Dedicated to the memory of Prof. Mihail Renert

Analysis of the Spherical Tanks Shell Stresses Concentration due to the Discontinuous Equatorial Supporting Solutions

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There are presented the results of the calculus simulations of the spherical shell stresses coefficient for different dimensions of the cylindrical supporting pillars, obtained using a MathCAD programme. The calculus result can help choosing the best supporting solution – which generate the lowest stress concentration of the spherical shell.

Keywords: spherical tanks, spherical shell, stress concentration coefficient, equatorial supporting system

Products which are gases at normal atmospheric temperatures and pressures, such as butadiene, butane, propylene and many other chemical and petrochemical products are stored most economically in spherical pressure tanks.

For low storage temperatures (less than -50°C) one can use either pressured spherical tanks or double shell spherical tanks (which consists of an inner sphere and an outer sphere). The double shell spherical tanks are used to store liquefied gases such as ethylene, oxygen, nitrogen, etc. at cryogenic temperatures. The space between inner and outer sphere is insulated with perlite or connected to a cryogenic installation.

The exterior part of the spherical tanks comprises: - the supporting system (made by individual cylindrical pillars (fixed equatorial or under-equatorial by the spherical shell), by a vertical skirt extending from the tank equator down to the foundation or by an egg-cup); - the maintenance platforms connected to the common stairs by means of the bridges (located at the top of the tank); - the upper and the bottom calottes (where are positioned: the pipes connections/fittings, the relieve/safety pressure valves, the measuring and control devices and the access openings).

Bodies of tanks are supplied disassembled, metal parts come as separate units and welding assembled on the erecting spot. The main construction materials are carbon and corrosion-resistant steels.

The spherical tanks users are: - the chemical industry, oil-refining industry, gas-processing industry, petrochemical industry, pulp and paper industry, glass industry etc.

Sometimes there are connected two tanks – one for liquid and one for gas.

In the table 1 are shown some characteristics of spherical tanks, for different fluids and the place where they were located [1].

Stresses concentration coefficient

In the paper [2] it was presented a logical scheme for the calculus of the spherical shell stresses, on this basis it was done a calculus program and there were studied the influences on the stress concentration of the spherical shell due to supporting solution, in the case of equatorial supporting on individual cylindrical pillars, in working conditions and in the hydraulic pressure test conditions. It was analyzed the case of a 1000 m^3 spherical tank, equatorial supported on cylindrical pillars, for propylene storage, at 2.1 MPa. There were considered different supporting cylinder geometries and a different number of supporting pillars to emphasis their influence on the spherical shell stress concentration coefficient. The supporting hypothesis is shown in figure 1.

The stress concentration coefficient is defined as the ratio between total stress and the membrane stress:

$$C_c = \frac{\sigma_{ech}^{t}}{\sigma_{ech}^{m}} = \frac{\sigma_{ech}^{m} + \sigma_{ech}^{c}}{\sigma_{ech}^{m}}\ , \qquad (1)$$

where:

- σ_{ech}^{m} is the membrane stress and it was calculated superposing the stresses of the following loadings: inner pressure, shell own weight, snow weight and wind dynamic pressure (calculus relations are given in [2,3]);
- σ_{ech}^{c} is the supplementary contour stress calculated superposing the stresses of the following loadings: horizontal seismic load manifested like a reaction loading exercised by the supporting pillars, radial deformation restraint imposed by the supporting cylinders (determined by the thermal dilatation, due to the difference between erecting and working temperatures, as well as due to the inner pressure), erecting eccentricities (permitted deviation from the theoretical position of the pillar, namely the cylinder's axis tangent to the medium shell's radius) and supplementary loading due to the discontinuous supporting (the calculus relations were deduced using [4-7]) .

The influence of the contour loadings is manifested on the l_s distance,

$$l_s = \sqrt[4]{\frac{R_m^2 \cdot s_p^2}{12\left(1-\mu^2\right)}} \qquad (2)$$

where:

R_m is the medium spherical shell radius;
s_p – shell thickness;
μ - Poisson's coefficient.

To calculate the stresses one supposes that the contact between the cylinder (support) and the spherical shell is an equivalent circle whose radius is determined equalizing the circle area with the contact spatially curved ellipse area, resulting $r_{ech} = \sqrt{a \cdot b}$ (a and b are shown in fig.1).

Because the σ_{ech} have different values at the inner and respectively outer radius, the stress concentration coefficient will have different values too.

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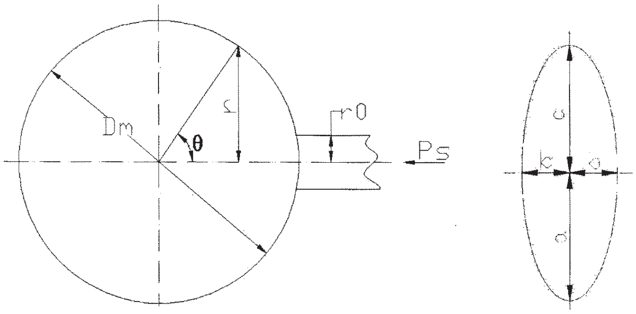
Table 1

No.	Location	Diameter (m)	Thickness (mm)	Design Pressure (MPa.)	Service fluid	Observations
1.	Kerala Minerals & Metals Ltd., Cochin	5.8	5	atmospheric	Liquid Oxygen & Liquid Nitrogen	Cryogenic Double Walled with Vacuum Insulation and Stainless Steel
2.	Brega Petroleum, Libya	11-14.5	35-40	1.4	LPG	One shell
3.	Essar Oil Ltd., Jamnagar	10.5-19	48-73	2.0-4.5	LPG & Hydrogen	One shell
4.	RIL, Hariza	14.5-21	22-68	1.45-2.4	Ethylene & Propylene	One shell
5.	Atomic Energy Power Project, Madras	9.5	30	1.2	Nitrogen	One shell
6.	National Fertilisers Ltd., Bhatinda	17	32	0.65	Liquid Ammonia	One shell
7.	IOC, Panipat	14.5	48	1.45	LPG	One shell
8.	SCOP, Iraq	14	38.1	1.4	Propane & Butane	One shell
9.	Hindustan Steel Ltd., Rourkela	12.57	5		Liquid Oxygen	Cryogenic Double Walled with perlite insulation and aluminum alloy steel



a) b)

Fig.1. a) The horizontal loading P_s exercised by the supporting cylindrical pillar on the spherical shell; b) the contact geometry (spatially curved ellipse) between the spherical shell and the supporting cylindrical pillar.

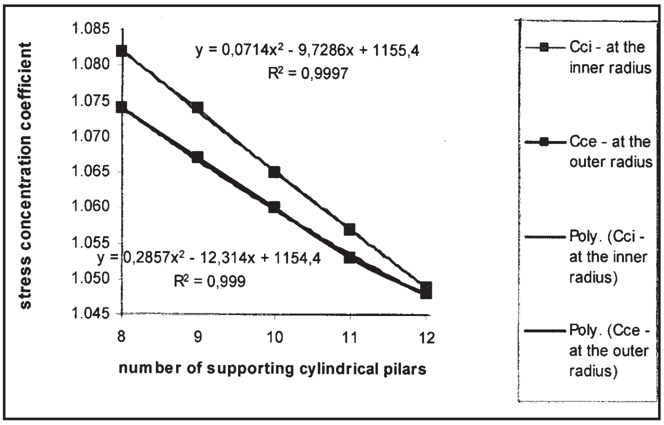


Fig. 2. Stress concentration coefficient variation with the number of supporting cylindrical pillars, in exploatation conditions, Des = 609.6 mm; s = 11.9 mm

The figure 2 presents the calculus results for the stress concentration coefficient function of the number of cylindrical supporting pillars for exploitation conditions (*Cci* - stress concentration coefficient at the inner shell surface; *Cce* - stress concentration coefficient at the outer shell surface) and those for hydraulic pressure tests are presented in the figure 3. The spherical shell thickness is 45 mm. The coefficient which introduces the influence of the seismic intensity for the tank emplacement is $k_s = 0.08$. It was considered a non-uniform weight repartition on each pillar (of about $\pm 0.2 \cdot G_1$, where G_1 is the total shell weight (considering also the auxiliary devices mounted on it and the upper part of the supports which are welded on the shell) distributed on a pillar). The erecting eccentricity (permitted deviation from the theoretical position of the pillar, namely the cylinder axis tangent to the medium shell radius) $e = \pm 15$ mm. The number of pillars varied between 8 and 12; the diameter of the pillars varied between 507.8 mm and 710.4 mm. For the here presented results the thickness of the cylindrical pillar was 11.9 mm.

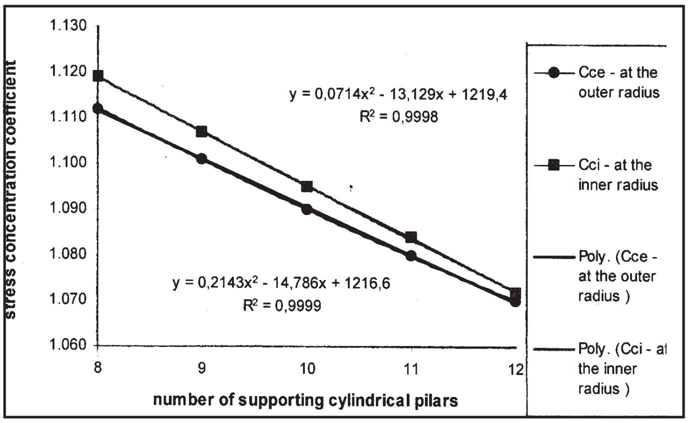


Fig. 3. Stress concentration coefficient variation with the number of supporting cylindrical pillars, in pressure test conditions, Des=609.6;s = 11.9 mm

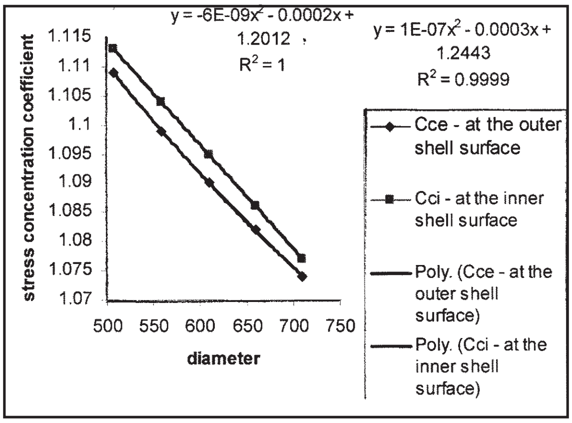


Fig. 5. Stress coefficient variation function of the support diameter, in pressure test conditions n = p pillars, s = 11.9 mm

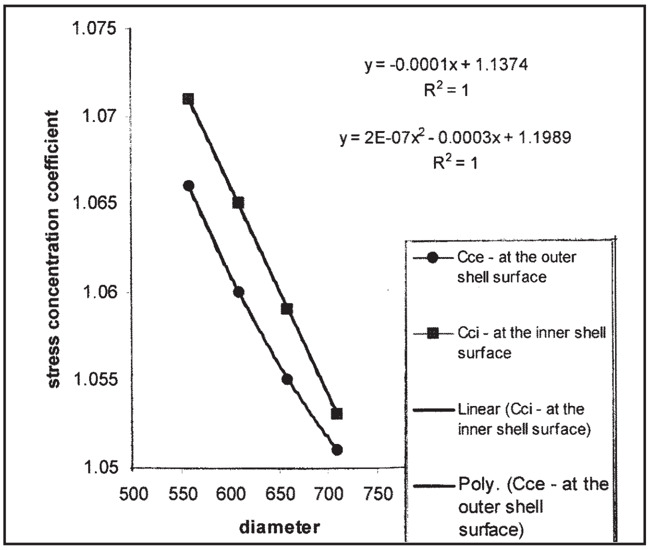


Fig. 4. Stress concentration coefficent variation function of cylinders's support diameter, in working conditions, n = 9 pillars, s = 11.9 mm

In figures 4 and 5 there are presented the variations of the stress coefficient function of the support diameter, for working conditions and hydraulic test conditions, respectively.

In this paper it was presented only a part of the simulation results.

The stress concentration coefficient variation presented was for the equator (supporting zone), which is the maximum loading zone. As one moves away from the equator the stresses diminishing, reaching σ_{m} at $l>l_s$.

Conclusions

As one can see, the calculus simulations can help to choose the most suitable supporting solution from the point of view of the spherical shell's stress values. The lowest stress in the supporting zone is assured if one uses more pillars. As the number of pillars increases the spherical shell stresses tends to have the same value both for the inner and the outer surface. The increases of the number of supporting pillars can be limitative because of the higher welding assembling sews as the width of the equatorial segment is smaller, having like effect, the bigger stress concentration coefficients (because of the welding, this time). So here it is an optimum to asses. As well the economic aspects must further be taken into account to obtain the optimum cost, because the solution with more pillars could be more expensive as the manufacturing costs are bigger, even the thickness of the shell can be reduced. Some economical aspects for the LPG spherical tanks are presented, for example in [8].

The pillar geometry influences also the stress concentration coefficient, as the cylinder diameter is bigger the stresses decreases. As one can see the variations are slightly nonlinear (the variation profiles are almost the same for the inner and outer shell surface; the *Cci* values are bigger than *Cce* values). The stress concentration coefficient values variation depend on the supporting geometry, the bigger values are obtained for the hydraulic test conditions.

The program allows geometric simulations and a rapid evaluation of the spherical shell stresses, helping to choose, on this basis, the best supporting solution/geometry.

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