches for suggestions for possible way of distribution in [1], [3], [4], [5], but there is little information regarding this matter. Due to this reason it was necessary that the author improvised and relied on his sense of engineering.

a) combination of the loading and their distribution on the roof

The schemes of the loadings used for the research of the spherical dome are shown on fig. 2.

б) the following sections of the elements of the roof construction have been calculated:

- radial girders – IPE 220 according to the Euronorm 19-57 from steel S235;
- TA – thick sheet with dimensions 32x600 mm from steel S235;

Loading Combinations:

- 1.) $1,1.G_n + 1,4.S_n + 0,8.(1,2.p_v^n)$
- 2.) $1,1.G_n + 1,4.S_n + 0,8.(1,2.p_v^n)$
- 3.) $1,1.G_n + 1,4.S_n + 1,4.w_n$
- 4.) $1,1.G_n + 1,4.(1,2.S_n + 0,8.S_n) + 0,8.(1,2.p_v^n)$
- 5.) $1,1.G_n + 1,4.S_n + 1,4.w_n$
- 6.) $0,9.G_n + 1,4.w_n + 0,8.(1,2.p_0^n)$
- 7.) $0,9.G_n + 1,2.p_0^n$

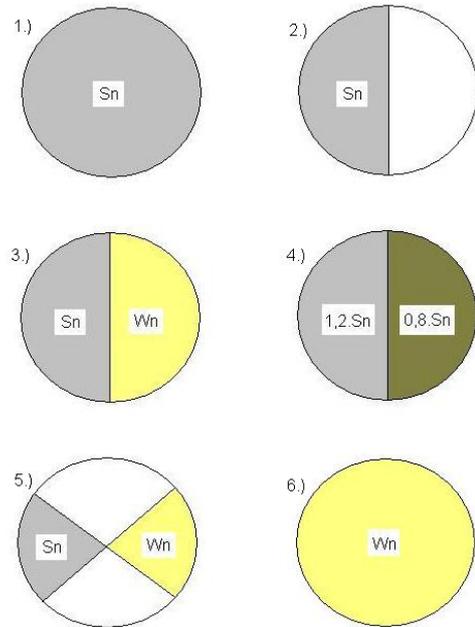


fig. 2 Loading schemes

Most important load combinations for design of various roof's elements are as follow:

- for TA – loading $0,9.G_n + 1,4.w_n + 0,8.(1,2.p_v^n)$, which cause the pressure in the TA;
- for the elements in the radial girders the actual combinations are different, depending on the position of the loads and the construction in plan but for the biggest part of them the most unfavorable combination is $1,1.G_n + 1,4.(1,2.S_n + 0,8.S_n) + 0,8.(1,2.p_v^n)$

в) deformation during the exploitation

The deflection Z in the middle of the dome from design load combination:

$$\max Z \downarrow = 3,49\text{cm} - \text{when the load combination is } 1,1.G_n + 1,4.S_n + 0,8.(1,2.p_v^n)$$

$$\max Z \uparrow = 1,91\text{cm} - \text{when the load combination is } 0,9.G_n + 1,4.w_n + 0,8.(1,2.p_v^n)$$

3.2.2. Measurement for roof structure for mounting condition

3.2.3. In order to facilitate the roof erecting works, roof elements are grouped in shields. They are mounted on the bottom of the tank in the same time with the erecting of the first courses of the shell. In order to follow the design geometry, a temporary supporting device is put in the middle of the tank. It facilitates assembling of the roof and helps to reach design shape. (fig. 3).



fig. 3 Temporary support for roof assembling

After the mounting of all roof shields on the bottom and their mutual welds are made, the tank will be filled with the water, and as a result of it the roof will began to float. On its moving to top of the shell the roof is used as a mounting platform.

The loadings upon the different shields during the mounting and assembling of the roof on the bottom are:

- dead weight of the construction – G_n ;
- live load of erectors and equipment – $Q_n = 0,5 \text{ kN/m}^2$.

a) first decision of internal supporting

The roof's shields are attached to two supports (to the bottom and on the supporting structure in the middle of the tank).

The radial girders IPE 270 from steel S235 match the requirements for strength, but vertical movement is very serious:

$$(8) \quad f_{\max} = 48\text{cm} < [f_u] = \frac{L}{200} = 16\text{cm}$$

It is obligatory to use supplementary supports during the mounting of the roof.

б) second decision of internal supporting

The roof's shields are supported on 3 points (on the bottom, on the support in the middle and on the supplementary support) (fig. 4).

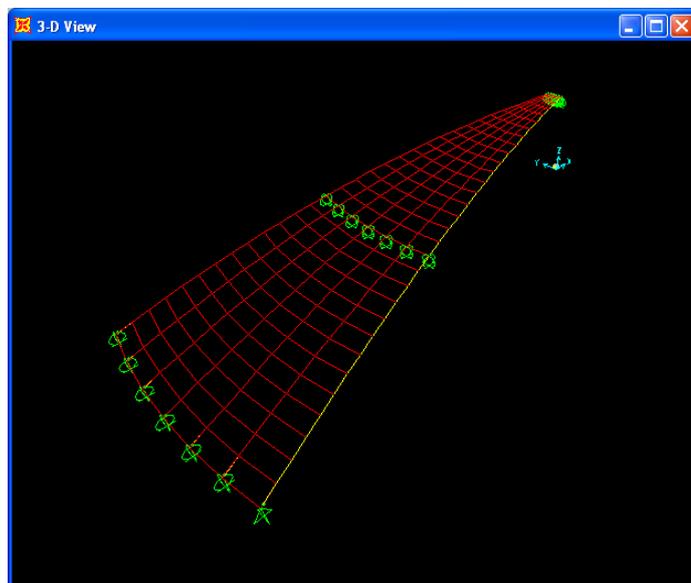


fig. 4 Scheme of temporary supporting of roof shields on 3 points

Radial girders IPE 240 from steel S235 match the requirements for strength.

In this case the maximum of vertical movement is $f_{\max} = 3,7 \text{ cm} < [f_u]$

4. Total weight of the roof construction

- radial girders IPE 240 according to Euronorm 19-57 from S235 – 84 410 kg;
- TA – sheet 32x600 mm from S235 – 30 305 kg;
- roof plates from S235:
 - $t_r = 6 \text{ mm}$ – 58 700 kg;
 - $t_r = 5 \text{ mm}$ – 81 450 kg;
- central ring of the roof from S235 – 6 130 kg

The total weight of the roof including weight of top angle is $\sum G_r = 260995\text{kg}$. Using this figure, the average metal quality for 1 m^2 unit can be calculated as:

$$(9) \quad g_{r,m} = \frac{\sum G_r}{A_r} = \frac{260995}{3217} = 81,13\text{kg/m}^2$$

5. Conclusions

5.1. Steel dome roofs can be used successfully to cover tanks with diameter of the shell $D \leq 64$ m, e.g. capacity $V \leq 70\,000$ m³.

Considering the higher requirements for decreasing of vapor leaks in the atmosphere, this type of roofs can work under increased internal pressure as well as with the mounted internal floating roof in the tank. So they are better solution than supported cone roofs of the tanks with big diameters.

5.2. Very serious problem is the lack of information about real distribution of snow load upon the roof and the possibility for loading of the roof from snow and wind in one and the same time.

5.3. For the different roof's elements the most unfavorable load combination is different. Even for one radial rib from the dome the actual load combination changes for its length.

Usually for dome roofs most unfavorable are non symmetric loads in plan, which can impose dome to lose stability.

5.4 Often when determining the necessary sections of roof structure, the thing to be considered is the mounting condition.

Literature:

1. Инструкция за проектиране на СВЦР с обем от 100 до 10 000 m³ за системата на енергетиката, Енергопроект, 1995.

2. Норми за натоварване и въздействия върху сгради и съоръжения, ДВ, бр. 92 от 2004 г.

3. Рекомендации по определению снеговой нагрузки для некоторых типов покрытий, ЦНИИСК им. Кучеренко, Москва, 1983 г.

4. API Std 650, Welded Steel Tanks for Oil Storage, Tenth Edition, Addendum 1÷4, December 2005.

5. EN 14015:2004, Specification for the design and manufacture of site built, vertical, cylindrical, flat-bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above, November 2004.