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Optimization of Water Tank

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***Abstract**:*
In general there are three kinds of water tanks-tanks resting on ground Underground tanks and elevated tanks. Here we are studying only the tanks resting on ground like clear water reservoirs, settling tanks, aeration tanks etc. are supported on ground directly. In the design and are compared considering the total cost of the tank. These water tanks are subjected to the different capacity and dimensions. As an objective function with the properties of tank that are tank capacity, width &length etc.
The paper gives idea for safe design with minimum cost of the tank and give the designer the relationship curve between design variable thus design of tank can be more economical, reliable and simple. The paper helps in understanding the design philosophy for the safe and economical design of water tank. The wall of tanks subjected to pressure and the base is subjected to weight of Water. In below paper, reinforced concert resting on ground monolithic with the base are design and their results are made optimum

***Keywords**: Optimization of Steel, Economic design, Water Tank*

1. Introduction

Since time it has been seen that man tries to find easiest at the same time most effective method to solve the problem. So we structural engineers also not different in this idea of doing things, we want to design the structural systems to satisfy safety, functional and aesthetic requirement in the most effective manner. A structural engineer has to go through repetitive calculations and it is very tedious task. A little change in the Requirement or design parameter which may also be due to actual site conditions. Necessitates the repetition of the complete analysis and design procedure and that of drafting. They are designed as crack free structures to eliminate any leakage A crack width of 0.1mm has been accepted as permissible value in liquid retaining structures. While designing liquid retaining structures recommendation of "Code of Practice for the storage of Liquids- IS3370 (Part I to IV)" should be considered reinforcement is recommended as:

- For thickness ≤100 mm = 0.3 %
- For thickness ≤450 mm = 0.2%
- For thickness between 100 mm to 450 mm = varies linearly from 0.3% to 0.2%

It is also desirable that longer side should not be greater than twice the smaller side drafting is the most important activity in the design process because it convey the structural engineer's idea to construction engineer who actually executes the work in the site, or in the other word it's a language with which the people at site are communicated with, to carry out the work.

Liquid retaining structure is a general term applied to underground thanks on the ground level over head tanks, reservoir and even dams. They are used to store water, liquid petroleum and chemical etc. A liquid containing structure can have a circular shape of rectangular shape; it can be built below or above the ground level. A reinforced concrete tank is very useful structure which is meant for the storage of water which is very common and also for swimming, sedimentation and for such similar purpose. Large capacity tanks will be built on the ground level and a tank is supported on the base slab.

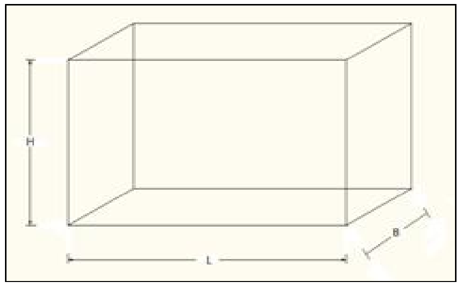


Figure 1: Rectangular water tank

2. Water Tank in General

The water tank is used to store water to tide over the daily requirements. Water tanks can be of different capacity depending upon the requirement. Water tanks can be of different capacity depending upon the requirement of consumption. There different type of water tank depending upon the shape, position with respect to ground level etc. In general water tanks can be tanks, resting on ground, elevated tanks, and underground tanks. From the shape point of view water tank may be of several types

- Circular tanks
- Circular tanks with conical bottoms
- Rectangular tanks

2.1. Circular tanks

Circular tanks are usually good for very larger storage capacities the side walls are designed for circumferential hoop tension and bending moment, since the walls are fixed to the floor slab at the junction. The co-efficient recommended in IS 3370 part 4 is used to determine the design forces. The bottom slab is usually flat because it's quite economical.

2.2. Conical or funnel shaped tank

This tank is best in architectural feature and aesthetic this tank has another important advantage that its suitable for high staging the tank's hallow shaft can be easily built. It can be economical and rapidly constructed using slip form processing of casting. They can also be built using pre-cast concrete elements.

2.3. Rectangular tanks

The walls of Rectangular tank are subjected to bending moments both in horizontal as well in vertical direction. The analysis of moment in the wall is difficult since water pressure results in a triangular load on them. The magnitude of the moment will depend upon the several factors such as length, breadth and height of tank, and conditions of the support of the wall at the top and bottom edge. If the length of the wall is more in compression to its height the moment will be mainly in vertical direction i.e. the panel will bend as a cantilever. If, however, height is larger in comparison to length, the moments will be in horizontal direction, and the panel will bend as a thin slab supported on the edges. For intermediate condition bending will take place both in horizontal as well as in vertical direction. In addition to the moments, the walls are also subjected to direct pull exerted by water pressure on some portion of side walls. The wall of the tank will thus be subjected to both bending moment as well as direct tension.

The aim of the work can be started as follows: the analysis of water tank is carried out considering the side wall as simply supported slabs and optimum design values is introduced by means of N Pandian method.

2.4. Methodology

- The mathematical formulas are taken from the N Pandian method, considering the wall as slab. The quantity of steel is reduced, the constant values for the formulas are taken from N Pandian principle and the minimum solutions are obtained.
- Computer program implementation is done using MATLAB software, for the theoretical design formulation presented above. The general program is written in order to solve the n number of numerical problems.
- Mathematical formulas of optimization based on design; example of optimum value along with normal design values are incorporated

3. Design Principle of Rectangular Water Tank

3.1. Problem

A rectangular water tank with open top is required to store 24000liters of water. The dimension of tank may be taken as 4m x 3m x 2m. The tank walls rest on the base slab. Design the side walls and base slab of tank using M-20 concrete and fe415 grade steel.

3.2. Design of 4m long wall

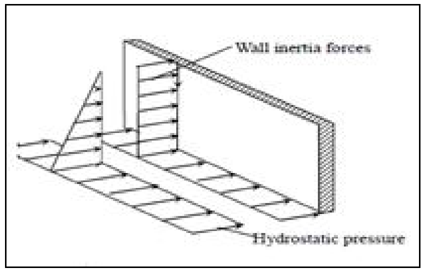


Figure 2: side wall of tank

Static and dynamic pressure distributions for rectangular tank wall are shown in Figure 2 the water pressure is taken as uniformly distributed load
L = 4m
Depth of slab
d = span/26
d = 153.84mm
Assume Effective depth (d) = 204 mm
Overall depth of the slab 'D' = 240 mm
Clear cover = 20 mm
Effective span = l_{ef}= 4.17 m
Assuming Bar diameter (main steel) d = 16 mm ϕ
Assuming dia of bar for distribution steel = 10mm ϕ

Load calculation:-

- Dead load = DL = 0.24×25 = 6 kN/m
- Water pressure = WP = 9.81x2x1.5 =29.43 kN.m
- Total load = w = 35.43 kN/m
- Factored load (Wu) = W×1.5 = 35.43 ×1.5 = 53.145 kN/m

Ulimate moment and shear force

- Mu('-'ve)=1.5(wl^2/10)
- Mu('-'ve)=1.5(35.43 $(4.17)^2$/10)
- Mu('-'ve)= 93.75 kN-m
- Mu('+'ve)=1.5(wl^2/12)
- Mu('+'ve)=1.5(35.43 $(4.17)^2$/12)
- Mu('+'ve)= 77.01 kN-m
- Vu=1.5x0.6(w)L
- Vu=1.5x0.6(35.43)4.17
- Vu= 132.93 kN

Check for depth for negative moment

- $d_{req} = (M_u \text{ X } 10^6/(0.138 \text{ X } f_{ck} \text{ X } b))^{1/2}$
- $d_{req} = (93.75 \text{ X } 10^6/(0.138 \text{ X } 20 \text{ X } 1000))^{1/2}$
- d_{req} = 184.30 mm < d_{pro}=204 mm
- Hence section is under reinforced

Main reinforcement for negative moment

$A_{st\ req} = 0.5 \text{ X } f_{ck} / f_y \text{ X } (1 - (1 – (4.6 \text{ X } M_u \text{ X } 10^6)/(f_{ck} \text{ X } bd^2))^{(1/2)}) \text{ X } bd$
$A_{st\ req} = 0.5 \text{ X } 20 / 415 \text{ X } (1 - (1 – (4.6 \text{ X } 93.75 \text{ X } 10^6)/(20 \text{ X } 10^3 \text{X} 160^2))^{(1/2)}) \text{ X } 1000\text{X}160$
$A_{st\ req} = 1547.3\ mm^2$
Using 16 mm ϕ spacing is
Spacing, S = (Π X d^2 /4)/ $A_{st.}$
S = (Π X 16^2 /4)/ 1749.46
S = 130 mm c/c
Hence provide 16mm diameter bars (main steel) @ spacing of 130 mm c/c
∴ Area provided $A_{stprov.}$ = (b X Π X d^2 /4)/ S
$A_{stprov.}$ = (1000 X Π X 16^2 /4)/ 130
$A_{stprov.}$ = 1546.83 mm^2
No. of bars = 2/0.13 = 16 no.

Check for depth for positive moment

- $d_{req} = (M_u X 10^6/(0.138 X f_{ck} X b))^{1/2}$
- $d_{req} = (77.01 X 10^6/(0.138 X 20 X 1000))^{1/2}$
- $d_{req} = 167.03$ mm < d_{pro}=204 mm
- Hence section is under reinforced

Main reinforcement for positive moment

$A_{st\ req} = 0.5 X f_{ck} / f_y X (1 - (1 – (4.6 X M_u X 10^6)/(f_{ck} X bd^2))^{(1/2)}) X bd$
$A_{st\ req} = 0.5 X 20 / 415 X (1 - (1 – (4.6 X 77.01 X 10^6)/(20 X 10^3 X160^2))^{(1/2)}) X$
1000X160
$A_{st\ req} = 1391.63$ mm^2
Using 16 mm ϕ spacing is
Spacing, S = (Π X d^2 /4)/ $A_{st.}$
S = (Π X 16^2 /4)/ 1391.63
S = 130 mm c/c
Hence provide 16mm diameter bars (main steel) @ spacing of 150 mm c/c
∴ Area provided $A_{stprov.}$ = (b X Π X d^2 /4)/ S
$A_{stprov.}$ = (1000 X Π X 16^2 /4)/ 150
$A_{stprov.}$ = 1340.41 mm^2

Distribution steel

- Area of distribution steel =0 .3 % of Gross Area of slab
- Area of distribution steel = 720 mm^2
- No. of bars = 4/0.1 = 40 no.

Deign of 3m wall

L = 3m
Depth of slab
d = span/26
d = 115.38mm
Assume Effective depth (d) = 160 mm
Overall depth of the slab 'D' = 200 mm
Clear cover = 20 mm
Effective span l_{ef} = 3.17 m
Assuming Bar diameter (main steel) d = 16 mm ϕ
Assuming dia of bar for distribution steel = 10mm ϕ

Load calculation:-

- Dead load = DL = 0.2×25 = 5 kN/m
- Water pressure = WP = 9.81x2x2 =39.24 kN.m
- W = 44.24 kN/m
- Factored load (Wu) = W×1.5 = 44.24×1.5 = 66.36 kN/m

Ultimate moment and shear force

- Mu ('-'ve)=1.5(wl^2/10)
- Mu ('-'ve)=1.5(44.24 (3.17)^2/10)
- Mu ('-'ve)= 66.26 kN-m
- Mu('+'ve)=1.5(wl^2/12)
- Mu('-'ve)=1.5(44.24(3.17)^2/12)
- Mu('+'ve)= 55.22 kN-m
- Vu=1.5x0.6(w)L
- Vu=1.5x0.6(44.24)3.17
- Vu= 125.82 kN

Check for depth for negative moment

- $d_{req} = (M_u X 10^6/(0.138 X f_{ck} X b))^{1/2}$
- $d_{req} = (66.26 X 10^6/(0.138 X 20 X 1000))^{1/2}$
- $d_{req} = 154$ mm < d_{pro}=160 mm
- Hence section is under reinforced

Main reinforcement for negative moment

$A_{st\ req} = 0.5 X f_{ck} / f_y X (1 - (1 – (4.6 X M_u X 10^6)/(f_{ck} X bd^2))^{(1/2)}) X bd$

$A_{st\ req} = 0.5 X 20 / 415 X (1 - (1 – (4.6 X 66.26 X 10^6)/(20 X 10^3 X160^2))^{(1/2)}) X$ 1000X160

$A_{st\ req} = 1402.89\ mm^2$

Using 16 mm ϕ spacing is

Spacing, $S = (\Pi X d^2 /4)/ A_{st.}$

$S = (\Pi X 16^2 /4)/ 1402.89$

S = 140 mm c/c

Hence provide 16mm diameter bars (main steel) @ spacing of 140 mm c/c

∴ Area provided $A_{stprov.} = (b X \Pi X d^2 /4)/ S$

$A_{stprov.} = (1000 X \Pi X 16^2 /4)/ 140$

$A_{stprov.} = 1436.36\ mm^2$

No. of bars = 2/0.14 = 15 no.

Check for depth for positive moment

- $d_{req} = (M_u X 10^6/(0.138 X f_{ck} X b))^{1/2}$
- $d_{req} = (55.22 X 10^6/(0.138 X 20 X 1000))^{1/2}$
- $d_{req} = 150.65\ mm < d_{pro}=190\ mm$
- Hence section is under reinforced

Main reinforcement for positive moment

$A_{st\ req} = 0.5 X f_{ck} / f_y X (1 - (1 – (4.6 X M_u X 10^6)/(f_{ck} X bd^2))^{(1/2)}) X bd$

$A_{st\ req} = 0.5 X 20 / 415 X (1 - (1 – (4.6 X 55.22 X 10^6)/(20 X 10^3 X160^2))^{(1/2)}) X$ 1000X160

$A_{st\ req} = 1306.11\ mm^2$

Using 16 mm ϕ spacing is

Spacing, $S = (\Pi X d^2 /4)/ A_{st.}$

$S = (\Pi X 16^2 /4)/ 1642.19$

S = 160 mm c/c

Hence provide 16mm diameter bars (main steel) @ spacing of 140 mm c/c

∴ Area provided $A_{stprov.} = (b X \Pi X d^2 /4)/ S$

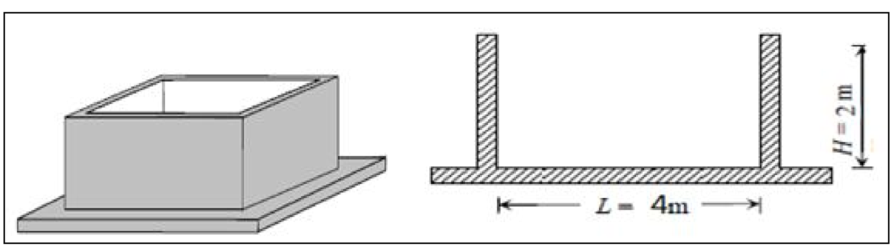
$A_{stprov.} = (1000 X \Pi X 16^2 /4)/ 140$

$A_{stprov.} = 1256.63\ mm^2$

Distribution steel

- Area of distribution steel =0 .3 % of Gross Area of slab
- Area of distribution steel = 600 mm^2
- No. of bars = 3/0.13 = 23 no.

Deign of base slab



L = 4m

Effective length = 4+(0.25x2) = 4.5m

Depth of slab

d = span/26

d = 153.84mm

Assume Effective depth (d) = 195 mm

Overall depth of the slab 'D' = 230 mm

Clear cover = 20 mm

Assuming Bar diameter (main steel) d = 16 mm ϕ

Assuming dia of bar for distribution steel = 10mm ϕ

Load calculation:-
Long Wall load = (4×0.24x2x25)2 = 96 kN
Short wall load = (3x2x0.24x25)2 = 72 kN/
Water load = 4x3x2x10 =240kN kN
Base slab = 4.5x3.5x0.23x25 = 90.56 kN
P = 498.56 kN
Pressure = P/ A
Where A = 4.5x3.5
= 498.56 / 4.5x3.5
= 31.65 kN/m^2
S B C = 180kN/m^2
Calculating bending moment
BM = 62.45 kN –m
Mu = 1.5 x 62.45
= 93.67 kN.m

Check for depth

- $d_{req} = (M_u \times 10^6/(0.138 \times f_{ck} \times b))^{1/2}$
- $d_{req} = (93.67 \times 10^6/(0.138 \times 20 \times 1000))^{1/2}$
- $d_{req} = 184$ mm < d_{pro}=195 mm
- Hence section is under reinforced

Main reinforcement for negative moment
$A_{st\,req} = 0.5 \times f_{ck} / f_y \times (1 - (1 - (4.6 \times M_u \times 10^6)/(f_{ck} \times bd^2))^{(1/2)}) \times bd$
$A_{st\,req} = 0.5 \times 20 / 415 \times (1 - (1 - (4.6 \times 93.67 \times 10^6)/(20 \times 10^3 \times 1195^2))^{(1/2)}) \times 1000 \times 195$
$A_{st\,req} = 1598.92$ mm^2
Using 16 mm ϕ spacing is
Spacing, $S = (\Pi \times d^2 /4)/ A_{st.}$
$S = (\Pi \times 16^2 /4)/ 1598.92$
S = 125 mm c/c
Hence provide 16mm diameter bars (main steel) @ spacing of 125 mm c/c
∴ Area provided $A_{stprov} = (1000 \times \Pi \times d^2 /4)/ S$
$A_{stprov.} = (1000 \times \Pi \times 16^2 /4)/ 125$
$A_{stprov} = 1608.49$ mm^2
No. of bars = 4/0.125 = 32 no.

Distribution steel

- Area of distribution steel =0 .12 % of Gross Area of slab
- Area of distribution steel = 585 mm^2
- No. of bars = 2/0.15 = 14 no.

4. Optimization Methods

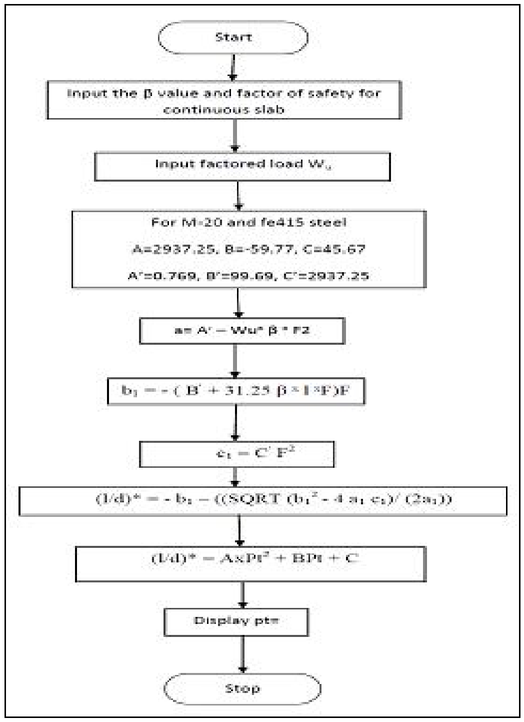
Optimization is the selection of a best element (with regard to some criteria) from some set of available alternatives. In the simplest case, an optimization problem consists of maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing the value of the function. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. The existence of optimization methods can be traced to the days of Newton, Lagrange, and Cauchy. The development of differential calculus methods for optimization was possible because of the contributions of Newton and Leibnitz in calculus. The foundation of calculus of variations, which deals with the minimization of functions, was laid by Bernoulli, Euler, Lagrange, and Weistrass. The method of optimization for constrained problems, which involve the addition of unknown multipliers, became known by the name of its inventor, Lagrange. Cauchy made the first application of the steepest descent method to solve unconstrained optimization problems. By the middle of the twentieth century, the high-speed digital computers made implementation of the complex optimization procedures possible and stimulated further research on newer methods. Further, Spectacular advances followed producing a massive literature on optimization techniques. This advancement also resulted in the emergence of several well defined new areas in optimization theory. The necessity to optimize more than one objective or goal while satisfying the physical limitations led to the development of multi-objective programming methods. Simulated annealing, genetic algorithms, and neural network methods represent a new class of mathematical programming techniques that have come into prominence during the last decade. Simulated annealing is analogous to the physical process of annealing of metals and glass. The genetic algorithms are search techniques based on the mechanics of natural selection and natural genetics. Neural network methods are based on solving the problem using the computing power of a network of interconnected 'neuron' processors. In general, optimization is desired to achieve the best solution among all the available solutions taking into account all the necessary aspects of a system or a problem in hand.

As the construction materials are getting extinct day by day it is important for the structural engineers to concentrate on optimum designing of the structures. With a special reference to structural problem it is always one of the minimizing or maximizing a certain specific characteristic of structural system like cost, weight, performance capability of the system depends on the problem. This to be achieved without sacrificing any of the functional requirements like stresses deformation and load capabilities. Thus, the optimization procedure must only be used to those problems where there is a definite need of achieving a quality product or competitive product.

4.1. N Pandian Method

This optimization method is applicable for slab optimization it is the direct method to minimize the steel volume of concrete and weight of structure. Pandian N gives the values for the optimum design of retaining structure under static loading (gravity loads)

Flow Chart



<u>Stipulation for N pandian method</u>

Capacity of water tank : 24000 liters

Simply supported $\beta = 0.125$ factor of safety = 1

Cantilever $\beta = 0.5$

Continuous $\beta = 0.1$

For M_{20} concrete and Fe415 HYSD bars

$A' = 0.769$

$B' = 99.69$

$C' = 2973.25$

$A = 30.876$

$B = -59.77$

$C = 45.67$

STEP 1:

$a_1 = A' - W_u{}^x \beta {}^x F^2$ [8]

$b_1 = -(B' + 31.25 \beta {}^x l {}^x F)F$ [8]

$c_1 = C' F^2$ [8]

STEP 2:

$(l/d)^* = - b_1 - (SQRT(b1_2 - 4a_1c_1)/(2a_1))$ [8]

STEP 3:

$(l/d)^* = AxPt^2 + BPt + C$ [8]

Optimum solution for the example solved in chapter-3 for long wall short wall and base slab
Long wall
a_1 = -5.22
b_1 = -151.78
c_1 = 5024.79
(l/d)* = 117.51
Pt* = 0.76%
Short wall
a_1 = -6.71
b_1 = -146.26
c_1 = 5024.97
(l/d)* = 116.77
Pt* = 0.77%
Base slab
a_1 = -4.21
b_1 = -151.61
c_1 = 5024.79
(l/d)* = 112.65
Pt* = 0.72%
N Pandian gives the simple method for the optimization of slab optimum design of retaining structure under static

4.2. C. N Pandian Method
This optimization method is applicable only for slab optimization it is the direct method to minimize the total cost
Optimization of one way slab design
Simply supported β = 0.125 factor of safety = 1
Cantilever β = 0.5
Continuous β = 0.1
For M20 concrete and Fe415 HYSD bars
A′ = 0.769
B′ = 99.69
C′ = 2973.25
A = 30.876
B = -59.77
C = 45.67
STEP 1:
a1 = A′ – Wu^x β ^{x} F2
b1 = - (B′ + 31.25 β ^{x} l ^{x}F)F
c1 = C′ F2
STEP 2:
(l/d)* = - b1 – ((SQRT(b12 - 4 a1 c1)/ (2a1))
STEP 3:
(l/d)* = AxPt2 + BPt + C

Optimum solution for the example solved for long wall short wall and base slab
Long wall
a1 = -50.8
b1 = -162.07
c1 = 5024.79
(l/d)* = 112.65
Pt = 0.72%
Short wall
a1 = -7.52
b1 = -146.34
c1 = 5024.79
(l/d)* = 118.72
Pt = 0.78%
Base slab
a1 = -4.21
b1 = -151.61
c1 = 5024.79
(l/d)* = 112.65
Pt = 0.72%

5. Steps for the program

The computer program for the project is done using MATLAB version 9.0. The program is written for the normal design and later to optimize the area of steel the optimization method using N Pandian function is called in mat lab to minimize the values.

- User defined material data like span, load and grade of concrete and steel are to be given as input
- The affective depth is calculated and the clear cover and the thickness of the bar is added to effective depth
- Effective span is calculated by adding the effective depth to the span
- Load calculations (g) has to b given as input total weight w and wu are calculated
- Maximum bending moment and shear force has to be calculated
- Check for depth is done using dmin formula if dpro is greater than dmin the depth provided is safe else change the depth
- With the maximum bending moment the area of steel is to b calculated

Consider rectangular water tank
fck = 20 N/mm2
fy = 415 N/mm2
Clear span = 4m
Loads = 25.495 kN/m (triangular load)
The theoretical values of steel obtained for the water tank have been presented in chapter-3, the computer programming based on N pandian of optimization method has been put forward in chapter-5. The number of examples are worked out with the generalized program. Table 6.1. The results obtained for 24000 liter capacity water tank solved in chapter-3

Material	Normal design	Optimum design	Minimum values
AST in mm^2	10480	9620	5970
Steel in kg	684	621	342
Volume of concrete in m^3	9	8.44	7

Table: The results obtained for the example of 240000 liter capacity water tank solved

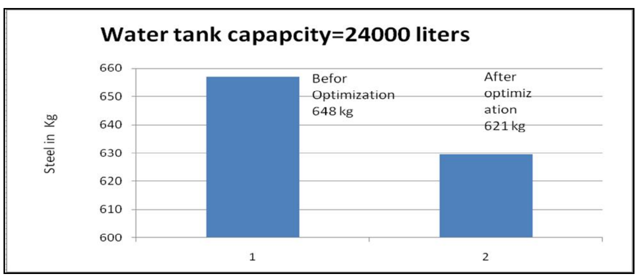


Figure 3: Quantity of steel for tank capacity 24000 liters before and after optimization

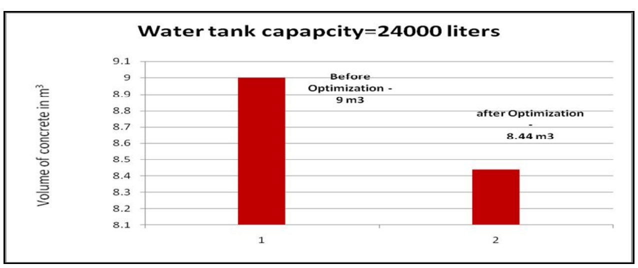


Figure 4: Volume of concrete for tank capacity 24000 liters before and after optimization

In this problem the results are discussed based on the normal design and optimum design of the above tables it shows that the area of steel obtained for optimum design is less than the normal design, the optimization method is applied only for main reinforcement the distribution bars should be provided as per specification. It should be noted that for very large capacity of water tank this optimization technique dose not holds good due to large water pressure.

6. Conclusion

The following conclusion may be made from the recent study:

- It has been observed that the area of steel which we get from optimum design is less than the normal design.
- It has been concluded that the optimization is done for all the parameters considered

- It has been concluded that the results obtained from the optimization method by N Pndian method is capable of obtaining the optimum solution. The present study deals with the minimizing of the area of steel
- It is believed that the present results of optimization values are optimized

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