DESIGN OF SELF – SUPPORTING DOME WITH RADIAL GIRDERS AND CIRCULAR ELEMENTS, ROOF OF TANK T016, La Reunion, France

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Abstract: *The concerned spatial dome with radial girders and circular elements is roof on tank T016 in La Reunion, France. The roof is self-supporting, supported only on the shell of the tank. Sections of dome roof are designed on two independent ways – manual and FEA analysis are performed. Controlling company, „Bureau Veritas", did not approve our design methods and it was necessary to make additional, non-traditional analysis of roof structure.*

Key words: *cylindrical steel tank, self-supporting dome roof, radial girders, rings, effective length, buckling analysis*

Several vertical steel cylindrical tanks for storage of oil products are designed for La Reunion and Martinique. All constructive calculations regarding the tanks are presented for verification and approval firstly to the contractor and after that to the monitoring company „Bureau Veritas".

One of the critics toward us was that the accepted by us effective length are not correct. It was recommended to accept effective lengths equal to the half of the tank' diameter as it is shown in [4], but this requirement is in contradiction with the shown in [1] methodology. Because of it a supplementary non-traditional analysis is done aiming to prove that the roofs are correctly designed and they can bear the load upon them.

1. Introduction

Roof structures in most of the cases, consist of radial elements (radial girders) and circular elements (rings) and roof plates (Fig. 1).

The number of the radial girders and rings depends mainly on the calculation of the thickness of roof plates.

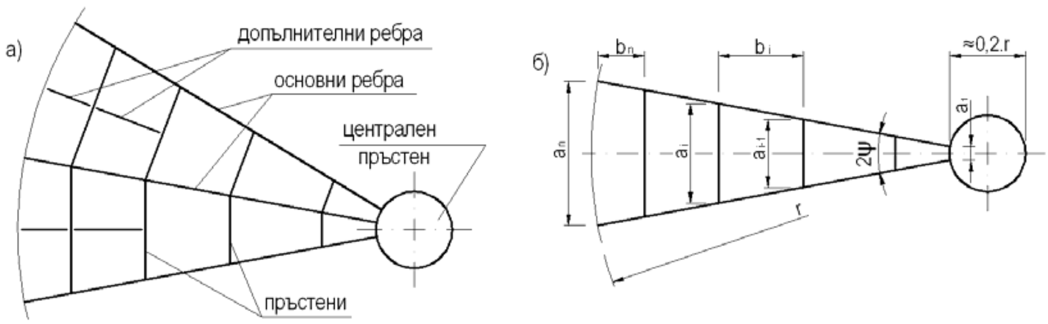

Fig. 1 Structure of the roof

a) basic elements б) design scheme

As an example of design procedures done for dome roofs with radial girders and circular elements is given the roof on tank T016 in La Reunion, France. The roof is self-supporting, steps only on the shell of the tank. The dome roof has the following dimensions and main characteristics:

- Diameter of the roof base (diameter of the tank shell) – D = 36 m;

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- Radius of sphere (radius at the neutral axis of radial girders) – $R_r = 48$ m;
- Height of the roof – $f = 3{,}50$ m;
- Number of radial girders– $n_b = 48$ m;
- Number of rings on the roof – $n_r = 7$
- Roof plates with thickness $t_r = 5$ mm, the roof plates are not welded to the internal roof structure.

2. Loading on the dome roof.

When the roof plates are not attached to the internal roof structure and there are not expected snow loads, as in our case, the roof structure is designed for working condition for only one combination of loads. That is the load combination $\boldsymbol{q}_1$, who acts in downwards direction:

$$q_1 = g_n.\gamma_{\text{Fg,sup}} + Q_n.\gamma_{\text{FQ}} + \psi_0.\gamma_{\text{Fv}}.p_{\text{v}}^{\text{n}} \downarrow, \tag{2.1}$$

where:

g_n is the characteristic value of the self weight of the roof-supporting structure and the roof plates;

$Q_n = 1{,}0$ kN/m^2 – the characteristic value of live load on the dome roof. It is accepted the minimum, according to requirements of [3];

$p_v^n = 0{,}5$kN/m^2 - the characteristic value of the negative pressure (vacuum), acting in the tank;

$\gamma_{Fg,sup} = 1{,}35$ –partial factor for self weight of roof structure and roof plates, when act unfavourably;

$\gamma_{FQ} = 1{,}5$ - partial factor for variable actions (live loads), acting on the roof;

$\gamma_{Fv} = 1{,}5$ - partial factor for variable actions (vacuum), acting in the tank;

$\psi_0 = 0{,}8$ – factor for combination of 2 variable actions that act simultaneously [2].

In Formulae (2.1) the effect of technological equipment is not taken into account, because it acts locally as concentrated forces.

3. Design of the roof structure elements, using simplified design models.

3.1. Design of the roof plates.

The roof plates are designed for bending as rigid rectangular disk, supported on rigid pin supports, loaded perpendicular to the plate's plane.

3.2. Design of the roof structure elements for erection case.

For self-supporting "shield" dome roofs, during erection, the main radial girder is supported from one side on the shell and from the other - on temporally support in the tank's centre. When workers are positioned on the "shield", they cause stresses usually grater than the stresses in working condition.

3.3. Design of the radial girders (ribs) and circular elements for working condition.

The dome roofs (structure of radial girders and circular elements - rings) are spatial statically undetermined systems, so it is difficult to obtain the design stresses and forces without FEA (finite element analysis) model. Accurate design of the elements of the roof structure can be achieved only by using adequate program product and taking into account the rigidity of the elements and flexibility of the joints.

Preliminary design of the elements of the dome roofs (structure of radial girders and circular elements - rings) is used to obtain the cross section and type of the elements that are defined in the FEA model. Preliminary design is based on the assumption that the roof is frame structure with pin connection between the elements. Detailed information about methodology is shown in [1], and it is not necessary to explain it there. Characteristic feature of that methodology is that effective length of compressed elements is equal to real geometric length (distance between pin joints). (Fig. 2).

4. Design of the roof structure elements with finite elements analysis (FEA)

4.1. Design model

For structural analysis is used the program product SAP 2000 v.14. The 3-D computational model of spherical dome is created by the program. In this model, as frame elements are defined the radial girders and the rings with their real geometrical characteristics and materials. Their sections are calculated using simplified methodology, shown in [1]. For radial girders are used hot rolled sections IPE 220 and for circular elements – IPE 140. Steel grade S235 is used, with characteristics, taken from EN 10025:

- Yield strength – f_y = 235MPa;
- Ultimate tensile strength – f_u = 470 MPa;
- Module of elasticity – E = 210 000 MPa;
- Density – ρ = 78,5 kN/m^3

The radial ribs of the dome curve are described by polygon of straight elements between the joints. The circular elements are rotated to their longitudinal axes so their upper flange tangents to the surface of the dome.

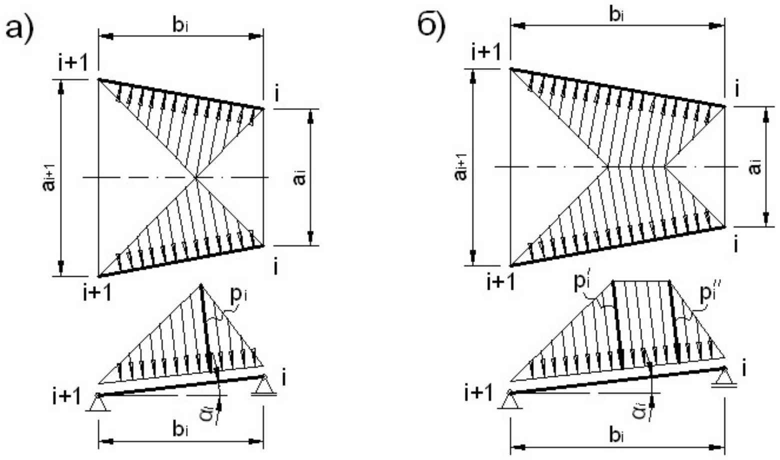

Fig. 2 Scheme of loads on the radial girders
a) triangular distributed load б) trapezoidal distributed load

For more accurate results it is advisable to provide the model without the roof plates.

The transmission of the load on the construction is simulated by loading areas, according to (Fig. 2). The loads from overpressure, vacuum and wind suction act perpendicular to the major principal axes of the frame elements. The loads from dead weight, insulation and snow act in the direction of gravity.

To consider the deformations of the roof structure supports in horizontal direction further the model includes upper stiffening ring and part of the upper shell course (Fig. 3).

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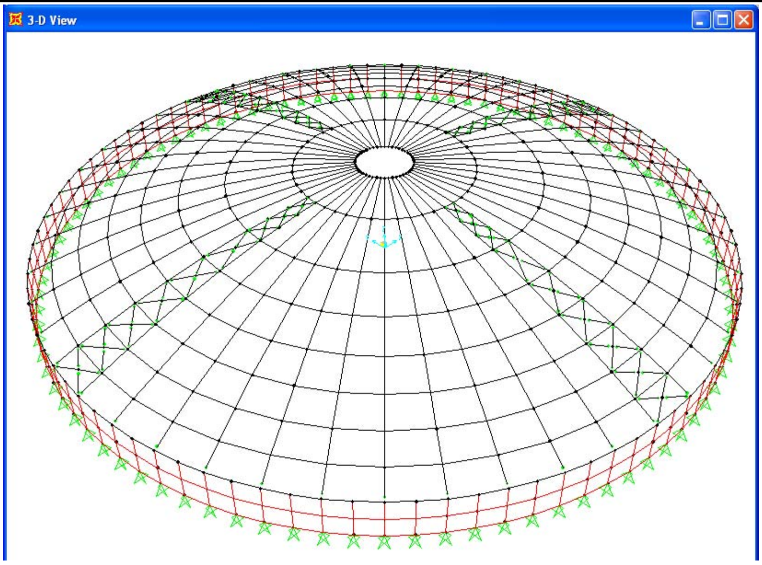

Fig. 3 Spatial frame model of the roof

4.2 Approaches for design of the dome roof with FEA model

For the needs of the analysis a number of independent solutions are provided, using different initial conditions.

4.2.1 Geometrically linear solution without taking into account large deformations

The design forces in the dome roof elements are obtained with assumption for geometrically linear conditions. The steel works in elastic range. Load combinations are according to (2.1), but is important to be noted that moving load $\boldsymbol{Q}$ (live or snow) is not evenly distributed. Moving loads are located on various zones of roof, to be discovered their unfavourable position.

The main purpose is to check and compare the results, obtained by simplified design models of the radial girders and the circular elements.

The buckling length is equal to the distance between the joints radial girders – circular elements, as is shown in [1].

4.2.2 Geometrically nonlinear solution with taking into account P-D effects and large deformations of structure

The design forces in the dome roof elements are obtained with assumption for geometrically nonlinear conditions with taking into account the large deformations. The steel works in elastic range.

The first load acting on the dome roof is the dead load $\boldsymbol{g_n}$, defined on undeformed structure. The rest of the loads are defined on deformed scheme of the structure from the dead load $\boldsymbol{g_n}$. Loads on the roof are the same and on the same position as in 4.2.1.

The goal of this nonlinear analysis is to determine if the solution is convergent. If so, the deformability of the system due to the applied loads is not enormous and the dome will not loose stability.

It is typical that, the largest vertical deflections are observed not in the middle of the roof, but in the middle of the radial girders (i.e. in the quarters).

4.2.3. Analysis of the structure for loosing stability with taking into account the geometric imperfections, witch are 1/100

Buckling Analysis option in SAP 2000 is used to perform this analysis. It is possible to observe the reserve of resistance, before loose stability, of the one particular element or the whole structure. The solution is linear, but taking into account the deformations in the dome roof‘s structure.

At the beginning of research, in geometrically non-linear conditions is defined dead load $\boldsymbol{g_n}$ due to the self weight of the steel structure. After that on a structure, deformed by the loading $\boldsymbol{g_n}$, is defined the loading due to the negative pressure (vacuum) $p_{\mathrm{v}}^{\mathrm{n}}$, for whom the reserve should be determined. The loading of self weight $\boldsymbol{g_n}$ and vacuum $p_{\mathrm{v}}^{\mathrm{n}}$ are defined with their characteristic values.

In order to take into account the geometrical imperfections in dome roofs, all its elements are translated horizontally at axes $\boldsymbol{x}$, stage-by-stage. Each ring, together with all rings with smaller radius are translated at distance Δ_x = 1/100 of the distance between two adjacent circular elements**.**

It is typical that, the dead load $\boldsymbol{g_n}$ and the vacuum $p_{\mathrm{v}}^{\mathrm{n}}$ are symmetrical loads, but the dome roof looses stability in nonsymmetrical shape (Fig. 4)

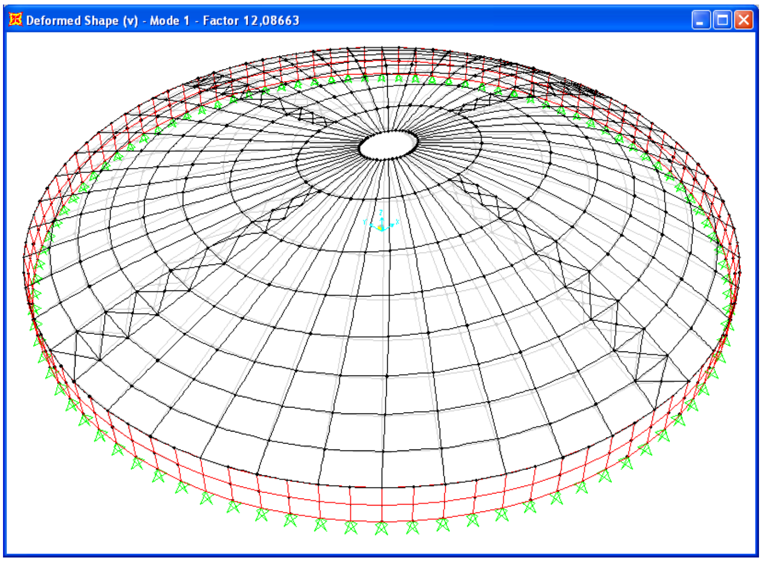

Fig. 4 Deformed shape of dome roof , that looses stability, due to loading of self weight $\boldsymbol{g_n}$ and vacuum $p_{\mathrm{v}}^{\mathrm{n}}$

The reserve coefficient for resistance of elements, when acting negative pressure(vacuum) $p_{\mathrm{v}}^{\mathrm{n}}$ is k_{f}=12,08663.

5. Results

The dead load $\boldsymbol{g_n}$ and vacuum $p_{\mathrm{v}}^{\mathrm{n}}$ are defined with their characteristic values. The live load on the roof Q_{n}= 1,0 kN/m^2 is not included in the FEA analysis. To take into account its effect some elementary calculations are made:

(5.1) $$k_{\mathrm{f,Q}}^{\mathrm{n}} = k_{\mathrm{f}}.\frac{N_{\mathrm{g}}^{\mathrm{n}} + N_{\mathrm{v}}^{\mathrm{n}}}{N_{\mathrm{g}}^{\mathrm{n}} + N_{v}^{n} + 2.N_{\mathrm{v}}^{\mathrm{n}}} = 12{,}0866.\frac{36{,}150 + 26{,}185}{36{,}150 + 3.26{,}185} = 6{,}568$$ - with Δ_x = 1/100,

where:

$N_{\mathrm{g}}^{\mathrm{n}}$ is the axial force in the end radial elements due to loading with characteristic values of dead load $\boldsymbol{g_n}$;

$N_{\mathrm{v}}^{\mathrm{n}}$ - is the axial force in the end radial elements due to loading with characteristic values of vacuum $p_{\mathrm{v}}^{\mathrm{n}}$ in the tank.

The coefficients $k^{n}_{f,Q}$ are obtained with the characteristic values of the loads. To obtain the general reserve coefficient k_f for design loads it is used analogical method:

(5.2) $$k_{f,Q} = k^{n}_{f,Q}.\frac{N^{n}_{g} + N^{n}_{v} + 2.N^{n}_{v}}{N^{n}_{g}.\gamma_{F,g} + (N^{n}_{v} + 2.N^{n}_{v})\gamma_{F,Q}} = 6,568.\frac{36,150 + 3.26,185}{36,150.1,35 + 3.26,185.1,5} = 4,521$$ - with Δ_x = 1/100

The dome roof with structure of radial girders and circular elements of tank T016 may be overloaded 4,521 times ($k_{f,Q} = 4,521$) the design values of vacuum and live load, before loses stability.

6. Conclusion

The calculation models obtained with SAP 2000 did not show the analytical correlation which to determine the effective lengths of radial girders in the vertical plane. It was ascertained only that those lengths are smaller than the half of the tank diameter. But the Buckling Analysis proved another more important thing – the spatial dome with radial girders and circular elements, roof of tank T016 have a no little reserve of loading capacity and will not lose general stability. This fact helps us to make the following conclusion:

In this spatial dome with radial girders and circular elements in which the roof cover plates is not welded to the roof construction and the considerable non symmetrical wind and snow loads are not expected, the traditional methodology, shown in [1] and used in the computer models gives us the enough correct results.

The shown in [4] calculated requirements for accepting of effective lengths of the radial girders would come into force if there are not radial rings in the roof construction or their work is not considered.

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