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RESILIENT INFRASTRUCTURE
June 1–4, 2016

COST ANALYSIS OF CONICAL TANKS; COMPARISON BETWEEN REINFORCED CONCRETE AND STEEL

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ABSTRACT

This paper provides a cost analysis case study to compare the effectiveness of using reinforced concrete versus steel as a construction material for conical tanks. Simplified design approaches, which were developed in previous investigations, are utilized to design a wide range of reinforced concrete conical tanks and steel counterparts having three different capacities (500 m^3, 1750 m^3 and 3000 m^3). The cost analysis is conducted for each of the concrete and steel tanks. This analysis includes the cost of material, formwork, labour and life-cycle cost. Also, a general study of the effect of tank dimensions on the cost is provided. The results of this study show that steel conical tanks are considered as a more economical choice for medium and small capacity tanks, regardless their dimensions. On the other hand, for large capacity conical tanks (3000 m^3), the tank dimensions govern which construction material (reinforced concrete or steel) is more cost effective.

Keywords: Conical tanks; hydrostatic load, cost analysis, analysis of variance

1. INTRODUCTION

The vessels used for elevated liquid storage containers are commonly built in a conical shape, including pure conical tanks and conical-cylindrical combined tanks. The construction of conical tanks is dominated by using either steel, conventional reinforced concrete or partially pre-stressed concrete. The decision to select the most proper construction material for conical tanks depends on various factors: structural performance, material cost, life service, material availability and cost of labour works (Barry 2001). The main advantages of reinforced concrete tanks over steel tanks are that they provide high resistance to compression stresses and have long service life (i.e. up to 50 years) compared to steel tanks (i.e. up to 20 years) (Cheremisinoff 1996). On the other hand, the main disadvantages of reinforced concrete tanks are related to the low tensile strength and the large thickness required to satisfy design requirements, which leads to a significant increase in their own weight. Despite the advantage of using reinforced concrete as a construction material for storage tanks, steel tanks are widely used in North America over the last 25 years. This is due to the fact that steel storage tanks are leak-free structures and they also provide high tension resistance and lighter own weight compared to reinforced concrete counterparts. The only concern about steel as a construction material is that it is sensitive to geometric imperfections, buckling, and corrosion problems.

Choosing the most proper construction material, which leads to an economical design, is not an easy task as it involves many parameters. These parameters include: type of the structure, construction techniques, and life-cycle cost of construction material. In fact, there is a limited data in the open literature regarding the comparison between the cost of reinforced concrete conical tanks and steel counterparts. Few researches presented trials to minimize the cost of storage tanks; Saxena et al. (1987) presented a cost function which includes the cost of different construction materials (e.g. concrete and steel) and the cost of formwork. It was concluded in their study that more savings in cost can be achieved in case of large storage capacity tanks. Later on, Copley et al. (2000) presented the design and cost analysis of a partially pre-stressed concrete conical tank having a storage capacity of 7570 m^3. In their cost analysis, they showed that the cost of construction of the steel tank is more economical than that of the pre-stressed concrete counterpart. However, the life-cycle cost analysis, which was implemented in Copley`s work, showed that pre-stressed concrete is a better alternative in terms of long service life.

Moreover, most of structural optimization techniques of conical tanks deal with minimizing the weight of the structure by achieving the minimum thickness, which satisfies design requirements (Kamal and Hoijat 1998; El Ansary et al. 2010; El Ansary et al. 2011). Also, Barakat and Altoubat (2000) introduced optimization techniques, which were coupled with the finite element method in the analysis and design of reinforced concrete conical and cylindrical water tanks. They illustrated the effect of different parameters, including wall thickness at the base and at the top of the tank, base thickness, tank height, inclination angle and concrete compressive strength. It was concluded that the total cost of cylindrical tanks is about 18% - 40% more than that of the conical water tanks having the same inner volume.

The main objective of this study is to investigate the economics of reinforced concrete conical tanks versus steel counterparts. This study considers only pure conical vessels having a constant thickness and subjected to hydrostatic loading as shown in Figure 1. The design of concrete tanks is conducted under the effect of hydrostatic load following the simplified approach presented by Azabi (2014), which complies with the requirements of the ACI350-06 (2006). On the other hand, the design of steel tanks was obtained by using the simplified approach provided by Sweedan and El Damatty (2009). The current cost study is based on an average unit prices for contractors working in Canada. It should be noted that these unit prices are variable depending on various factors such as site location, material availability, energy cost and others. A total of 51 tanks are chosen to cover a wide range of practical tank dimensions and are categorized into three capacities; 500 m^3, 1750 m^3, and 3000 m^3. These tanks are designed first as reinforced concrete tanks then as steel tanks. The cost of each tank is estimated and a comparison is then conducted to analyze the economics of using the two construction materials (i.e. reinforced concrete and steel) for these tanks. Statistical analyses are also performed in order to evaluate the factors having the most significant effect on the cost of conical tanks.

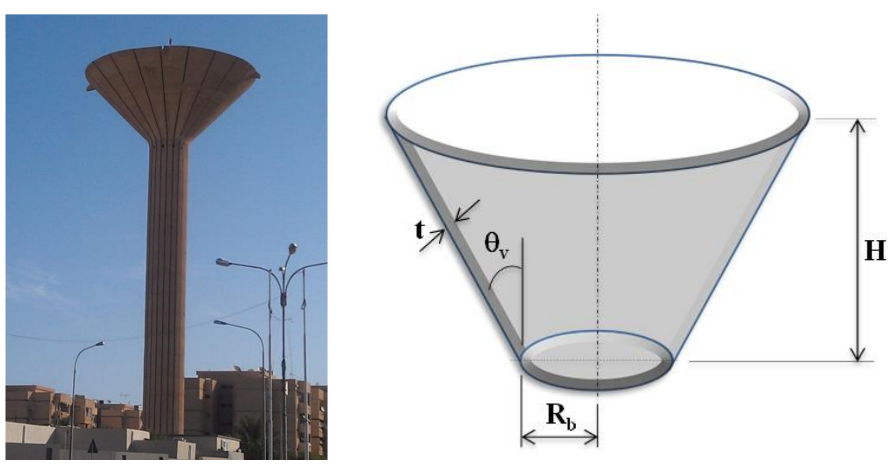

Figure 1: Typical pure conical tank

2. DESIGN OF REINFORCED CONCRETE CONICAL TANKS UNDER HYDROSTATIC LOAD

Design of reinforced concrete conical tanks includes many parameters; angle of inclination of tank’s wall, tank height, base radius, and wall thickness. In order to achieve an adequate design, it is essential to predict the maximum internal forces that include hoop tension acting in the circumferential direction and the meridional moment combined with the axial compression force acting in the longitudinal direction. Conducting this analysis needs modeling experience and knowledge about design steps. An alternative way is to rely on simplified design procedures which satisfy code provisions. In this study, a reliable simplified procedure proposed by Azabi (2014) was utilized in the design of reinforced concrete tanks. This approach includes certain design charts that were developed by modelling a wide practical range of reinforced concrete conical tanks having different dimensions. All analyzed tanks were modelled using a degenerated consistent sub-parametric shell element developed in-house (Koziey and Mirza, 1997; El Damatty et al., 1997, 1998).

The simplified design charts enable the designers to easily evaluate the required minimum thickness and the associated internal forces in both the circumferential and longitudinal directions. These forces are then employed to design for the required reinforcing steel. Consequently, the cost of the required construction material (i.e. reinforced concrete) can be estimated. The steps of the procedure involved in the design can be explained as follows:

1. The tank dimensions (angle of inclination θ_v, base radius R_b, and tank height H) are chosen according to the required tank volume (i.e. capacity). It should be mentioned that specific capacity ranges are assumed in this study covering a practical range starting from 500 m^3 up to 3000 m^3.
2. The design charts proposed by Azabi (2014) are then used to determine the minimum required thickness. By knowing the values of the base radius and the tank height, linear interpolation is applied to predict the minimum required thickness of the walls.
3. A factor (G_f), which relates the tank dimensions to the internal forces that are developed in the tank wall due to hydrostatic pressure, is calculated using Equation 1. This factor is then used in the design charts to estimate the internal forces developed in the tanks' walls due to un-factored hydrostatic pressure. The outputs of these charts include the maximum values of hoop tension, meridional moment and meridional compression.

   [1] $$(G_f) = \frac{H^2}{t_{min.} \cdot (Cos\ \theta_v)^2}$$

   The required circumferential reinforcement (A_{sh}) is then calculated using Equation 2.

   [2] $$A_{Sh} = \frac{T_u}{0.9 \times f_y}$$

   Where T_u is the maximum factored hoop tension force magnified by the environmental durability factor S_d, ($T_u = 1.4 \times S_d \times T$), where T is the service hoop tension obtained from step 3, f_y is the steel yielding strength, and S_d is the environmental durability factor calculated from Equation 3 according to requirements of ACI350-06 (Design Considerations for Environmental Engineering Concrete Structures).

   [3] $$S_d = \frac{\phi f_y}{\gamma f_s}$$

   In Equation (3), ϕ is the strength reduction factor, ($\phi = 0.9$) for both hoop tension and flexural members), f_y = 400 MPa is the steel yield strength, f_s = 140 MPa is the allowable stress in normal environment, and $\gamma = \frac{\text{factored load}}{\text{unfactorred load}}$ = 1.4 in case of hydrostatic pressure and dead loads.
4. The area of longitudinal reinforcement (A_{sv}) is calculated by performing sectional analysis and developing an interaction diagram showing section capacity under the combined meridional moment and meridional normal force following the ACI318-05.

3. DESIGN OF STEEL CONICAL TANKS UNDER HYDROSTATIC LOAD

Similar to reinforced concrete tanks, hydrostatic pressure acting on the walls of the steel tanks leads to tension hoop stresses (σ_h) that are acting in the circumferential direction and vary along the wall height. In addition, meridional compressive stresses (σ_m) that reach their maximum value at the base of the wall are acting in the meridional direction. Those stresses are magnified due to the effect of boundary conditions as well as geometric imperfections. Therefore, a magnification factor should be provided to relate the theoretical membrane stresses, which can be evaluated from static equilibrium of the shell to the actual maximum stresses acting on the wall. Sweedan and El Damatty (2009) developed a simplified procedure that can evaluate this magnification factor associated with the maximum stresses developed in the tank's wall. Consequently, the wall thickness can be designed to prevent steel yielding. This simplified procedure is utilized in the current study to design the steel conical tanks under consideration according to the following steps:

1. The tanks' dimensions (angle of inclination θ_v, base radius R_b, and tank height H) are chosen to be similar to the concrete tanks designed previously to keep storage capacities the same. For each tank, an initial value of the wall thickness (t_s) is assumed taking into account that the minimum thickness is 6.4 mm according to AWWA-D100 (2011) code provisions.
2. From static equilibrium, the theoretical tensile hoop stress (${\sigma_h}^{th}$) and the theoretical meridional compression stress (${\sigma_m}^{th}$) are calculated from Equations 4 and 5, respectively.

   [4] $${\sigma_h}^{th} = \frac{\gamma_w\, H\, R_b}{t_s\, cos\theta_v}$$

   [5] $${\sigma_m}^{th} = \frac{\gamma_w\, H\, tan\theta_v}{2\, R_b\, t_s\, cos\theta_v}\left[R_b\, H + H\, tan\theta_v\left({}^{1}\!/_{3}\, H\right)\right]$$

   Where, γ_w is the specific weight of water.
   Based on the Von Mises yield criterion, the theoretical maximum effective membrane stresses (${\sigma_l}^{th}$) is calculated from Equations 6 to 9.

   [6] $${\sigma_l}^{th} = \sqrt{\frac{3}{2}\left[(\bar{\sigma}_1)^2 + (\bar{\sigma}_2)^2 + (\bar{\sigma}_3)^2\right]}$$

   in which

   [7] $$\bar{\sigma}_1 = {\sigma_m}^{th} - \frac{{\sigma_m}^{th} - {\sigma_h}^{th}}{3}$$

   [8] $$\bar{\sigma}_2 = {\sigma_h}^{th} - \frac{{\sigma_m}^{th} - {\sigma_h}^{th}}{3}$$

   [9] $$\bar{\sigma}_3 = -\frac{{\sigma_m}^{th} - {\sigma_h}^{th}}{3}$$

3. The magnification factor (β) is then calculated from Equation 10.

   [10] $$\beta = a\left(\frac{R_b}{H}\right)^b + c\left(\frac{t_s}{H}\right)^d + e\left(\frac{R_b}{H}\right)^f\left(\frac{t_s}{H}\right)^g(\theta_v)^h$$

   Where, (*a, b, c, d, e, f, g, h)* are the regression factors that are given by Sweedan and El Damatty (2009). It should be mentioned that a good quality of welding of steel panels is assumed in the current study and regression factors for good conical shells are used in Equation 10. A yield stress of 300 MPa is assumed for all studied tanks.
4. The total actual stress (σ_l) is then calculated by multiplying the magnification factor (β) by the theoretical maximum effective membrane stresses (${\sigma_l}^{th}$) as shown in Equation 11.

   [11] $$\sigma_l = \beta\, {\sigma_l}^{th}$$

5. The actual total stress is then compared to the yield strength of steel (σ_y = 300 MPa). The yield strength should be greater than the actual total stress. The procedure is repeated until the optimum thickness is achieved (i.e. $\sigma_l \cong \sigma_y$).

4. COST ESTIMATION

The total cost of the storage vessel of a tank is the summation of the cost of different parameters. This study focuses on the construction costs, which includes material, labour, erection and life-cycle costs. This section presents the details and methodology of analyzing the cost of each tank using two different construction materials (reinforced concrete and steel).

4.1 Construction cost estimation

The cost of construction using each material (i.e. reinforced concrete and steel) is estimated to identify the most cost effective construction material for conical tanks. The cost of reinforced concrete, which includes labour works, is measured by concrete volume, the weight of steel rebar and the surface area of the formwork. For the cost of steel tanks, the material unit prices are presented by unit weight. The prices assumed in the current study are based on the average prices collected from local construction industry.

4.1.1 Construction cost estimation for concrete tanks

- The cost of materials and construction is estimated according to the volume of concrete and the reinforcing ratio of circumferential (i.e. horizontal) and longitudinal (i.e. vertical) steel as well as the surface area for the formwork (El Reedy 2011). Table 1 shows the unit prices for concrete considered in this study. The construction cost function is presented as the summation of the following parameters:
- Cost of concrete = (Tank's surface area × Wall thickness) × Cost of cubic meter of concrete.
- Cost of reinforcement steel = Concrete volume × 7.85 $\frac{ton}{m^3}$× $(\rho_{sh}+ \rho_{sv})$ × Cost of steel $\frac{CAD\$}{ton}$

Where ρ_{sh} is the ratio of circumferential steel $\left(\rho_{sh} = \frac{A_{sh}}{A_c}\right)$, A_{sh} is the area of circumferential reinforcement that is determined by using the simplified design charts provided by Azabi (2014). Referring to Equation 2, the area of the circumferential reinforcement can be calculated to be used in determining the ratio of circumferential steel. The ratio of vertical steel ρ_{sv} is always taken as (ρ_{sv} = 1% of gross area of concrete). Based on the constructability aspects, the tank's wall is assumed to have the same vertical reinforcement for external and internal sides.

- Cost of formwork = Tank's surface area × Cost of double face of formwork
- Total cost (material + construction) per volume ($\frac{CAD\$}{m^3}$) = Cost of concrete + Cost of reinforcement + Cost of formwork + Cost of labour

Table 1: Unit price for reinforced concrete conical tanks

Item description	Unit	Price (CAD$/Unit)
1. Cost of materials		
– Pumped concrete with admixtures and air entraining agents.	m^3	255
– Reinforcement steel M16/20.	ton	1324
– Impermeable plywood formwork double face.	m^2	266
2. Cost of labour		
– Fabrication of wood and reinforcement steel and pouring concrete (per concrete volume).	m^3	45

4.1.2 Construction Cost Estimation for Steel Tanks

The cost of the designed steel tanks is estimated assuming the material unit cost for steel to be 3000 $\frac{CAD\$}{ton}$. The construction and erection unit cost is taken as 30% of the total material cost, as stated by (EL Reedy 2011). The construction cost function is calculated as the summation of the cost of the following parameters:

- Material cost = Material weight × Material unit cost

= (Steel unit weight; 7.850 $\frac{ton}{m^3}$) × (Wall thickness; t_s) × (Tank surface area) × (Material unit cost; 3000 $\frac{CAD\$}{ton}$)

- Total cost (material + construction) per volume ($\frac{CAD\$}{m^3}$) = $\frac{(Material\ cost \times 1.3)}{volume}$

4.2 Life-Cycle Cost Estimation

In order to estimate the current cost of future maintenance and rehabilitation works, the present value analysis method is performed for all concrete and steel tanks for a service life of 50 years (El Reedy 2011). This method is widely used in construction applications and it also presents the future costs in today's monetary taking into consideration the inflation and interest rates. It should be mentioned that for comparison purposes, the same period of life-cycle (i.e. 50

years) is chosen for both steel and concrete tanks. El Reedy (2011) provided an expression to calculate the value of maintenance and repairs required, as shown in Equation 12.

[12] Present Value = Repair Cost $\times\ (1+m)^{(-n)}$

Where; m is the discount rate ($m = 4\%$), and n is the number of years of each maintenance period.
Based on the data collected from the local market, the maintenance cost of concrete tanks is assumed in the current study to be 89 $\frac{CAD\$}{m^2}$ every 5 years while in case of steel tanks, it is recommended to cost 40 $\frac{CAD\$}{m^2}$ at a period of 3 years. It is worth to mention that the operating cost is not taken as part of this study.

5. RESULTS AND DISCUSSION

This study includes 51 conical tanks having wide range of dimensions with different capacities; 500 m^3, 1750 m^3, and 3000 m^3. For illustration purposes, only 12 tanks out of the 51 studied tanks are presented. The dimensions of these twelve tanks are presented in Table 2.

Table 2: Design and estimated cost of conical tanks (-)

Capacity (m^3)	Tank #	R_b (m)	θv	H (m)	Section Design			Cost (CAD$/$m^3$)	
					Concrete		Steel	Concrete	Steel
					t_c (mm)	ρ_{sh} (%)	t_s (mm)		
500	7	4	15	6.6	200	0.92	6.4	339	198
	9	4	45	4.15	200	0.91	6.4	363	212
	11	4.5	30	4.61	200	0.84	6.4	315	184
	13	5.5	15	4.3	200	0.82	6.4	275	161
1750	16	3	60	6.52	273	1.67	22	352	385
	21	4	45	8.02	241	1.69	13	276	220
	29	5.5	15	11.2	267	1.61	8.5	251	157
	34	6	30	7.92	233	1.66	8	230	142
3000	37	3	45	11.25	316	1.66	24.5	256	295
	41	4	45	10.31	333	1.57	20	251	248
	47	5.5	30	11.62	343	1.68	13	226	168
	49	5.5	60	6.78	407	2.09	22.5	311	312

(-) The study included 51case studies. 12 tanks are presented in this table.

(-) The vertical reinforcement for reinforced concrete tanks is always taken as 1% (0.5% from each side).

The considered tanks are first designed as reinforced concrete and then as steel tanks according to the simplified design procedures mentioned earlier. The cost analysis is then conducted for all designed tanks as presented in Table 2. This table shows the design outputs and the total cost described as price per unit volume (i.e. CAD$ per m^3) for each tank. The comparison between the cost of reinforced concrete conical tanks and steel counterparts is displayed in Figures 2, 3, and 4 for tanks with volumes of 500 m^3, 1750 m^3, 3000 m^3, respectively. Also, each figure categorizes the tank cost according to the base radiuses, where R_b is varying from 3 m to 6 m with an increment of 0.5 m. In the current study, only the cost of tanks having radiuses of 3 m, 4 m, 5 m, and 6 m are shown in these figures. Table 2 and Figure 2 show that steel tanks are more cost effective than reinforced concrete for small capacity tanks, i.e. 500 m^3 tanks. The average total cost of reinforced concrete conical tanks is estimated to be 338 $\frac{CAD\$}{m^3}$, which is approximately 1.7 times the cost of steel counterparts.

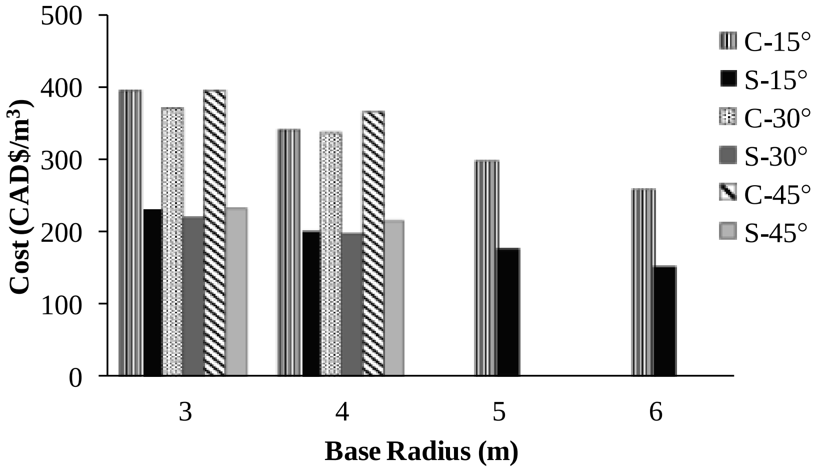

Figure 2: Cost analysis for tanks capacity 500 m^3 (C: Concrete, S: Steel)

For conical tanks having a volume of 1750 m^3, it is concluded that steel tanks are more economical than reinforced concrete tanks. Figure 3 shows that the total cost of steel tanks is less than that of reinforced concrete tanks having the same dimensions. In general, steel tanks show less cost compared to reinforced concrete counterparts with a percentage of reduction varying between 4% and 39%. It can be noticed from the results that in only two cases the cost of steel tanks is found to be greater than that of reinforced concrete tanks. The reported percentage of increase for these two cases are 9 % and 2 % for tanks having walls inclined to the vertical with an angle of 60° and having base radiuses of 3 m, and 3.5 m, respectively.

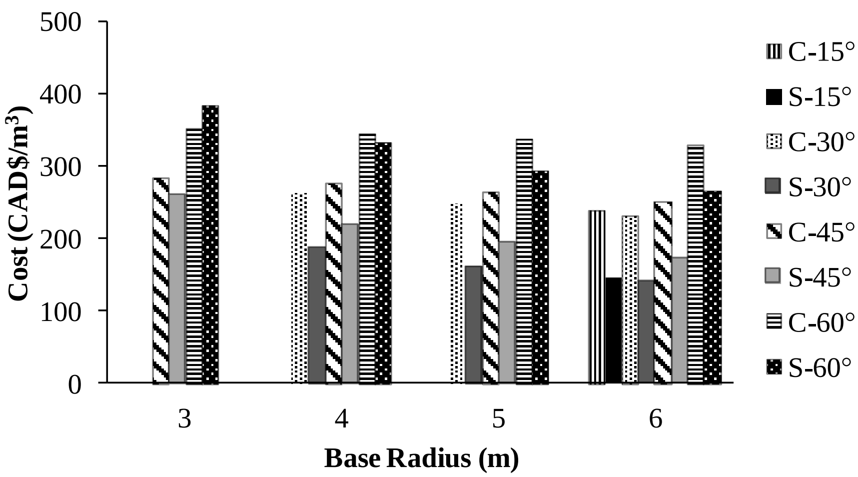

Figure 3: Cost analysis for tanks capacity 1750 m^3 (C: Concrete, S: Steel)

Based on the cost analysis of large capacity tanks (i.e. 3000 m^3) as presented in Figure 4, it can be observed that in some cases concrete as a construction material is a more economical choice. Figure 4 shows that the cost of concrete tanks is less than steel for the case of wide conical tanks having walls inclined to the vertical with an angle greater than 45° and a base radius less than 4 m. Otherwise, steel provides a more economical choice for all conical tanks having 30° inclination angle and tanks with 45° walls and having a base radiuses of (4 m to 6 m). Based on the results reported for large capacity tanks, no clear trend can be reached in order to decide which construction material is the most cost effective one.

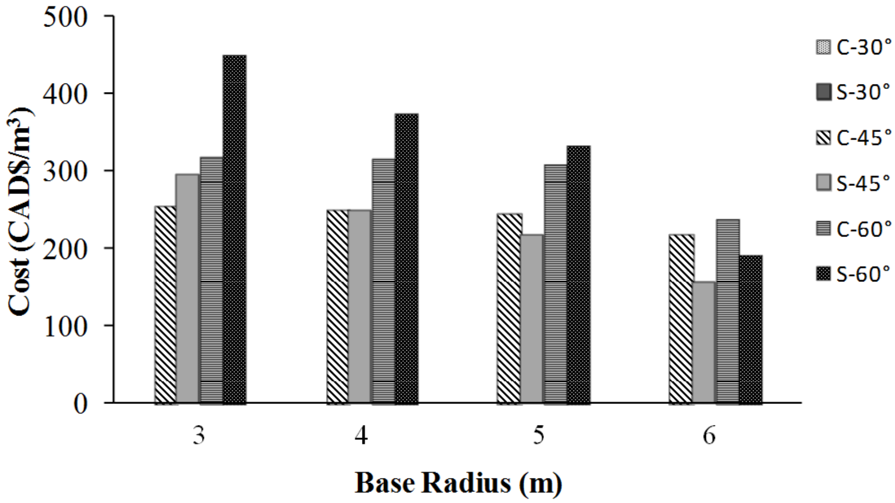

Figure 4: Cost analysis for tanks capacity 3000 m^3 (C: Concrete, S: Steel)

The results obtained from the cost analysis are evaluated statistically by using one way analysis of variance ANOVA for a single factor (Stamatis 2002). This analysis is conducted to assess the significance in the change of the cost from one case to another. Two different case studies are performed using ANOVA. The first case is conducted for reinforced concrete tanks and steel counterparts in order to study the variance in the cost function with the change of material type. In the second case of this study, ANOVA is employed to evaluate the effect of tank dimensions on its cost for each type of the studied tanks.

As a result of the analysis of variance of the first case study, small capacity tanks show significant differences in cost due the difference in construction material (i.e. concrete and steel). It is found that for 500 m^3 and 1750 m^3 capacities, where (*p-value* $\leq$ 0.05) as presented in Table 3, the cost of steel conical tanks is significantly less than concrete counterparts. On the other hand, for large tanks having 3000 m^3 capacity, there is no significant difference in cost (*p-value* > 0.05). It can be stated that for large capacity tanks the effect of the type of construction material (steel or concrete) on the cost is negligible.

Table 3: Effect of material type on cost of conical tanks; descriptive of ANOVA

Tank Capacity (m^3)	Groups (1)	Count (Tanks)	Sum (2)	Avg.(2)	Variance	*P*-value
500	C	14	4731	337.9	1794.6	4.85E-11
	S	14	2765	197.5	604.4	
1750	C	22	6267	284.8	1748.0	0.0025
	S	22	5011	227.7	5201.2	
3000	C	15	4067	271.1	1432.2	0.7128
	S	15	4208	280.5	8138.1	

(1) C: Concrete, S: Steel.

(2) Sum: Summation in CAD$/m^3.

(3) Avg.: Average in CAD$/m^3.

For the second case study, ANOVA results, as presented in Table 4, show that regardless the type of the construction material, the effect of changing the inclination angle θv has a significant effect on the cost of the tanks. This is noticed for 1750 m^3 and 3000 m^3 capacities where *p*-values are less than 0.05. Therefore, increasing the inclination angle increases the cost of both concrete and steel conical tanks. It is also noticed that the change of the inclination angle in case of small capacity tanks (i.e. 500 m^3) has a negligible effect on the cost (*p-value* > 0.05). The reason of this negligible effect is that the minimum wall thickness governs the design of these small capacity tanks. Moreover, the results show that the change in the base radius has a minor effect on the cost of conical tanks except in case of small capacity tanks (i.e. 500 m^3).

Table 4: P-Value of ANOVA – effect of tank dimensions on cost based on a significant level (*α=0.05)*

Tank Capacity (m^3)	Effect of θ_v		Effect of R_b	
	Concrete	Steel	Concrete	Steel
500	0.288133	0.326551	0.055180847	0.04254477
1750	1.66E-09	1.12E-06	0.971745071	0.812747932
3000	3.23E-10	0.000494	0.999773457	0.804062029

6. CONCLUSIONS

The current study presents a cost analysis to compare the effectiveness of using reinforced concrete versus steel as a construction material for conical tanks. In order to conduct this comparison, 51 conical tanks having different capacities (i.e. 500 m^3, 1750 m^3, 3000 m^3) and different dimensions are designed first as reinforced concrete tanks and then as steel tanks. Two simplified design approaches that were developed in previous investigations are utilized in designing the studied tanks. The cost analysis conducted in this study includes the cost of materials, formwork, labour and life-cycle. At the end of the study, statistical analyses using one way ANOVA are conducted to study the significance of type of construction material on the cost function and to investigate the effect of dimension parameters on the cost for both reinforced concrete tanks and steel counterparts. The main conclusions of this study are listed below:

- Compared to reinforced concrete, steel is a more cost-effective construction material for conical tanks with capacities of 1750 m^3 or less. Steel tanks provide a reduction in the cost up to 42%, and 22% for 500 m^3, and 1750 m^3, respectively. This conclusion can be generally applied for conical tanks having different dimensions except for those tanks with inclination angle 60° and base radiuses of 3 m and 3.5 m.
- For 1750 m^3 capacity conical tanks having dimensions of 60° inclination angle and base radius less than 4 m, reinforced concrete is considered to be more economical construction material compared to steel.
- Cost analysis for conical tanks with 3000 m^3 volume shows that concrete is more economical for tanks that have inclination angle of 60° and base radiuses of (3 m to 3.5 m). For all other studied cases, no general conclusion is reached.
- ANOVA technique demonstrates that the angle of wall inclination has the main effect on the cost of conical tanks as increasing the wall inclination increases the cost. Moreover, tanks with angles of inclination 15° and 30° are found to be more economical than those with angles of 45° and 60° and having the same capacities. On the other hand, the change in the base radius has a slight effect on the cost function. The effect of the base radius is only noticed in case of small capacity (500 m^3) tanks, where the increase in base radius leads to a slight reduction in cost.

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