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COST OPTIMIZATION OF A REINFORCED CONCRETE WATER TANK

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Abstract: The research aims to investigate the cost optimization of a reinforced concrete water tank design under Eurocode 2 guidelines. Water tanks are essential for domestic, industrial, and agricultural use, but their substantial construction and maintenance costs necessitate cost optimization strategies. This study utilizes Eurocode 2, to develop a cost optimization framework for reinforced concrete water tanks. The research employs a multi-objective optimization approach to balance the conflicting objectives of minimizing construction costs while ensuring structural safety and serviceability. A comprehensive cost model, incorporating material costs is developed to assess the total cost of the water tank. To evaluate the performance of the cost optimization framework, a case study is conducted using multiple hypothetical water tank projects. The results demonstrate the effectiveness of the proposed approach in achieving significant cost savings of 37.07%, 33.48% and 10.03% for concrete water tanks of 8000, 12000 and 18000 liters respectively, while meeting the necessary structural requirements. The findings of this research contribute to the field of structural engineering and provide guidance for engineers and designers involved in water tank projects. The cost optimization framework presented in this study can aid decision-making processes, enabling the selection of cost-effective designs that meet Eurocode 2 requirements.

Keywords: concrete, cost optimization, Eurocode 2, serviceability, water tank

INTRODUCTION

Reinforced concrete water tanks are critical infrastructure components that enable water storage in a variety of settings, including residential, commercial, and industrial settings. They are influenced by a wide range of external elements, including seismic stresses, wind loads, and material restrictions (Manning, 1973). Furthermore, economic issues are critical, particularly in locations with low financial resources (Salam and Badaruzzaman, 2011). As a result, the design of reinforced concrete water tanks must be based on a thorough understanding of structural engineering concepts.

However, the building and maintenance expenses connected with these structures can be significant, necessitating the use of cost-cutting techniques. In the construction of reinforced concrete water tanks, cost optimization entails striking an ideal balance between structural integrity and associated costs. It necessitates taking into account a variety of aspects, such as material amounts and design parameters, while also guaranteeing compliance with essential design norms and standards. Eurocode 2, also known as EN 1992-1-1, is a set of recommendations for the design of concrete structures, including water tanks.

The creation of a detailed optimization framework in which the cost of the reinforced concrete water tank is the objective function and the constraints are derived from Eurocode 2 is appropriate for investigating the structure's cost optimization. Cost optimization entails determining the best tank dimensions, wall thickness, reinforcement details, and concrete strength parameters. The crack width was taken into account to ensure the tank's serviceability and functionality (Eurocode 2, 2004). Furthermore, Eurocode 2's practical constraints and design limitations are incorporated into the optimization framework.

Hasan (2011) conducted a notable study on the application of optimization methods to the structural design of concrete rectangular and circular water tanks. The total cost of the tank was considered as an objective function, with tank capacity, width and length of tank in rectangular, water depth in circular, unit weight of water, and tank floor slab thickness as design variables. A computer program has been created to solve numerical examples using equations from the Indian IS: 456-2000 Code. According to the findings, the minimum total cost of a rectangular tank is more sensitive to changes in tank capacity and floor slab thickness, whereas the minimum total cost of a circular tank is more sensitive to all variables. Increases in tank capacity, width, length, floor slab thickness, and water depth affect the cost.

Saxena et al. (1987) used the heuristic flexible tolerance method to present the minimum cost design of reinforced concrete water tanks based on the Indian and ACI ("building" 1969) codes. The cost function factored in the costs of concrete, steel, and formwork. They came to the conclusion that large capacity water tanks can save a significant amount of money.

Tan (1993) used a direct search method and the (SUMT) to present the minimum cost design of reinforced concrete cylindrical water tanks based on the British Code for water tanks. Only the material costs of concrete and steel were included in the cost function. The thickness of the tank wall was idealized using piecewise linear slopes, with the maximum thickness at the base.

Another relevant study by Martnez-Martn et al. (2022) proposed an adaptive threshold acceptance method with a neighborhood move based on the mutation operator from genetic algorithms as an optimization framework for water tank design. Their research sought to examine the design of elevated tanks in relation to the full prescriptions of Eurocode 2, Eurocode 8, and the Spanish Structural Code of Practice. This includes variable loads such as seismicity, wind, and snow, as well as the action of self-weight and dead loads. The analysis revealed significant nonlinearity as a result of seismic forces and column rigidity. The study also discovered that for seismic zones of high degrees, steel reinforcement and concrete volume per unit height remained relatively constant with height.

Salam and Badaruzzaman (2011) investigated the cost optimization of a water tank model 9 m long, 6 m wide, and 24 m high with a capacity of 28530.6 gallon. The model was created for twelve different cases using the Staad Pro.2007 computer program, which is based on the American code (ACI) and the Euro code (EU2 and EU3). Case 7 was the best case for water tank design because it was designed using Euro 2 code and the model was a full concrete structure. A comparison of the ACI and Euro codes revealed that the Euro code is 6% more optimum in design than the ACI code, so it is recommended that the Euro code be used in the design of concrete water tank structures.

Furthermore, flexural cracking was investigated because it is important in the structural behavior of reinforced concrete tanks. Jelušic (2022) used a mixed-integer nonlinear programming (MINLP) algorithm and the Eurocode standard. The case study demonstrates the value of the optimization approach by proposing two different economic designs of reinforced concrete sections. A previously unseen direct comparison of different methods for modeling cracking in reinforced concrete cross-sections is also presented.

While previous research has primarily concentrated on optimizing water tank design parameters, few studies have investigated the comprehensive cost estimation of reinforced concrete water tanks. Eurocode 2 provides design and analysis guidance, but specific cost estimation methods are frequently lacking. As a result, the purpose of this study is to bridge that gap by developing a comprehensive cost model that includes material costs, labor costs, and construction time, allowing for a more accurate assessment of the total project cost.

The study focuses on creating a comprehensive cost model that estimates the total cost of building the water tank. This model takes into account the various material costs. The cost optimization framework seeks to identify the most cost-effective design alternatives while maintaining structural performance by taking these factors into account. A case study is conducted using a hypothetical water tank project to evaluate the effectiveness of the proposed cost optimization framework. Furthermore, the study analyzes and compares the costs and performance of three different tank designs, each of which increases capacity, demonstrating the potential cost savings achievable through optimization.

This study advances structural engineering by presenting a systematic approach to cost optimization in the design of reinforced concrete water tanks. The findings provide engineers and designers involved in water tank projects with practical guidance, allowing them to make informed decisions and choose cost-effective designs that meet Eurocode 2 requirements. This research promotes resource efficiency and sustainability in infrastructure development by optimizing the costs associated with water tank construction. The goal of this study was to create a cost-optimization framework for the design of reinforced concrete water tanks using Eurocode 2. The study used a multi-objective optimization approach to reduce construction costs while ensuring the structural safety and serviceability of the water tank.

MATERIALS AND METHODS

Materials

Eurocode 2 (2004) was used to create a mathematical model of a concrete structure. The model was created using an Excel spreadsheet, and the optimization process was carried out using Excel's Solver Tool.

Methods

— Formulation of the Optimization Problem

The water retaining structure is shown in Figure 1, 2 and 3. The assigned dimensions and the derived material quantities of concrete, reinforcement steel and formwork were used to develop a cost objective function with constraints for water retaining structures under Eurocode 2.

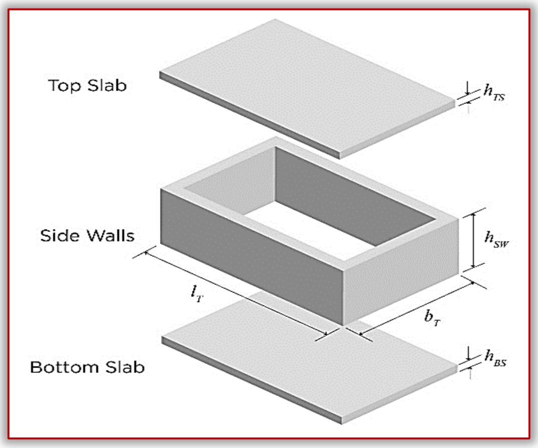

Figure 1: External dimensions of the reinforced concrete water tank.

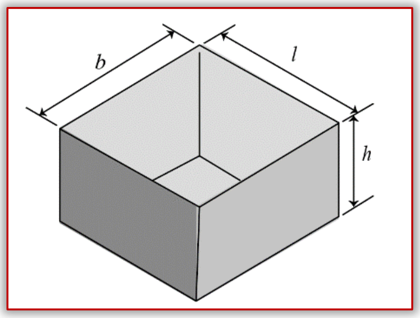

Figure 2: Interior dimensions of the reinforced concrete water tank.

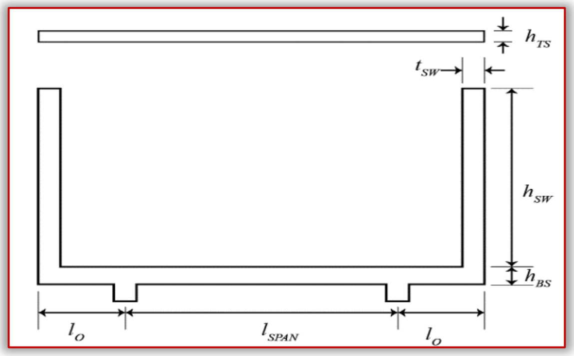

Figure 3: Cross-section of the reinforced concrete water tank.

— Development of the Objective Function

The cost of the water tank is the sum of the cost of concrete, steel and formwork components. The quantity of each of these components depends mostly on the dimensions of the tank.

The cost objective function can be defined as:

Total Cost, C = (cost of concrete) + (cost of steel) + (cost of formwork)

Which can be rewritten in full as:

$$C = [C_c \times V_c \times u_c] + [C_s \times \sum A_s] + [C_f \times F_a] \quad (1)$$

where:

C = Total cost of manufacturing the water tank.

C_c = Cost coefficient of concrete in cost per mass (naira per kg).

C_s = Cost coefficient of reinforcement steel, in cost per cross-sectional area (naira per mm²).

C_f = Cost coefficient of formwork, in cost per area (naira per m²).

u_c = Unit weight of concrete (kg/m³).

V_c = Volume of concrete (m³).

F_a = Total formwork area (m²).

$\sum A_s$ = Total area of steel reinforcement (mm²).

— Inputted and Computed Parameters

Given that the cost of manufacturing the reinforced concrete water tank is related to the various parameters listed in the previous section above, further derivations were used to calculate the variables necessary for the calculation of the parameters present in the objective function.

Input parameters were classified into those that could be directly imputed and used in the objective function; those which were needed to compute values of parameters to be used in the objective function; and finally those that would be adjusted in the optimization process to produce an optimal cost of manufacturing the water tank. These parameters that needed additional calculations before being used were separated in the Excel spreadsheet as computed parameters.

The cost coefficients were each calculated based on their necessary dimensions and underlying real-world market prices as follows:

- Cost Coefficient of Concrete (C_c): This is the total cost per mass of concrete (naira per kg). It was found by calculating the total cost of manufacturing a given mass of concrete and dividing that cost by the mass of concrete manufactured.
- Cost Coefficient of Steel (C_s): This is the cost per cross-sectional area of reinforcement steel (naira per mm²). It was found by dividing the cost of specific sizes of steel bars by their areas. Given that reinforcement bars are manufactured and sold based on their diameter sizes, the bar diameters were used to derive the cross-sectional areas.
- Cost Coefficient of Formwork (C_f): Here, the cost coefficient of formwork is the cost per area of the formwork material used (commonly wood). Its dimensions are in naira per m².

The material properties of both the concrete and the steel, which were used to compute values in the objective function and in the derivation of some constraints, are:

- Characteristic Strength of Concrete (f_{ck}): This is the compressive strength of 150 mm sized cubes tested at 28 days at which not more than 5% of the test results are expected to fail. It is taken in Eurocode 2 as 25 N/mm^2.
- Characteristic Strength of Steel (f_{yk}): This is the minimum yield stress, at which not over 5% of the test outcomes should fail. Taken as 500 N/mm^2 according to Eurocode 2.
- Unit weight of Concrete (U_c): This is the ratio of the mass of concrete per unit volume. Taken as 2400 kg/m^3.

The inputs for the geometric dimensions of the beam (as shown in Figure 1, 2 and 3):

- Total length of the tank (l_T)
- Total width of the tank (b_T)
- Total height of the tank (h_T)
- Thickness of the sidewalls of the tank (t_{SW})
- Thickness of the top slab (h_{TS})
- Height of tank side walls (h_{SW})
- Thickness of the bottom slab of tank (h_{BS})
- Span distance between the tank support (l_{span})
- Distance of overhang from tank support (l_o)
- Capacity of tank (C)

The computed parameters included the internal dimensions of the concrete tank, the volume of the tank and water within it, area of reinforcements and the required formwork area.

The internal dimensions of the tank are derived from:

$$l = l_T - 2t_{SW} \quad (2)$$

$$b = b_T - 2t_{SW} \quad (3)$$

$$h = h_{SW} \quad (4)$$

Volume of the tank (V_T), maximum volume of water (V_W) and concrete (V_C) were derived from:

$$V_W = l \times b \times h \quad (5)$$

$$V_T = l_T \times b_T \times h_T \quad (6)$$

$$V_C = V_T - V_W \quad (7)$$

Area for reinforcements are derived based on the part of the tank they were to be placed and the resulting load acting on such sections.

Area for the top slab was derived from:

$$A_{s(TS)} = 0.002bh_{TS} \quad (8)$$

Therefore, the total area of reinforcement at the top slab was give as:

$$A_{(TS)} = A_{s(TS)} \times b_T \quad (9)$$

Area for each of the side wall was derived from:

Main reinforcement:

$$A_{s(SW)} = \frac{M_{ult(SW)}}{0.87f_{yk}(0.95(t_{SW} - 50))} \quad (10)$$

where:

$$M_{ult(SW)} = 1.2 \times M_{ser(SW)} \quad (11)$$

$$M_{ser(SW)} = \frac{1}{2}(9.81 \times h_{SW}) \times h_{SW} \times \left(\frac{h_{SW}}{3} + \frac{h_{BS}}{4}\right) \quad (12)$$

Distribution reinforcement:

$$A_{d(SW)} = 0.002bt_{SW} \quad (13)$$

Therefore, the total area of reinforcement within the sidewalls was given as:

$$A_{(SW)} = 4\,(A_{s(SW)} \times h_{SW} + A_{d(SW)} \times l_T) \quad (14)$$

Area for each of the bottom slab was derived from:

Main reinforcement:

$$A_{s(BS)} = \frac{M_{ult(BS)}}{0.87f_{yk}(0.95(h_{BS} - 50))} \quad (15)$$

Where:

$$M_{ult(BS)} = \left((\text{weight of slab} \times 1.35) + (\text{weight of water} \times 1.2) \times \frac{l_{span}^2}{8}\right) - M_{ult(support)} \quad (16)$$

$$M_{ult(support)} = M_{ult(SW)} + \left(\text{weight of sidewall} \times \left(l_o - \frac{t_{SW}}{2}\right) \times 1.35\right) + \left((\text{weight of slab} \times 1.35 + \text{weight of water} \times 1.2) \times \frac{(l_o - t_{SW})^2}{2}\right) \quad (17)$$

$$\text{weight of sidewall} = (h_{SW} + h_{BS}) \times t_{SW} \times 25 \quad (18)$$

$$\text{weight of slab} = h_{BS} \times 25 \quad (19)$$

$$\text{weight of water} = 9.81 \times h \quad (20)$$

Distribution reinforcement:

$$A_{d(BS)} = 0.002bh_{BS} \quad (21)$$

Therefore, the total area of reinforcement at the bottom slab was give as:

$$A_{(BS)} = A_{s(BS)} \times l_T + A_{d(BS)} \times b_T \quad (22)$$

The total area of reinforcement along the entire tank was given as:

$$\sum A_s = A_{(SW)} + A_{(TS)} + A_{(BS)} \quad (23)$$

The total area of formwork used F_a was found using:

$$F_a = (l_T \times b_T) + ((h_{SW} + h_{BS}) \times b_T) + 4(b \times h) + (b \times h) \quad (24)$$

— Development of Constraints

The constraints used were of two types: behavioral and geometric.

The behavioral constraint was concerned with the permissible crack width on the water tank. This was not to exceed 0.3 mm, according to Eurocode 2. This was stated mathematically as:

$$\text{Crack width, } w_K \leq 0.3 \quad (25)$$

where:

$$w_K = s_{r,max} \times \varepsilon_{cr} \quad (26)$$

$$s_{r,max} = 3.4c + 0.425(k_1k_2\emptyset/\rho_{p,eff}) \quad (27)$$

$$\varepsilon_{cr} = \frac{\sigma_s - k_t\left(\frac{f_{ct,eff}}{\rho_{p,eff}}\right)(1+\alpha_e\rho_{p,eff})}{E_s} \quad (28)$$

where:

c = concrete cover.

$K_1 = 0.8$
$K_2 = 0.5$ for bending.
$\emptyset$ = bar diameter.
$\rho_{p,eff} = \frac{A_{s,min}}{A_{c,eff}}$
$A_{s,min} = k_c k f_{ct,eff} A_{ct}/f_{yk}$
$K_c = 1.0$, for pure tension
K = 1, when h = 300 mm
$f_{ct,eff} = 0.3 f_{ck}^{\left(\frac{2}{3}\right)}$, for concrete grades ≤ C50/60.
σ_s = serviceability level stress in the reinforcement.
$A_{c,eff} = (h - x)/3$
$\alpha_e = \frac{E_s}{E_{cm}}$
E_s = 200, 000 MN/mm²
$E_{cm} = 22\left(\frac{f_{ck}+8}{10}\right)^{0.3}$

The geometric constraints include the permissible extents possible for the dimensions of the water tank and its reinforcements. In addition to these, the expected tank capacity must also be considered, if the tank's cost is to be minimized.

Behavioral constraint:

$$w_K \leq 0.3 \tag{30}$$

Geometric constraint:

$$C = V_W \tag{31}$$
$$h_T = h_{BS} + h_{SW} + h_{TS} \tag{32}$$
$$1800 \leq l_T \leq 8000 \tag{33}$$
$$1000 \leq b_T \leq 3000 \tag{34}$$
$$1000 \leq h_T \leq 3500 \tag{35}$$
$$150 \leq t_{SW} \leq 300 \tag{36}$$
$$100 \leq h_{TS} \leq 150 \tag{37}$$
$$1200 \leq h_{SW} \leq 2600 \tag{38}$$
$$150 \leq h_{BS} \leq 400 \tag{39}$$
$$300 \leq A_{TS} \leq 500 \tag{40}$$
$$5000 \leq A_{SW} \leq 20000 \tag{41}$$
$$500 \leq A_{BS} \leq 5000 \tag{42}$$

Optimization Model and Outputs

The optimization model consists of the objective function and its related constraints. These have been described in the previous sections in detail. It can be summarized as:

Minimize:

$$C = [C_c \times V_c \times u_c] + [C_s \times \sum A_s] + [C_f \times F_a] \tag{43}$$

Subject to:

$$w_K \leq 0.3 \tag{44}$$
$$C = V_W \tag{45}$$
$$h_T = h_{BS} + h_{SW} + h_{TS} \tag{46}$$
$$1800 \leq l_T \leq 8000 \tag{47}$$
$$1000 \leq b_T \leq 3000 \tag{48}$$
$$1000 \leq h_T \leq 3500 \tag{49}$$
$$150 \leq t_{SW} \leq 300 \tag{50}$$
$$100 \leq h_{TS} \leq 150 \tag{51}$$
$$1200 \leq h_{SW} \leq 2600 \tag{52}$$
$$150 \leq h_{BS} \leq 400 \tag{53}$$
$$300 \leq A_{TS} \leq 500 \tag{54}$$
$$5000 \leq A_{SW} \leq 20000 \tag{55}$$
$$500 \leq A_{BS} \leq 5000 \tag{56}$$

The design variables and the cost of manufacturing the tank were the outputs of the optimization model. The design variables included the geometric dimensions of the water tank and the total area of reinforcements.

MODEL OPTIMIZATION

The optimization model and its related formulas were replicated in Microsoft Excel were optimization of the model was performed using its Solver feature.

Development of Excel Spreadsheet

The objective function, input parameters, design parameters, computed values, constraints and their aforementioned formulas were appropriately placed in the Excel spreadsheet.

Use of Excel Solver

Once the spreadsheet was created, the Solver button was selected from the Data tab on the Excel interface. The Solver dialogue box displayed was then filled with pertinent data from the spreadsheet. The constraints were added individually, by clicking the "Add" button shown in Figure 4.

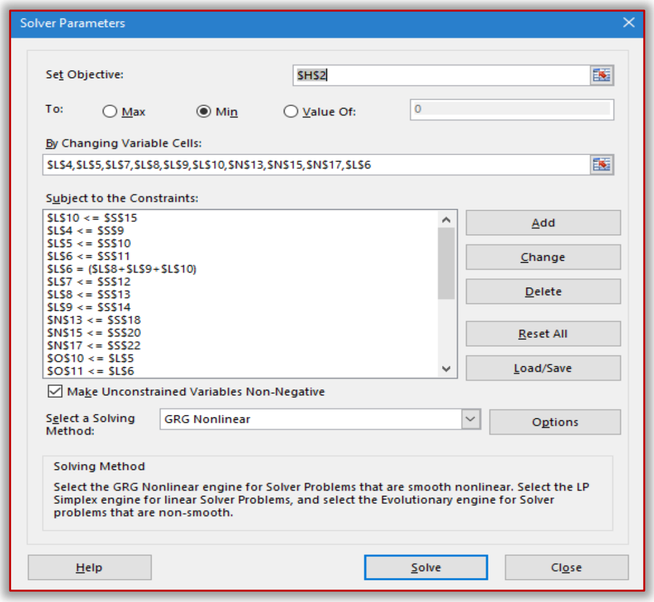

Figure 4: Excel's Solver Add-in, with objective function, design variables and constraints fully imputed.

Clicking the "Solve" button at the end of the dialogue box led to the software processing the optimization problem. After a few minutes, the new values of the cost objective function and design variables were obtained and recorded.

RESULTS AND DISCUSSION

This consisted of the cost optimization of a reinforced concrete tank with known dimensions. The cost, dimensions and reinforcement areas of the tank and their resulting values after cost optimization are shown in Table 1.

Table 1: Design case study of a RC water tank under cost optimization.

Parameters	Initial Values	Optimized Values
l_T	5000	2322.39
b_T	1000	1689.21
h_T	1850	1528.869
t_{SW}	200	100
h_{TS}	100	100
h_{SW}	1500	1265.549
h_{BS}	250	163.320
A_{TS}	200	100
A_{SW}	10721.1	10000
A_{BS}	1679.84	1500
Capacity (litres)	4000	
V_W (m^3)	4.14	3.999
Cost	489128.302	393536.265
Gain	95592.037	
Gain (%)	19.543	

A cost savings of 95592.037 naira (19.543%) was made through the cost optimization process. Whilst there was an overall reduction in all the tank's parameters, the width of the tank (b_T) was increased from 1000 mm to 1689.21 mm. The volume of water present in the tank after optimization approximately equals the design capacity of the tank.

Comparison of Select Model Reinforced Concrete Tanks

Three tanks of increasing capacities: 8000, 12000 and 18000 liters were designed and set up for cost optimization. The results are shown on Table 2, 3 and 4.

From the below tables, there is a steady decline in the gains from cost optimization of the tanks as the capacity increases. As the tank capacity rises from 8000 to 12000 to 18000 liters, the gain (%) reduces from 37.07 to 33.48 to 10.03% respectively.

Table 2: Cost optimization results for Tank A (8000 liters).

Tank A		
Parameters	Initial Values	Optimized Values
l_T	5000	3107.029
b_T	1500	2485.748
h_T	1800	1575.892
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	1500	1303.896
h_{BS}	200	171.996
A_{TS}	300	497.15
A_{SW}	9057.56	5890.54
A_{BS}	2101.88	1776.45
Capacity (litres)	8000	
V_W (m^3)	8.46	7.999
Cost	487144.937	306556.647
Gain	180588.29	
Gain (%)	37.071	

Table 3: Cost optimization results for Tank B (12000 liters).

Tank B		
Parameters	Initial Values	Optimized Values
l_T	5000	3462.435
b_T	2000	2756.325
h_T	1800	1834.298
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	1500	1544.806
h_{BS}	200	189.492
A_{TS}	400	551.265
A_{SW}	9057.56	6629.04
A_{BS}	2301.88	2181.04
Capacity (litres)	12000	
V_W (m^3)	11.985	12
Cost	530000.36	352534.926
Gain	177465.434	
Gain (%)	33.484	

Table 4: Cost optimization results for Tank C (18000 liters).

Tank C		
Parameters	Initial Values	Optimized Values
l_T	5000	4367.874
b_T	2300	3000
h_T	2350	1888.858
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	2000	1638.858
h_{BS}	250	150
A_{TS}	460	600
A_{SW}	13323.4	11459
A_{BS}	2159.95	2088.83
Capacity (litres)	18000	
V_W (m^3)	18.8	18.000
Cost	439580.867	395467.817
Gain	44113.05	
Gain (%)	10.035	

Another trend is the consistent increase in cost that was also matched by an increase in the optimized cost as well.

The width of the tank (b_T) (as shown in Figure 1) consistently increases for all tanks after cost optimization as the other geometric parameters of the tank reduce.

CONCLUSIONS

The design case study was carried out in order to improve the cost-efficiency of a reinforced concrete tank with predefined dimensions. Following the cost optimization process, a significant cost reduction of 95,592.037 naira was achieved, representing a significant 19.54% decrease in overall expenditure.

Various parameters governing the tank's design were reduced during the optimization process, with the exception of the tank's width (referred to as b_T), which increased from 1000 mm to 1689.21 mm. As expected, the volume of water contained within the tank after optimization closely matched the tank's original design capacity.

The investigation was expanded to three reinforced concrete tanks, each with a capacity of 8000, 12000, and 18000 liters, respectively. These tanks went through the same cost-cutting procedure.

A significant cost reduction of 37.07% was achieved for Tank A (8000 liters), resulting in a significant financial gain of 180,588.29 naira. Similarly, the cost of Tank B (12000 liters) was reduced by 33.48%, resulting in a significant gain of 177,465.434 naira. Tank C (18000 liters) achieved a less significant cost reduction of 10.03%, resulting in a gain of 44,113.05 naira.

As tank capacity increases, this data shows a trend of diminishing returns in cost optimization. It was consistently observed that as tank capacity increased, so did the cost of tank construction. Furthermore, the width of the tank (b_T) increased consistently across all tanks during the cost optimization process, while other geometric parameters decreased.

In summary, the study's findings show that cost optimization resulted in significant cost savings in all cases, albeit with diminishing returns as tank capacity increased. Furthermore, during the optimization process, the expansion of the tank's width emerged as a consistent design trend.

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References

[1] EuroCode 2. (2004). "Design of concrete structures - Part 1-1: General rules and rules for buildings."
[2] Hasan, J. M. (2011). Economical Design of Water Concrete Tanks. European Journal of Scientific Research, Vol.49 No.4 (2011), pp. 510-520.
[3] Jeluši˘c, P. (2022). Cost Optimization of Reinforced Concrete Section According to Flexural Cracking. Modelling, volume 3, pages 243–254
[4] Manning, G. P. (1973). Reinforced Concrete Reservoirs and Tanks, 1st ed. London.
[5] Martínez-Martín, F. J., Yepes, V., González-Vidosa, F., Hospitaler, A., Alcalá, J. (2022). Optimization Design of RC Elevated Water Tanks under Seismic Loads. Applied Sciences, 12, 5635
[6] Salam, J. H. and Badaruzzama, W. H. W. (2011). Cost Optimisation of Water Tanks Designed According to the ACI And Euro Codes. Proceedings of the Engineering Postgraduate Conference
[7] Saxena, K. C. and Adeli, H. (1987). Cost Optimization of Intze Tanks on Shafts Using Nonlinear Programming. Engineering. Optimization, Vol.10, No.4.
[8] Tan, G. H. (1993). Design of Reinforced Concrete Cylindrical Water Tanks for Minimum Materials Cost. Computers and Structures, Vol.48, No.5.

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