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Design of alternatives for elevated bottoms of vertical steel tanks with double cells to water storage

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Abstract:
With the growing demand for water reserves due to the implantation of new allotments and horizontal condominiums, the metallic tanks started to have internal physical divisions (vertical cells) so that the upper cell has the height of the bottom suspended at a height that guarantees the necessary pressure gauge for meet the NBR 12.218-1994 standard. This standard prescribes that the water distribution network has a minimum dynamic pressure of 100 kPa. Due to the lack of specific Brazilian technical standards for storing water in a metallic tank, the AWWA D100-05 has been used as a sizing parameter for metallic reservoirs with several vertical water storage cells, or only partially, mainly due to efforts axials on the sides (shells) to determine permissible stresses in buckling (FL). This article addresses choosing the most suitable type of vertical metal tank suspended bottom and compares the results of five different types of bottoms, sized according to the AWWA D100-05 standard. Within the typology of the five analyzed bottoms, the most economical bottom was the segmented spherical one.

***Key Word**: Metallic tank, AWWA D100 standard, Elevated bottoms, Autodesk Simulation Mechanical 2008*

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I. Introduction

This paper addresses choosing the most suitable type of vertical metal tank suspended bottom and compares the results of five different types of bottoms, sized according to the AWWA D100-05 standard [1].

With the implantation of new allotments and horizontal condominiums due to the government housing policy's incentives, mainly due to the Ministry of Cities' housing program, Minha Casa Minha Vida Program [2], which caused a significant increase in demand for water storage metallic tanks, mostly aerial (aboveground), cylindrical, and with varying diameter and height, is called a water castle.

The Brazilian standard NBR 12.218-1994 [2] prescribes that the public water supply network's minimum dynamic pressure must be 100 kPa (10.20 m.w.g – meter water gauge). Furthermore, the tanks started to have internal physical divisions (vertical cells) whose upper cell have the elevation of the bottom suspended at a height that guarantees the necessary manometric pressure to meet the referred norm since usually, the elevations of the land do not offer conditions for the tank to be supported.

The bottoms of suspended metallic tanks can be of various types, such as flat, conical, and spherical or segmented spherical [4].

The storage tanks operate without pressure (or very little), called atmospheric tanks, differentiating them from pressure vessels. They are generally cylindrical, perpendicular to the ground with a flat bottom and a fixed or floating roof [5].

The design and construction of atmospheric cylindrical tanks require knowledge of specific technical standards, materials, and labor suitable for each type of application and involve a series of other special precautions because anomalies and irregularities in this equipment can cause significant financial losses or even loss of life [6].

According to [7], the standard commonly used in Brazil for the design and construction of metallic tanks are NBR 7821-1983 [8], API 650-2013 [9], and AWWA D100-05 [1].

The NBR 7821-1983 [8] - Welded Tanks for the Storage of Petroleum and Derivatives, of the Brazilian Technical Standards Association (ABNT) and the American regulatory standard API 650-2013 [9] - Welded Steel Tanks for Oil Storage - of the American Petroleum Institute (API), are specific to the oil and oil products storage [10] [11].

The AWWA D100-05 [1] - Welded Carbon Steel Tanks for Water Storage, from American Water Works Associations, aims to provide minimum requirements for the design, construction, inspection, and testing of new welded carbon steel tanks for storing water atmospheric pressure. Within the design requirements, the AWWA D100-05 [1] presents three methods for determining the allowable buckling stress (FL) for cylindrical sections, which allows the verification of the maximum compression stress due to the axial load and axial load due to the wind loading applied to the shells.

Due to the lack of specific Brazilian standards for storing water in a metallic tank, the AWWA D100-05 [1] has been used as a sizing parameter for the metallic tank with several vertical water storage cells, or just partially, mainly due to the axial stresses on the sides (shells) to determine the allowable shell buckling stresses (FL).

II. Material and Methods

The pattern tank presented in this article is a metallic tank for water, composed of two cells, eleven courses, with a capacity of 150.00 m³ each cell (total of 300.00 m³), with a metallic cone-type cover (Figure 1).

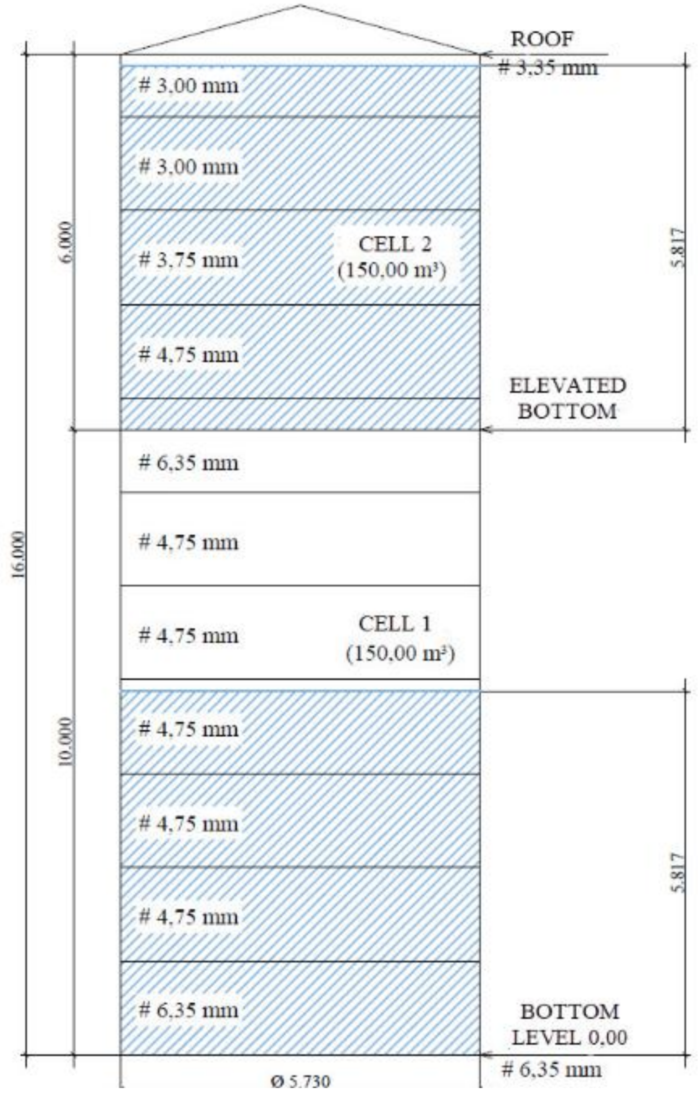


Fig1. Pattern two-cell metallic tank with a capacity of 300.00 m³.

The five types of suspended bottoms are present below (Figures 2A; 2B; 2C; 2D and 2E).

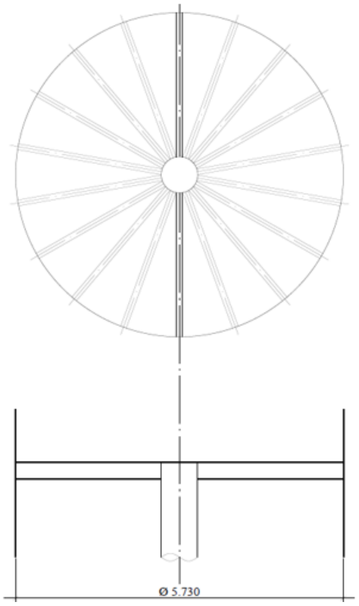


Fig2A. Flat bottom with radial beams and column

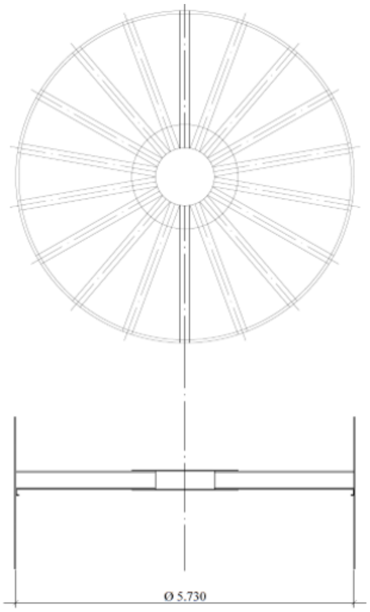


Fig2B. Flat bottom with radial beams and no column

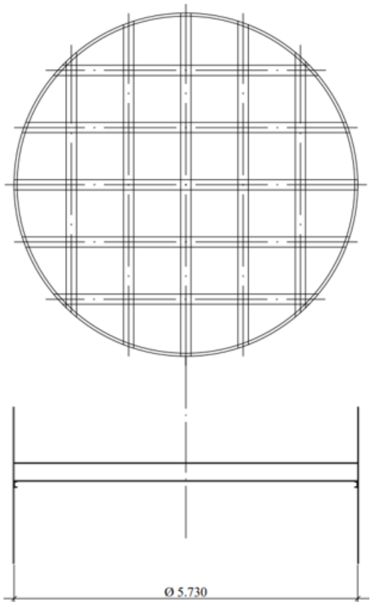


Fig2C. Flat bottom with orthogonal beams and no column

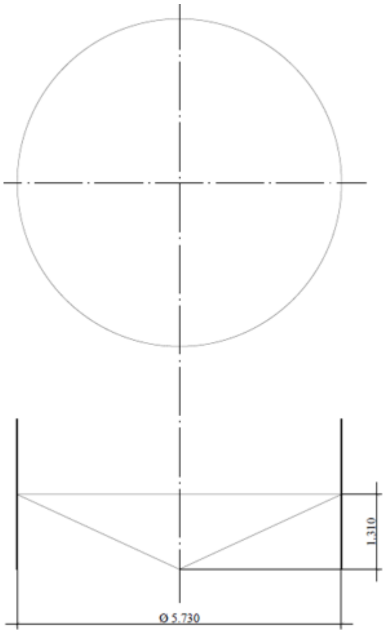


Fig2D. Conic bottom

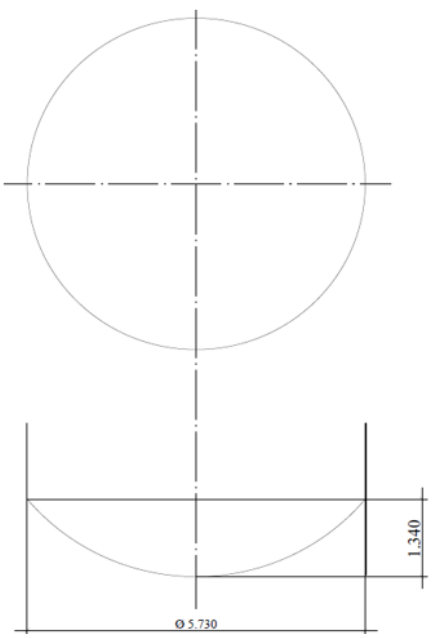


Fig2E. Segmented spherical bottom

The loads considered on the tank are the wind, the stored water (hydrostatic pressure), the life on the roof, and the weight of the structure (dead) (Figure 3A), launched in the Autodesk Simulation Mechanical software (Figure 3B).

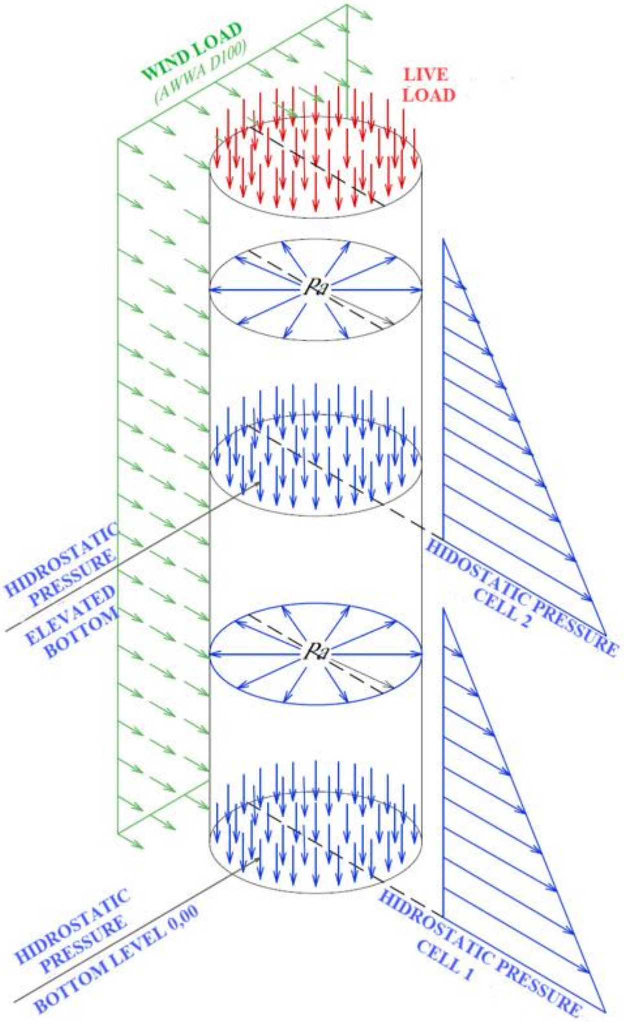


Fig3A. Loads

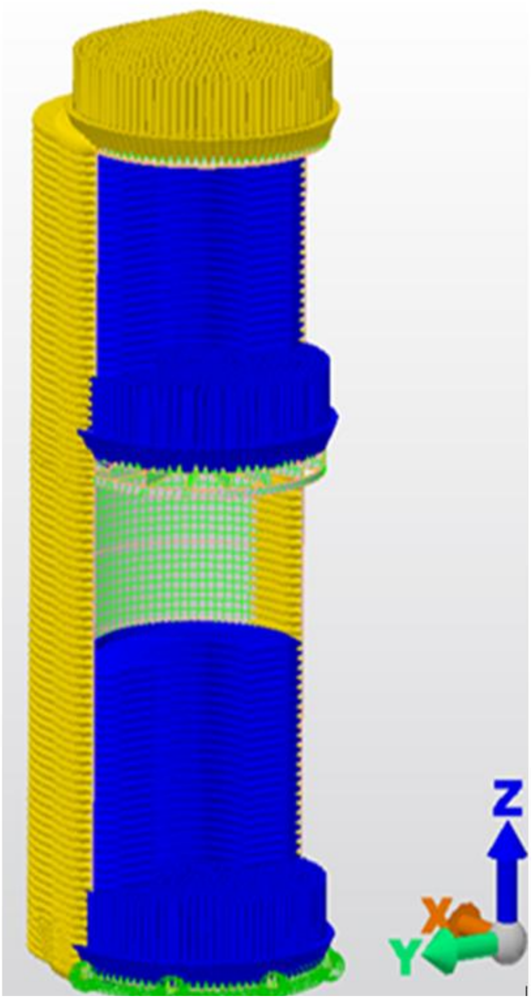


Fig2E. Loads by Simulation Mechanical

The wind load is according to Brasilian Standard NBR 6123 - 1987 [12]- Forces due to wind in buildings and, as a general rule, it assumed that the wind could act in any horizontal direction. As the tank structure is asymmetric concerning the Z-axis, perpendicular to the wind direction, it considers that the wind can impact perpendicularly to any generatrix in the tank (Andrade Junior, 1998).

The static wind pressure component ($\mathbf{D_P}$), which acts perpendicularly in an area element, is given by:

$$\Delta_{\boldsymbol{p}} = C_{pe} \cdot q \qquad \text{equation (1)}$$

The external pressure coefficients Cpe are expressed for the structure's body type, assuming for the application of AWWA D100-05 that Cpe = Cf (Table 1).

Where q is the wind pressure (N/m²) at a point where air stagnation occurs, obtained from expression 2:

$$q = 0.613 \cdot V_k^2 \qquad \text{equation (2)}$$

Where V_k is the characteristic wind speed (m/s) on place, is given by:

$$V_k = S_1 \cdot S_2 \cdot S_3 \qquad \text{equation (3)}$$

The V_0 is called the basic speed, corresponds to a burst of 3 seconds, exercised on average once in 50 years, measured at 10 m above the ground, in flat and open terrain. The NBR 6123 (1987) [12] presents the basic isopleths in m / s. For this paper, V_0 = 40 m / s was adopted.

The topographic factor S1 is used to assess the terrain relief around the building and adopted equal to 1.0 for this paper.

The factor S2 considers the combined effect of the terrain's roughness, the wind speed variation with the height above the terrain, and the building's dimensions. The factor S2 obtain by using equation 4:

$$S_2 = b \cdot F_r \cdot \left(\frac{Z}{10}\right)^P \qquad \text{equation (4)}$$

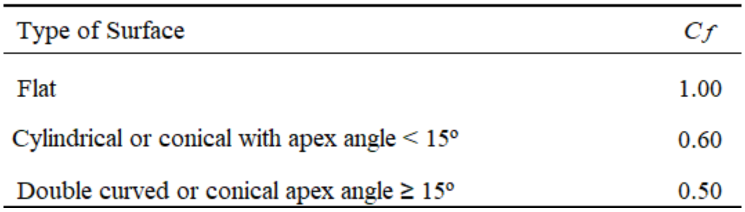
Where:
Z = height above the terrain,
Fr = Gust factor,
b = meteorological parameter,
p = function of the terrain roughness and the time interval.

For the tank height of 16.0 m, roughness II, class A, $S_2 = 1.05$.

The factor S_3 is a statistical factor that considers the degree of safety required and the structure's useful life, considering tank' installations with a low human occupation factor [13]. For this paper, $S_3 = 0,95$.

The tanks are subjected to uniform wind pressure load (q), acting along the Z-axis, as shown in figures 3A and 3B, according to [14]. The AWWA D100-05 [1] recommends the use of force coefficient (Cf), according to the shape of the structure, according to Table 1. For a tubular tank with a cylindrical shape, the adopted C_f is 0.6.

Table 1. Force coeficiente C_f



Type of Surface	Cf
Flat	1.00
Cylindrical or conical with apex angle < 15°	0.60
Double curved or conical apex angle ≥ 15°	0.50

For $V_o = 40$ m / s and applying the values of S_1; S_2 and S_3.

$$V_k = 40 \cdot 1.0 \cdot 1.05 \cdot 0.95 = 39.90\, m/s$$

$$q = 0.613 \cdot 39.90^2 = 975.90\, N/m^2 \text{ (99.51 } kgf/m^2\text{)}$$

$$\Delta_p = 0.6 \cdot 975.90 = 585.54 \text{ N/m}^2 \text{ (57.71 kgf/m}^2\text{) -}$$

The hydrostatic loads result in effects that act in the radial and vertical directions, resulting in lateral pressure load on the side and pressure load on the tank's bottom.

Lateral pressure in the shells: $p = \gamma \cdot z$ equation (5)
Vertical pressure in the bottom: $q_f = \gamma \cdot h$ equation (6)
The live load applied on the roof: The minimum roof design live load shall be 15 lb/ft^2 (720 N/m^2).

The deadweight structure is automatically released by the Autodesk Simulation Mechanical 2018 software, considering the steels' specific weight in the tank design.

The thickness of the shells under circumferential pressure due to the tank's hydraulic pressure must calculate according to equation 3-40 of Sec. 3.7 of AWWA D100-05 [1] - Cylindrical Shell Plates (equation 7):

$$t = \frac{4.9 \cdot h_p \cdot D \cdot G}{s \cdot E} \qquad \text{equation (7)}$$

Where:
t = the required design shell-plate thickness, in mm
h_p = the height of liquid from TCL to the bottom of the sehll course being design, in m
D = the nominal tank diamenter, in m
G = product specific gravity (1.0 for water)
s = allowable design stress, in MPa
E = Joint efficiency

The minimum thickness of the cylindrical side in contact with water must be in line with Table 2, according to Sec. 3.11 of AWWA D100-05 [1]. For the tank with a nominal diameter of 5.73 m, the minimum prescribed thickness is 4.76 mm.

Table 2. Minimum thickness of cylindrical shell plates in contact with water

Nominal Shell Diameter, *D*		Nominal Shell Height, *H*		*Minimum Shell Thickness*			
				Ground-Supported Flat-Bottom Tanks		Other Tanks	
ft	*(m)*	*ft*	*(m)*	*in*	*(mm)*	*in*	*(mm)*
$D \leq 20$	$D \leq 6.1$	All	All	3/16	4.76	1/4	6.35
$20 < D \leq 50$	$6.1 < D \leq 15.2$	$H \leq 48$	$H \leq 14.6$	3/16	4.76	1/4	6.35
$20 < D \leq 50$	$6.1 < D \leq 15.2$	$H > 48$	$H > 14.6$	1/4	6.35	1/4	6.35
$50 < D \leq 120$	$15.2 < D \leq 36.6$	All	All	1/4	6.35	1/4	6.35
$120 < D \leq 200$	$36.6 < D \leq 61.0$	All	All	5/16	7.94	5/16	7.94
$D > 200$	$D > 61.0$	All	All	3/8	9.52	3/8	9.52

The AWWA D100-05 classifies the structural materials to be used in the tanks into three classes, for determining the allowable design stress Based on their published minimum yield strength, *Fy*. Table 3 shows this classification.

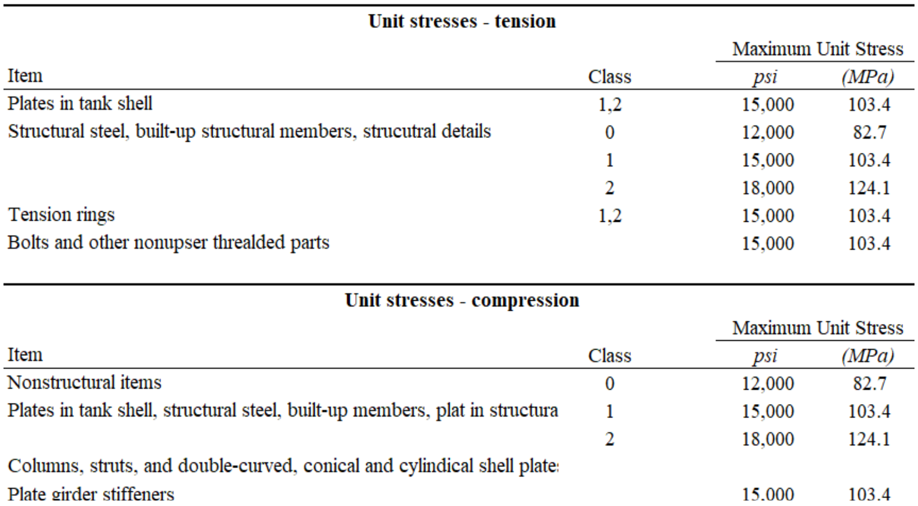
Table 3. Material classes

Class	F_y^*	
	psi	*(MPa)*
0	$F_y < 27{,}000$	$(F_y < 186.2)$
1	$27{,}000 \leq F_y \leq 34{,}000$	$(186.2 \leq F_y \leq 234.4)$
2	$F_y > 34{,}000$	$(F_y > 234.4)$

The material used in the cylindrical shells, bottoms, and the roof is ASTM A36, characterized by an elasticity modulus (E) equal to 205,000 MPa, Poisson's ratio (μ) equal to 0.30, density (γ) of 77,000 N / mm³, yield stress fy = 250.00 MPpa and last tension fu = 400.00 MPa. The material used in the suspended bottom' support structures (beams W and C) is ASTM A572 (grade 50) with yield stress fy = 345.00 MPa and ultimate stress fu = 450.00 MPa. They are classified as Class 2 material.

Table 4 shows the principal allowable stresses prescribed by AWWA D100-05 [9], depending on the class of materials and applications in the metallic tanks.

Table 4. Maximum stresses allowed



Unit stresses - tension

Item	Class	Maximum Unit Stress	
		psi	*(MPa)*
Plates in tank shell	1,2	15,000	103.4
Structural steel, built-up structural members, strucutral details	0	12,000	82.7
	1	15,000	103.4
	2	18,000	124.1
Tension rings	1,2	15,000	103.4
Bolts and other nonupser threalded parts		15,000	103.4

Unit stresses - compression

Item	Class	Maximum Unit Stress	
		psi	*(MPa)*
Nonstructural items	0	12,000	82.7
Plates in tank shell, structural steel, built-up members, plat in structura	1	15,000	103.4
	2	18,000	124.1
Columns, struts, and double-curved, conical and cylindical shell plate:			
Plate girder stiffeners		15.000	103.4

In order to verify stability due to buckling of the cylindrical shell, the AWWA D100-05 [1] prescribes three methods of analysis. Method 1 is used for this work, which is a simplified procedure based on membrane analysis techniques. For Class 2 materials, the thickness/radius ratio of the reservoir at which the buckling changes from elastic to inelastic (t / R)c is 0.0025372. The following formulas give the allowable buckling stress for Class 2 material:

When $0 \leq t / R \leq (t / R)c$ means that buckling occurs in the elastic regime and the allowable tension for buckling is given by equation 8:

$$F_L = 12.066 \cdot \left(\frac{t}{R}\right) \cdot \left[1 + 50.000 \cdot \left(\frac{t}{R}\right)^2\right] \qquad \text{equation (8)}$$

When $(t / R)\ c \leq t / R \leq 0.0125$, it means that buckling occurs in the inelastic regime, and the allowable tension for buckling is given by equation 9:

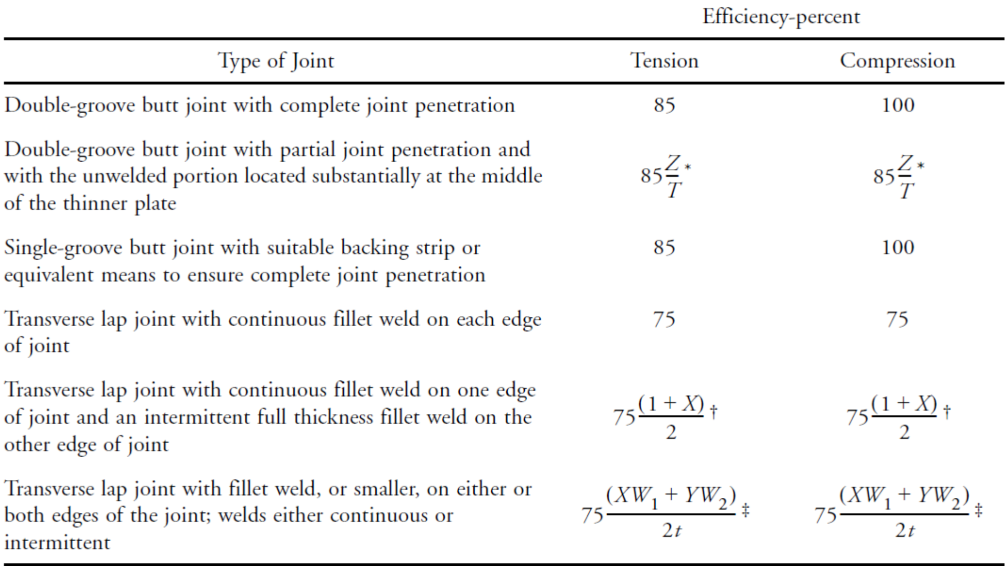
$$F_L = 47{,}75 + 6109 \cdot \left(\frac{t}{R}\right) \qquad \text{equation (9)}$$

When t / R> 0.0125, it means that the buckling occurs in a plastic regime and the permissible tension for buckling is constant and is:

$$F_L = 124{,}10\ MPa\ (18.000\ psi)$$

Table 5 - Welding efficiency values are presented partially from Table 15 Weld design values - tank plate joints, where only continuous welding values present. For the work on canvas, a double front chamfer weld with the complete filling consider.

Table 5. Weld design values - tank plate joints



	Efficiency-percent	
Type of Joint	Tension	Compression
Double-groove butt joint with complete joint penetration	85	100
Double-groove butt joint with partial joint penetration and with the unwelded portion located substantially at the middle of the thinner plate	$85\frac{Z}{T}$*	$85\frac{Z}{T}$*
Single-groove butt joint with suitable backing strip or equivalent means to ensure complete joint penetration	85	100
Transverse lap joint with continuous fillet weld on each edge of joint	75	75
Transverse lap joint with continuous fillet weld on one edge of joint and an intermittent full thickness fillet weld on the other edge of joint	$75\frac{(1+X)}{2}$ †	$75\frac{(1+X)}{2}$ †
Transverse lap joint with fillet weld, or smaller, on either or both edges of the joint; welds either continuous or intermittent	$75\frac{(XW_1 + YW_2)}{2t}$ ‡	$75\frac{(XW_1 + YW_2)}{2t}$ ‡

III. Results

Numerical modeling and analysis performed using commercial analysis and structural design software Autocad Simulation Mechanical 2018. Each cylindrical tank shell is modeling a shell element with constant design thicknesses, isotropic properties, and a central plane. A circular vertical ring is modeled with an L shape rigidly attached to the top of the tank's elements. The dimensions of the finite elements are 0.20 x 0.20 m (discretization). For each type of tank, according to each suspended bottom type, a 3D finite element model was created (Figure 4).

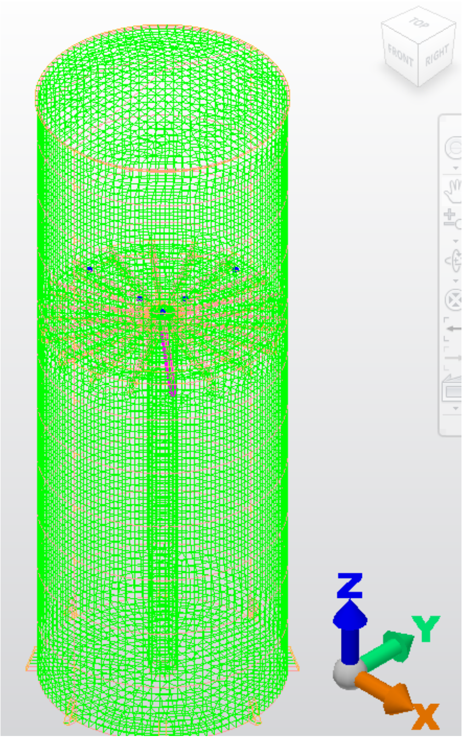


Fig4. Discretized pattern metallic tank

Starting from the minimum thickness according to Table 2, for the dimensioning of the cylindrical shells, the thickness due to circumferential pressure was also verified, using equation (7) and the thickness due to buckling, with the determination of the allowable tension (FL), using equations (8) and (9) and the axial stresses of the cylindrical shells determined by the Simulation Mechanical software and compared with the calculated allowable stresses (FL). The required thickness of each cylindrical shell is the most significant thickness within the three criteria. Table 6 shows the Van Misse stresses, circumferential stresses, and axial stresses in each cylindrical shell of the five tanks studied with different types of suspended bottoms.

Table 6. Design the cylindrical tank shell according to AWWA D100 - 05

				Flat bottom + beams + column			**Flat botton + beam without column**			**Flat bottom + orthogonal beams**			**Conic bottom**			**Spherical bottom**		
	cylindrical shell side		*FL*	Stress (Mpa)			Stress (Mpa)			Stress (Mpa)			Stress (Mpa)			Strees (Mpa)		
	Course	(mm)	(Mpa)	Van Misse	Circunf.	Axial	Van Misse	Circunf.	Axial	Van Misse	Circunf.	Axial	Van Misse	Circunf.	Axial	Van Misse	Circunf.	Axial
Cell 2	11	4,75	21,8	3,7	3,5	0,6	3,7	3,6	0,6	3,9	3,5	0,7	4,2	3,8	0,6	3,8	3,5	0,7
	10	4,75	21,8	12,9	12,7	0,3	12,9	12,6	0,3	13,3	13,0	0,8	13,7	12,6	0,8	13,2	12,7	0,8
	9	4,75	21,8	21,9	21,8	0,4	21,9	22,1	0,4	22,5	22,0	0,9	23,4	22,9	1,4	22,4	21,8	1,1
	8	4,75	21,8	31,9	33,1	2,1	33,8	32,9	1,9	32,0	33,2	3,1	31,5	30,7	4,0	30,9	30,3	3,4
Cell 1	7	6,35	33,0	8,8	0,8	8,3	14,4	0,7	14,2	14,9	0,8	14,6	15,9	0,7	16,4	15,7	0,7	16,1
	6	4,75	21,8	11,2	0,0	11,1	17,6	0,1	17,5	17,0	0,2	17,0	21,5	0,2	19,9	22,1	0,1	19,8
	5	4,75	21,8	11,5	0,1	11,2	17,7	0,3	17,6	17,4	0,4	17,3	22,2	0,4	21,2	22,8	0,3	21,1
	4	4,75	21,8	16,4	7,1	11,7	27,4	7,2	17,9	21,9	7,3	17,7	26,8	7,1	21,4	27,7	7,1	21,3
	3	6,35	21,8	18,1	12,5	8,6	32,5	17,1	14,0	30,6	16,4	14,1	35,8	16,7	18,3	36,7	16,6	18,2
	2	6,35	33,0	25,3	20,2	8,9	33,4	20,3	14,3	29,4	20,4	14,2	32,8	19,5	18,5	33,8	20,4	18,4
	1	6,35	33,0	34,9	29,7	20,9	39,1	29,8	22,7	38,8	28,1	22,9	39,5	29,7	27,6	39,2	32,7	24,6

Figures 5A, 5B, 5C, and 5D show the analysis results with Van Misse stresses, circumferential stresses, and axial stresses in each cylindrical shell of the tank with cell bottom 2, with radial W beams and central column. The values obtained are put into table 6. The same analysis was made in the other four tanks that complete this work

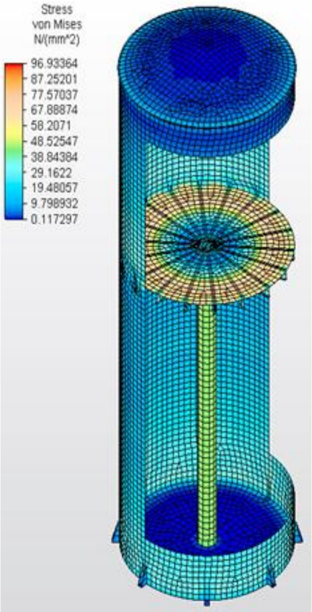


Fig5A. Van Mises stress cut veiew

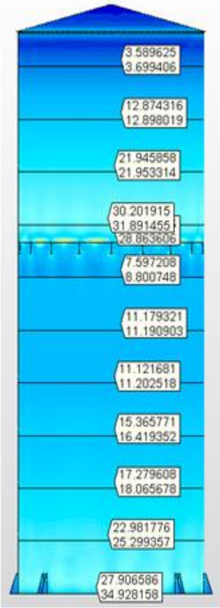


Fig5B. Van Mises stress

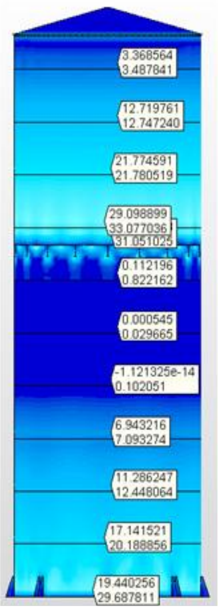


Fig5C. Circunferencial stress

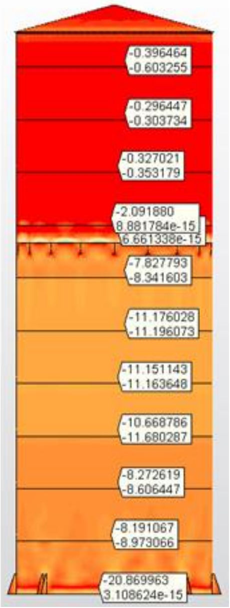


Fig5D. Axial Strees

Figure 6 shows the tank with the required thickness for each cylindrical shell (course) of the tank.

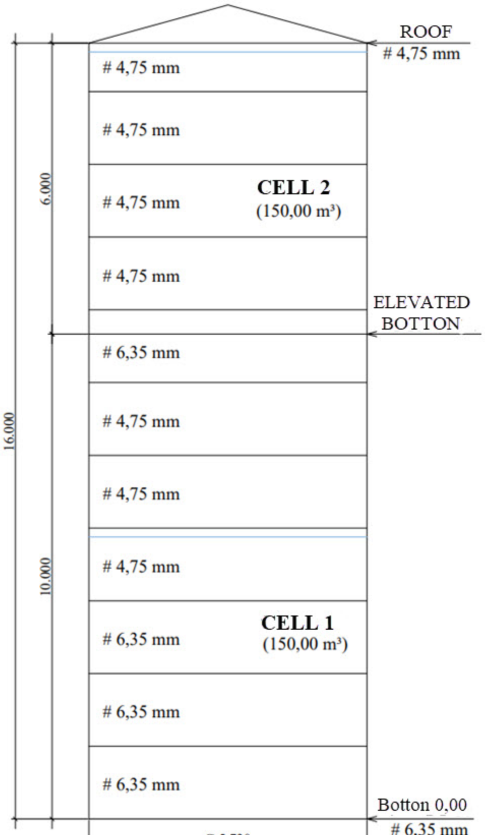


Fig6. Tank with the final course thicknesses

The suspended bottoms analyzed in this work, except for the bottom with radial beams and central mast (Figure 2A), were designed as self-supported and supported only on the tanks' sides. The results of the analyzes are presented below.

The suspended bottom with radial W beams and column whose geometry is in Figure 7. The nominal diameter are the same as that of the tank, D = 5,730.00 mm, the number of support beams = 18 pieces, beam shape W = 310 x 28.3, beam material W = ASTM A572 - grade 50, the diameter of the column = 640.00 mm, the thickness of the column = 6.35 mm, the material of the column = ASTM A36, plate thickness bottom = 7.95 mm (5/16 ”), bottom plate material = ASTM A36. Bottom loading = hydrostatic pressure h = 5.80 m.w.g.

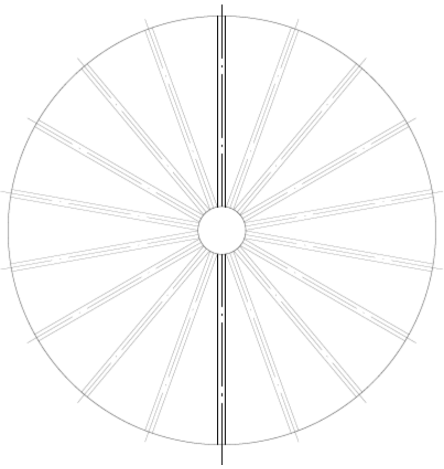


Fig7. Bottom layout with radial beams and column

Figure 8A and 8B shows the Van Mises stress of the bottom and the W beams:

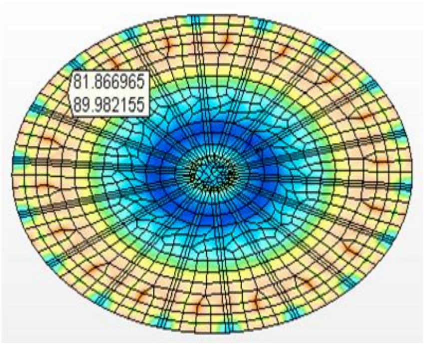


Fig8A. Stress Van Mises in bottom

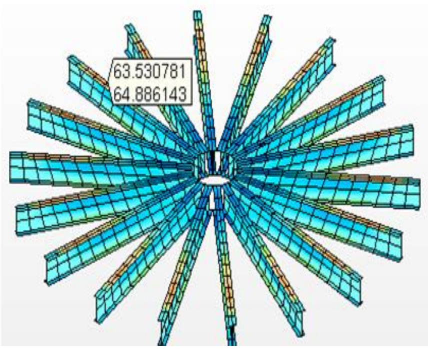


Fig8B. Stress Van Mises in the beams

Figure 8C shows the vertical displacement (axis Z) in the bottom, and Figure 8D shows the Von Mises stress in the column.

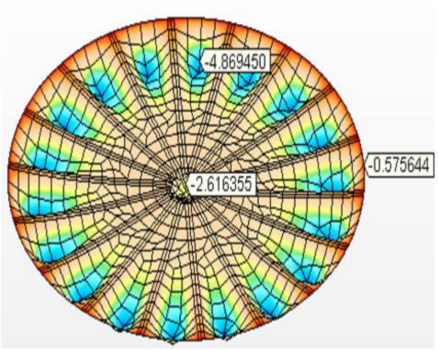


Fig8C. Vertical displacement (mm)

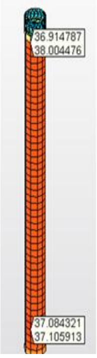


Fig8D. Stress Van Mises in the column

The suspended bottom with radial W beams and without column (Figure 9), where the nominal diameter is the same as the tank, D = 5,730.00 mm, the number of support beams = 18 pieces, beam shape W = 310 x 44.5, beam material W = ASTM A572 - grade 50, circumferential support beam U 6" first core, beam material U = ASTM A572 - grade 50, bottom plate thickness = 7.95 mm (5/16"), bottom plate material = ASTM A36.
Bottom loading = hydrostatic pressure h = 5.80 m.w.g.

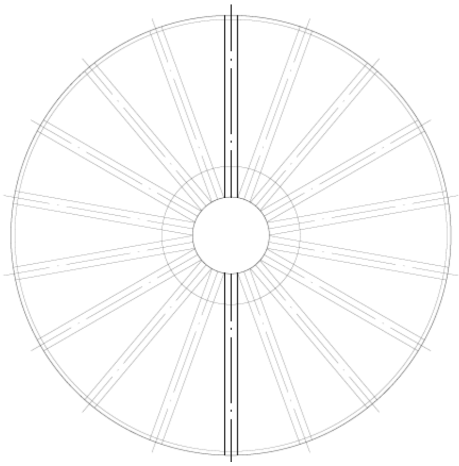


Fig9. Bottom layout with radial beams without column

Figure 9A and 9B shows the Van Mises stress of the bottom and the W beams:

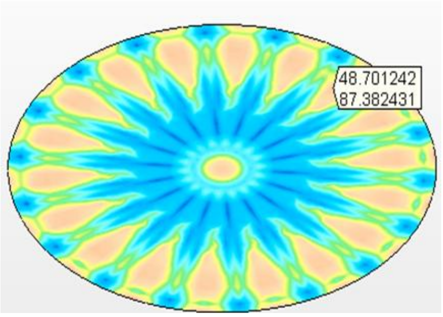


Fig9A. Stress Van Mises in bottom

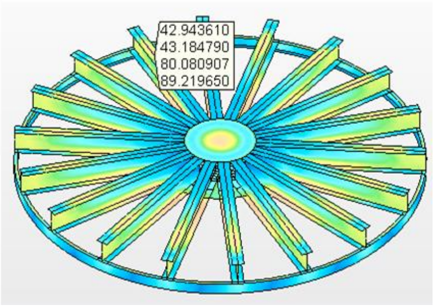


Fig9B. Stress Van Mises in the beams

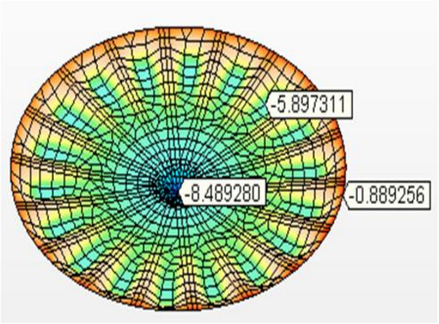


Fig9C. Vertical displacement (mm)

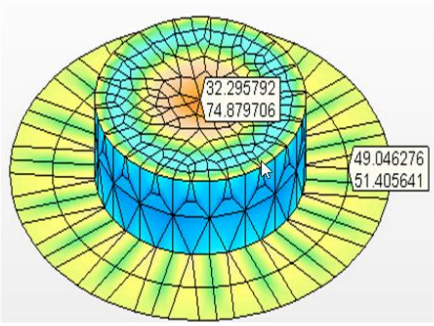


Fig9D. Stress Van Mises in the center mounting

The suspended bottom with orthogonal beams (grid) type W and without a column (Figure 10), where the nominal diameter is the same as that of the tank, D = 5,730.00 mm, the number of support beams = 10 pieces, the shape of the beam W = 360 x 72, beam material W = ASTM A572 - grade 50, circumferential support beam U 6" first web, beam material U = ASTM A572 - grade 50, the thickness of the bottom plate = 9.53 mm (3/8"), bottom plate material = ASTM A36.

Bottom loading = hydrostatic pressure h = 5.80 m.w.g.

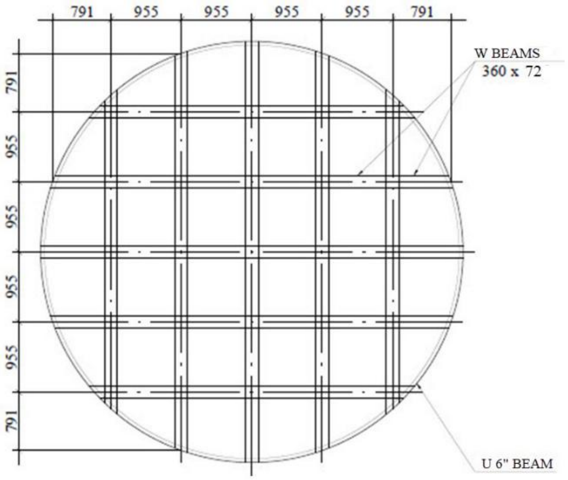


Fig10. Conic bottom layout with orthogonal beams without column

Figure 10A and 10B shows the Van Mises stress of the bottom and the W beams:

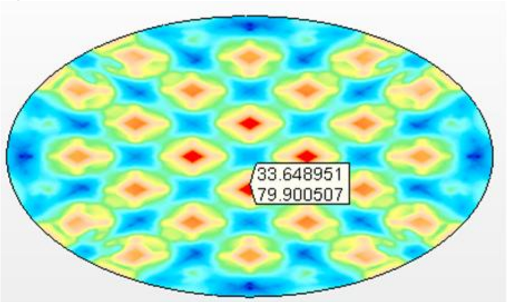


Fig10A. Stress Van Mises in bottom

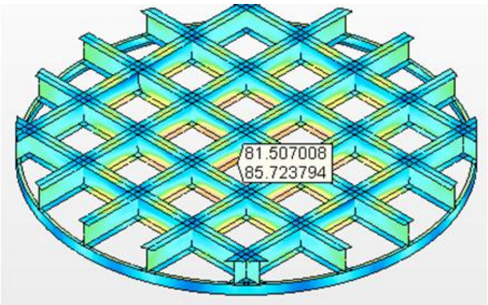


Fig10B. Stress Van Mises in the beams

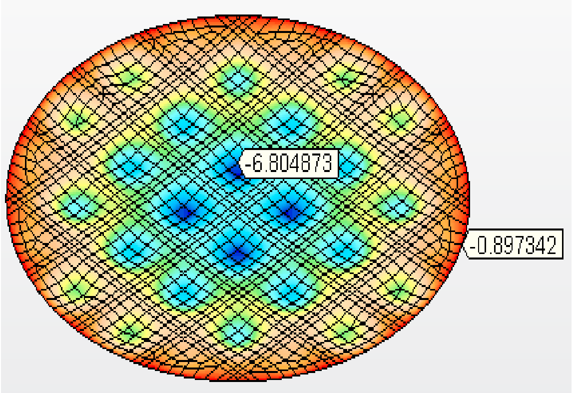


Fig10C. Vertical displacement (mm)

Figure 11 shows the cone-shaped suspended bottom, where the nominal diameter is the same as that of the tank, D = 5,730.00 mm, the thickness of the bottom plate = 9.53 mm (3/8"), bottom plate material = ASTM A36. Bottom loading = hydrostatic pressure h = 5.80 m.w.g..

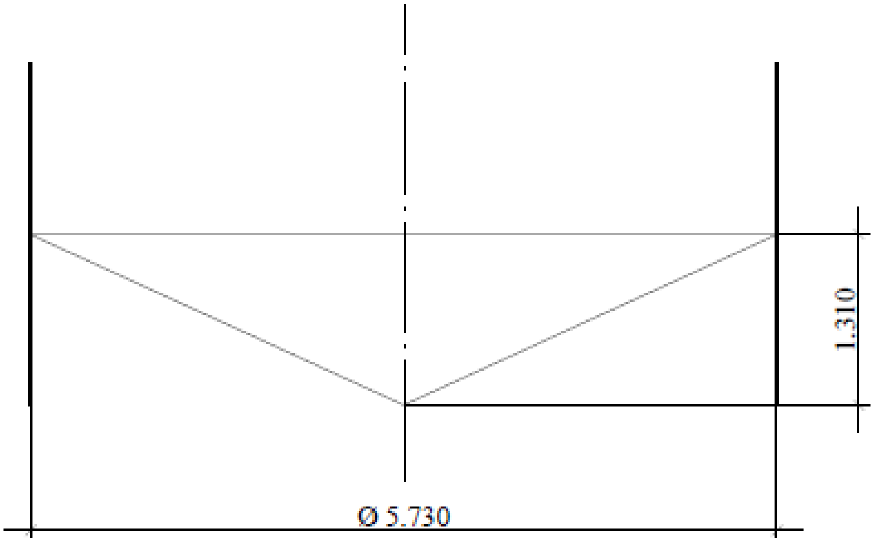


Fig11. Conic bottom layout

Figure 11A shows the Van Mises stress of the bottom, and figure 11B shows the vertical displacement:

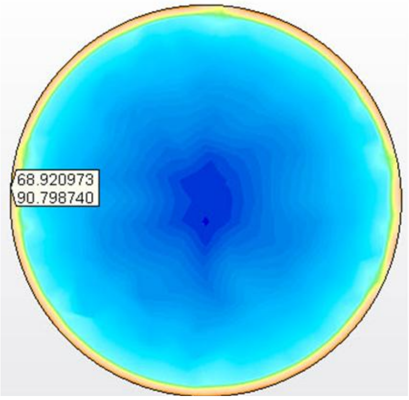


Fig11A. Stress Van Mises in bottom

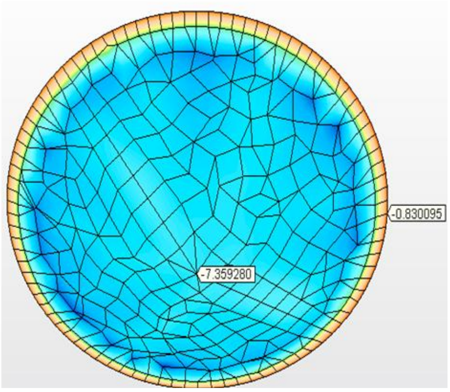


Fig11B. Vertical displacement (mm)

Figure 12 shows the suspended bottom in the shape of a semi-sphere or spherical segmented bottom, where its nominal diameter is the same as that of the tank, D = 5,730.00 mm, the thickness of the bottom plate = 4.75 mm (3/16"), bottom plate material = ASTM A36. Bottom loading = hydrostatic pressure h = 5.80 m.w.g.

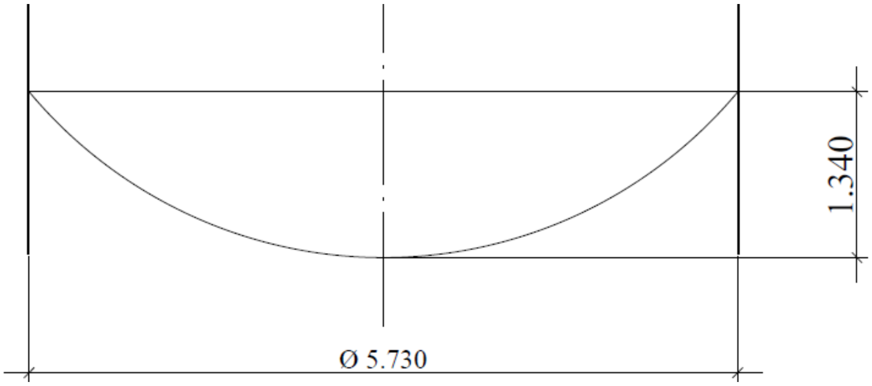


Fig12. Semi-sphere bottom layout

Figure 12A shows the Van Mises stress of the bottom, and figure 12B shows the vertical displacement:

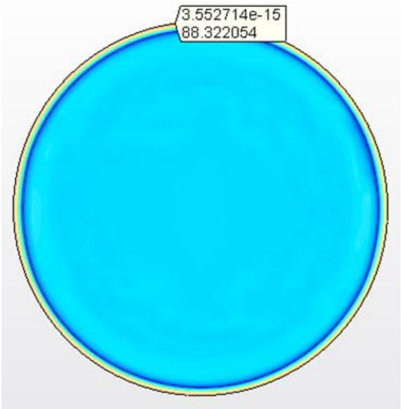


Fig12A. Stress Van Mises in bottom

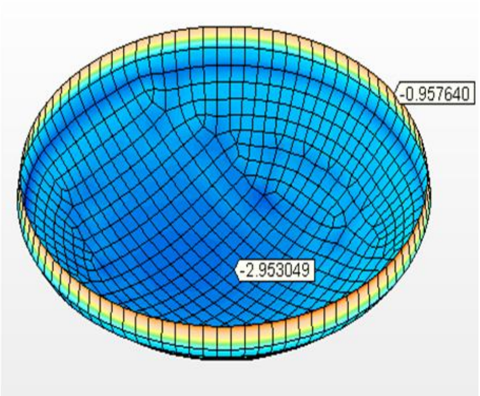


Fig12B. Vertical displacement (mm)

The suspended bottoms weights were calculated only the sheet surfaces multiplied by the weight/m². Table 7 shows the general summary of the weights of the five types of suspended funds, and these differences can see in the chart total weight x type of bottoms, in Figure 13.

Table 7. Weights of suspended bottoms

	Types of suspended bottoms									
Location	Flat bottom + beams + column		Flat bottom + beams		Flat bottom + orthogonal beams		Conic bottom		Espheric bottom	
	Data-sheet	weight	Data-sheet	weight	Data-sheet	weight	Data-sheet	weight	Data-sheet	weight
Bottom	7,95 mm	1.619,61	7,95 mm	1.619,61	9,53 mm	1.929,35	9,53 mm	2.331,83	4,75 mm	1.632,56
Column	6,35 mm	971,85	nt	0,00	nt	0,00	nt	0,00	nt	0,00
Complements	nt	0,00	7,95 mm	79,55	nt	0,00	nt	0,00	nt	0,00
Beam	W 310 x 28,3	1.296,42	W 310 x 44,5	2.038,54	W 360 x 72	3.480,48	nt	0,00	nt	0,00
U Belt	nt	0,00	U 6"	219,62	U 6"	219,62	nt	0,00	nt	0,00
Total wiegh (kg)		**3.887,88**		**3.957,32**		**5.629,45**		**2.331,83**		**1.632,56**

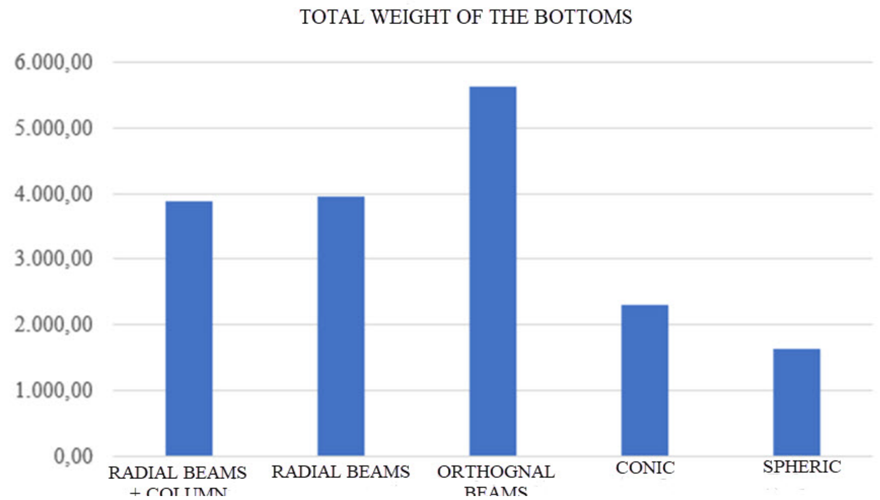


Fig13. Total weight of the suspended bottoms

Figure 14 shows the maximum vertical displacements of the suspended bottoms.

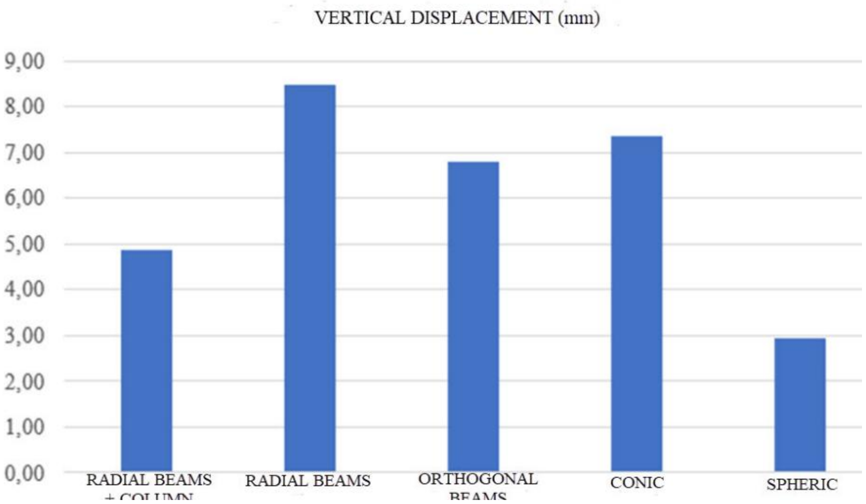


Fig14. Maximum vertical displacements of the suspended bottoms

IV. Conclusion

From the results obtained, it is concluded that the suspended bottom of the segmented spherical type is the most economically viable and also the most technically recommended, as it presents the least vertical displacement under full loading even with the smallest thickness between all the bottoms.

The cone-shaped suspended bottom is also economically viable but presents a vertical displacement under a little excessive loading, and it must check if it interferes with the pipes. The vertical displacement could be reduced using triangular reinforcement plates, supporting the bottom on the side sides.

The suspended bottom supported by orthogonal beams is uneconomical.

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