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Research Article

COST MINIMIZATION OF REINFORCED CONCRETE ELEVATED WATER TANK USING OPTIMIZATION TECHNIQUES

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ABSTRACT

In general the optimization techniques enable designers to find the best economical design for the structure under consideration. In this work Cost Minimization of RC structure using optimization techniques such as fmincon SQP algorithm is presented. The cost of Reinforced Concrete (RC) structures is influenced by several cost items including the cost of concrete and reinforcement. Therefore in case of RC structures, the minimum weight design is not necessarily the same as the minimum cost design. In fact, for RC structures the optimum cost design is a compromise between the consumption of concrete, reinforcement which minimizes the total cost of the structure and satisfies the design requirements. The structure is designed economically without impairing the functional purposes of the structural elements is supposed to serve and not violating provisions given in IS456-2000,IS 2911 (part I)-2010 and IS 3370-2009 using the cross-sectional dimensions and area of longitudinal steel as design variables. An fmincon solver is incorporated with a cost function and constraint function as an alternative to traditional methods for cost optimization of RC elements. An fmincon SQP Algorithm Program has been developed for the cost optimization of reinforced concrete structure using MATLAB software. In order to validate the working of algorithm and to prove its efficiency simple problems like singly reinforced beam and axially loaded column have been solved and the results were studied. Then Optimization of Elevated Circular water Tank is started by varying the D/H ratio of tank portion. Finally Design Curves were prepared for various capacities of tank vs. Optimum D/H Ratio. In future the optimum D/H ratio for intermediate capacities may be interpolated from design curves.

INTRODUCTION

Optimum design of structures has been the topic of many studies in the field of structural design. A designer's goal is to develop an "optimal solution" for the structural design under consideration. An optimal solution normally implies the most economic structure without impairing the functional purposes the structure is supposed to serve. There are some characteristics of RC structures which make design optimization of these structures distinctly different from other structures. The cost of RC structures is influenced by several cost items including the cost of concrete and reinforcement. Therefore, in case of RC structures, the minimum weight design is not necessarily the same as the minimum cost design. In fact, for RC structures the optimum cost design is a compromise between the consumption of concrete, reinforcement which minimizes the total cost of the structure and satisfies the design requirements. In the design optimization of RC structures the cross-sectional dimensions of elements and detailing of reinforcement, e.g. size and number of steel bars, need to be determined. Consequently, the number of design parameters that need to be optimized depends on cracking and durability requirements of RC structures. These requirements increases the number of design constraints of the optimization problem of RC structures. The reinforced concrete (RC) elements may be subjected to axial loads, bending moment, shear force. The width and depth of the member and area of longitudinal reinforcement of the sections are taken as the design variables. The optimality criteria (OC) method is applied to minimize the cost of the concrete, steel and formwork for the structure. An expensive and incurs a great amount of time.

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Andres Guerra *et al*. (2002) investigated the "Design optimization of reinforced concrete frames" and presented a novel approach for optimal sizing and reinforcing multi-bay and multi-story RC frames incorporating optimal stiffness correlation among structural members. This paper incorporates realistic materials, forming, and labour costs that are based on member dimensions, and implements a structural model with distinct design variables for each member. The resulting optimal designs show costs savings of up to 23% over a typical design method. Comparison between optimal costs and typical design method costs demonstrates instances where typical design assumptions resulted in efficient structures and where they did not. The formulation, including the structural FEA, the ACI-318-05 member sizing and the cost evaluation, was programmed in MATLAB (Math works, Inc.) and was solved to obtain the minimum cost design using the SQP algorithm implemented in MATLAB's intrinsic optimization function fmincon. A number of fairly simple structural optimization problems were solved to demonstrate the use of the method to achieve optimal designs, as well as to identify characteristics of optimal geometric spacing for these structures.

Govindaraj *et al*. (2004) investigated the "Optimum detailed design of reinforced concrete continuous beams using Genetic Algorithms" based on Indian Standard specifications produced optimum design satisfies the strength, serviceability, ductility, durability and other constraints related to good design and detailing practice. The optimum design results are compared with those in the available literature. An example problem is illustrated and the results are presented. It is concluded that the proposed optimum design model yields rational, reliable, economical and practical designs.

Charles *et al*.(2008) did research on "Flexural Design of Reinforced Concrete Frames Using a Genetic Algorithm" and presented a design procedure implementing a genetic algorithm is developed for discrete optimization of reinforced concrete frames RC-GA. The design procedure conforms to the American Concrete Institute ACI Building code and commentary. The objective of the RC-GA procedure is to minimize the material and construction costs of reinforced concrete structural elements subjected to serviceability and strength requirements described by the ACI Code. Examples are presented demonstrating the efficiency of the RC-GA procedure for the flexural design of simply-supported beams, uni axial columns, and multi-story frames.

Sharafi *et al*.(2009) investigated the "Heuristic Approach for Optimum Cost and Layout Design of 3D Reinforced Concrete Frames" and presented a new methodology for cost optimization of the preliminary layout design of three-dimensional (3D) reinforced concrete (RC) frames. This approach is capable of being easily employed for the optimal layout design of a realistic large RC structure that accounts for constraints imposed by design standards. The new approach considers modelling, structural analysis, concrete member design, and discrete optimization together with data on the cost of systems and materials. Using the cross-sectional action effects as design variables, a heuristic cost function is presented as an alternative to traditional cost functions for layout optimization of RC structures. Using the cost function, a structural optimization problem is formulated for column layout design of 3D RC frames.

Hasan Jasim Mohammed *et al*. (2011) proposed "The optimization method to the structural design of concrete rectangular and circular water tanks" .The total cost of the tank as an objective function with the properties of the tank that are 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 developed to solve numerical examples using the IS: 456-2000 code equations .the results shown that the tank capacity taken up the minimum total cost of the rectangular tank and taken down for circular tank. The tank floor slab thickness taken up the minimum total cost for two types of tanks. The unit weight of water in tank taken up the minimum total cost of the circular tank and taken down for rectangular tank

Prasad *et al*. (2014) did research on "Effect of Variation of Diameter to Height (D/H) Ratio on the Cost of Intze Tank Using IS 3370:1965 and IS 3370:2009". The code of practice for the design of reinforced concrete structures for the storage of liquids, IS 3370:1965(Part I and II), has been revised recently in 2009. The revision incorporates the Limit States Design philosophy. Until recently, liquid retaining structures, such as water tanks, were designed using working stress design method, prescribed in IS 3370 (part 2):1965. This had necessitated thicker concrete sections to limit the tensile stresses in concrete. In the revised code, the old working stress design provisions are retained as an alternative to limit states design. It would be interesting to study the relative economics of using these two different design philosophies prescribed in the revised code. This is explored in the present study, with reference to intze tank supported on circular shaft.

Snehal Wankhede *et al*. (2015) proposed "Optimization of water storage tank". In the present study cost optimization of elevated circular water tank is presented. The objective is to minimize the total cost in the design process of the elevated circular water tank considering the cost of materials. The design variables considered for the cost minimization of the elevated water tank, are thickness of the wall, floor slab depth, floor beam depth (i. e. X1, X2, X3 resp.) Design constraints for the optimization are considered according Standard Specifications. The optimization problem is characterized by having a combination of continuous, discrete and integer sets of design variables. For An optimization purpose MATLAB Software with SUMT (Sequential Unconstrained Minimization Technique) is used that is capable of locating directly with high probability the minimum design variables.

Bhandari *et al*. (2015) investigated "Economic Design of Water Tank of Different Shapes With Reference To IS: 3370 2009". The conventional method of designing water tanks which is working stress method outlined in the previous version of IS: 3370 1965 is irrational and leads to relatively thicker sections with a substantial amount of reinforcement. Limit state method which is widely used has been recently adopted in the new version of IS 3370-2009 concrete structures for storage of liquids - code of practice. For quick cost prediction of tanks, this study therefore examines the cost effectiveness in terms of amount of materials and formwork used for Circular, Square and Rectangular overhead water tanks each of three capacities of 100kl, 150kl, 200kl and draw reasonable inferences on tank's shape design effectiveness. Each water tank was designed by Limit State method and then the crack width was checked by limit state of serviceability IS 3370 (2009).

METHODOLOGY

The cost function which is to be minimized is termed as the objective function and the conditions that the objective function should satisfy is termed as constraint function .The objective function and constraint function is to be formulated for various members such as axially loaded column, singly reinforced beam, pile cap. The total cost of the member consists of cost of concrete, cost of reinforcement, and cost of formwork. The optimum cost of member will be derived from member dimensions and Reinforcement obtained by constrained nonlinear minimization using fmincon solver. On the other hand conventional design of the structure using Limit State method concept as per Indian Code (IS 456-2000 for axially loaded column, singly reinforced beam, IS 2911(I)-2010 for pile cap, IS 3370-2009 for water tank) to be done and the cost of the structure will be calculated. The total cost in both cases will be compared and percentage of cost saving is calculated.

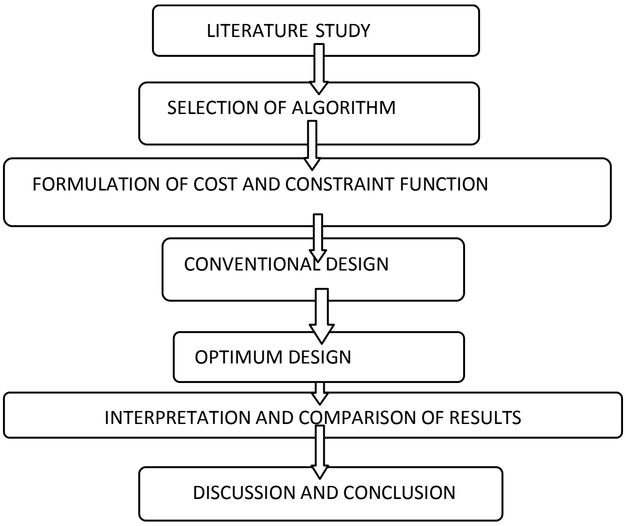

Fig 1 Flowchart of Methodology

Optimization Techniques

Optimization is a branch of mathematics which is concerned with obtaining the conditions that give the extreme value of function under given circumstances. An optimization problem can be mathematically stated as follows:

Find $\boldsymbol{X} = (x1, x2, \ldots, an)$ which minimizes $if(\boldsymbol{X})$ $I = 1, 2, \ldots,$
Subject to
$g\,j(\boldsymbol{X}) \leq 0, j = 1, 2, \ldots, ng$
$He(\boldsymbol{X}) = 0, k = 1, 2, \ldots, ne$
$x^l_m \leq x_m \leq x^u_m = 1, 2, \ldots, ns$

Where X is the vector of n design variables, $if(\boldsymbol{X})$ is an objective or merit function, $gj(\boldsymbol{X})$ and $he(\boldsymbol{X})$ are the inequality and the equality constraints, respectively. These constraints represent limitations on the behavior or performance of the system. Therefore, they are called behavioral or functional constraints. Side constraints restrict the acceptable range of potential solutions of the problem based on non-behavioral constraints. In this expression x^l_m, x^u_m is the lower and upper limits on the design variable, respectively. In the above expressions ng, ne and ns are the number of objective functions, number of inequality, equality and side constraints, respectively. Depending on the specific choice of design variables, objective functions, and constraints, various types of optimization problems may exist.

Fmincon SQP Algorithm

fmincon SQP methods represent the state of the art in nonlinear programming methods. Schittkowski has implemented and tested a version that outperforms every other tested method in terms of efficiency, accuracy, and percentage of successful solutions, over a large number of test problems. Based on the work of Biggs, Han, and Powell, the method allows one to closely mimic Newton's method for constrained optimization just as is done for unconstrained optimization. At each major iteration, an approximation is made of the Hessian of the Lagrangian function using a quasi-Newton updating method. This is then used to generate a QP subproblem whose solution is used to form a search direction for a line search procedure. The SQP algorithm takes every iterative step in the region constrained by bounds. Furthermore, finite difference steps also respect bounds. Bounds are not strict; a step can be exactly on a boundary. This strict feasibility can be beneficial when your objective function or nonlinear constraint functions are undefined or are complex outside the region constrained by bounds. During its iterations, the SQP algorithm can attempt to take a step that fails. This means an objective function or nonlinear constraint function you supply returns a value of Inf, NaN, or a complex value. In this case, the algorithm attempts to take a smaller step. The sqp algorithm uses a different set of linear algebra routines to solve the quadratic programming subproblem, these routines are more efficient in both memory usage and speed than the active-set routines.

DEMONSTRATION OF WORKING OF ALGORITHM

Optimization of Axially Loaded Column

An axially loaded column subjected to an ultimate load of 1000kN with concrete grade M20 and steel of grade Fe415 was optimized. The details of optimization are given below.
P_u=1000kN, C_c=Rs.3500/m^3, C_s=Rs.60/kg, C_f= Rs.320/m^3

Objective Function

The objective function consists of sum of cost of the concrete, cost of steel reinforcement, and cost of formwork involved in the particular structure

Function = concrete cost+steel cost+formwork cost
Function = $C_c x((bxD-A_{sc})+C_s x\ A_{sc} x\ l\ x\ \dot{\rho}+C_f\, x(2bxD)$;

Design Constraints

Constraints are nothing but conditions which must be satisfied according to relevant Indian Code (IS 456-2000) to arrive the design satisfying both safety and serviceability criteria

1. $Pu<0.4f_{ck}x\ A_{sc}+0.67f_y x\ A_{sc}$% load carrying capacity
2. $A_{sc}>0.8\%\ bxD$ % Minimum Reinforcement
3. $A_{sc}<4\%\ bxD$% Maximum Reinforcement
4. $b/d \leq 1.5\%$ Aspect Ratio

Optimization Process of Column

fmincon solver with SQP algorithm is used to find the constraint and non-linear optimization. The optimized results satisfied all the constraints as per IS456-2000. The optimization process will be terminated when the objective function is non decreasing in feasible directions, to within the default value of function tolerance, and constraints were satisfied (Fig 2).

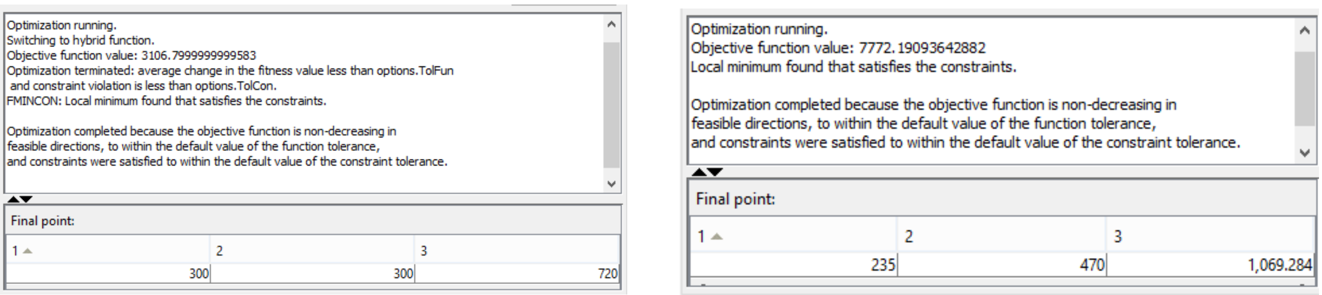

Fig. 2 Optimization Process of Column and Beam

Case	Pu (kN)	f_{ck} (MPa)	f_y (MPa)	Breadth (mm)		Depth (mm)		Area of Steel (mm^2)	
				$b_{con.}$	$b_{opt.}$	$d_{con.}$	$d_{opt.}$	A_{stc}	A_{sto}
1	1000	20	415	275	315	275	315	1465	788
2	1000	25	415	250	290	250	290	1398	660
3	1000	20	250	275	330	275	330	2476	870
4	1000	25	250	250	300	250	300	2380	720

Case	M_u (kNm)	f_{ck} (MPa)	f_y (MPa)	Breadth (mm)		Depth (mm)		Area of Steel mm^2	
				$b_{con.}$	$b_{opt.}$	$d_{con.}$	$d_{opt.}$	A_{stc}	A_{sto}
1	145.00	20	415	300	235	470	470	1002	1128
2	145.00	25	415	300	220	450	440	1020	1140
3	145.00	20	250	300	240	470	500	1663	1603
4	145.00	25	250	300	240	450	480	1694	1626

Table 1 Comparative Results of Size and Reinforcement of Column and beam

S.No	Conventional Cost(Rs.)	Optimized Cost (Rs.)	% saving (P_s)
1	3905	3343	14.30
2	3576	2890	19.18
3	5322	3602	32.31
4	4954	3106	37.30

S.No	Conventional Cost (Rs.)	Optimized Cost (Rs.)	% saving P_s
1	8404	7772	7.52
2	8252	7506	9.04
3	10259	9677	5.71
4	10143	9455	6.78

Table 2 Comparative Results of Cost of Column and Beam

OPTIMIZATION OF ELEVATED CIRCULAR WATER TANK

Brief Background

Water is considered as the source of every creation and is thus a very crucial element for humans to live a healthy life. High demand of Clean and safe drinking water is rising day by day as one cannot live without water. It becomes necessary to store water. Water is stored generally in concrete water tanks and later on it is pumped to different areas to serve the community. Water tanks can be classified as overhead, resting on ground or underground depending on their location. The tanks can be made of steel or concrete. Tanks resting on ground are normally circular or rectangular in shape and are used where large quantities of water need to be stored. Overhead water tanks are used to distribute water directly through gravity flow and are normally of smaller capacity. As the overhead water tanks are open to public view, their shape is influenced by the aesthetic view in the surroundings. Elevated tanks are supported on staging which may consist of solid or perforated masonry walls, R.C.C columns braced together or a thin hollow shaft. The actual tank portion is designed for water pressure, live load and self-weight of different parts. The staging is to resist wind forces and earthquake forces in addition to the forces transferred from tank proper. The foundation slab in such cases, is generally provided as raft or on piles depending upon the soil conditions. Leakage and seepage is a common problem in water retaining structures. To minimize it, impervious concrete of minimum grade M 20 must be used. The design for water retaining components is based upon no crack theory. The following three factors must be considered while designing a R.C.C tank: Strength, Water tightness, Overall stability.

Problem Formulation

To optimize the overhead flat bottomed R.C.C cylindrical water tank to store
The top of the tank is covered with dome.
Height of staging = 12m above the ground level.
Depth of foundation= 2m below ground level
Intensity of wind pressure= 1.5 kPa
Safe bearing capacity of soil = 250 kPa
Adopt M25 grade concrete, Fe 415 grade steel
Cost of concrete= Rs.3500/m^3
Cost of formwork= Rs.320/m^2
Cost of steel= Rs.60/kg

Objective Function

The total cost of the structure consists cost of individual elements like Top dome, Ring beam, Cylindrical wall, Floor slab, bottom Ring beam, Columns, Bracing, Circular Girder and foundation

Constraint Function

- Meridional stress in top dome ,T1 $=\frac{Wu\,R}{1+\cos\theta}<$ Permissible Value
- Hoop stress in top dome $= Wu\,R(\cos\theta \quad \frac{1}{1+\cos\theta})<$ Permissible Value
- Hoop Tension in Ring Beam $F_t = \frac{T1\cos\theta\, D}{2} < 0.7\sqrt{f_{ck}}$
- Ast in Ring Beam, $A_{st,min} = \frac{0.85\,bd}{fy}$
- Hoop tension in cylindrical wall $Ft= \frac{Wu\,H\,D}{2} < 0.7\sqrt{f_{ck}}$
- $A_{st,min}$ in cylindrical wall $A_{st,min} = 0.24\%$

- Depth of floor slab d> $\sqrt{\frac{Mu}{Q\,b}}$
- Effective depth of bottom Ring Beam d> $\sqrt{\frac{Mu}{Q\,b}}$
- Ast in bottom Ring Beam, $A_{st,min} = \frac{0.85\,bd}{fy}$
- Ast in Ring Beam, $A_{st,min} = \frac{0.85\,bd}{fy}$
- Ast $>\rho_{cri}$ (critical steel ratio)
- $P_u < 0.4 f_{ck} x A_c + 0.67 f_y x\ A_{sc}$ % load carrying capacity
- $p/f_{ck} \longrightarrow P_u/f_{ck}\, bxD$ and $M_u/f_{ck}\, bxD^2$
- $(M_{ux}/M_{ux1})^{\alpha} + (M_{uy}/M_{uy1})^{\alpha} < 1$
- $A_{sc} > 0.8\%$ bxd % Minimum Reinforcement
- $A_{sc} < 4\%$ bxD % Maximum Reinforcement
- b/d ≤ 1.5% Aspect Ratio

Table 3 Cost Analysis for D/H ratio =2 and 2.5 (Capacity= 100m^3)

Particulars	Conventional Design	Optimized Design
Top dome	Thickness = 100 mm A_{st}= 300 mm^2	Thickness =100 mm A_{st}= 225 mm^2
Top Ring Beam	165 X 165 mm A_{st}= 180 mm^2	160 X 160 mm A_{st}= 180 mm^2
Cylindrical wall	Thickness=150 mm A_{st}= 360 mm^2	Thickness=125 mm A_{st}= 240 mm^2
Slab	Depth = 300 mm A_{st}= 1438 mm^2	Depth = 270 mm A_{st}= 1600 mm^2
Bottom Ring Beam	300 x 350 mm A_{st}= 4900 mm^2	300 x375 mm A_{st}= 3000 mm^2
Staging column	300 x 300 mm A_{sc} = 720 mm^2	275 x275 mm A_{sc} = 620 mm^2
Bracing	300 x 300 mm A_{st} = 950 mm^2	300 x 300 mm A_{st} = 950 mm^2
Circular Girder	400 x 400 mm A_{st} = 1220 mm^2	400 x 425 mm A_{st} = 1038 mm^2
Annular Raft Slab	Width = 1.4 m Depth =150 mm A_{st} = 450 mm^2	Width = 1.3 m Depth =150 mm A_{st} = 450 mm^2
Total cost	Rs.626090	Rs.568301
% cost saving		9.23%
Dia. of Tank= 6m and Height of tank=3 m		

Particulars	Conventional Design	Optimized Design
Top dome	Thickness = 100 mm A_{st}= 300 mm^2	Thickness =75mm A_{st}= 225 mm^2
Top Ring Beam	160 x 160 mm A_{st}= 180 mm^2	150 x 150 mm A_{st}= 180 mm^2
Cylindrical wall	Thickness=150 mm A_{st}= 360 mm^2	Thickness=100 mm A_{st}= 240 mm^2
Slab	Depth = 300 mm A_{st}= 1438 mm^2	Depth = 270 mm A_{st}= 1600 mm^2
Bottom Ring Beam	300 x 350 mm A_{st}= 4900 mm^2	300 x 400 mm A_{st}= 3915 mm^2
Staging column	300 x 300 mm A_{sc} = 720 mm^2	230 x 230 mm A_{sc} = 620 mm^2
Bracing	300 x 300 mm A_{st} = 950 mm^2	300 x 300 mm A_{st} = 950 mm^2
Circular Girder	400 x 410 mm A_{st} = 1220 mm^2	400 x 450 mm A_{st} = 1038 mm^2
Annular Raft Slab	Width = 1.4 m Depth =150 mm A_{st} = 450 mm^2	Width = 1.4 m Depth =150 mm A_{st} = 450 mm^2
Total cost	Rs.626085	Rs.510163
% cost saving		18.516 %
Dia. of Tank= 6.8m and Height of tank=2.8 m		

Cost Minimization of Water Tank of 100 M^3 Capacity

The cost of tank, 100 m^{3}capacity is optimized by fmincon algorithm. Tank having diameter 6 m, height 3 m and D/H =2, 2.5, 3, 3.5 and 4 were taken for the study. Optimized cost are then compared with Conventional cost. Taking the Dia. of Tank= 6m and Height of tank=3 m

Table 4 Cost Analysis for D/H ratio =3.5 and 4(Capacity= 100m^3)

Particulars	Conventional Design	Optimized Design
Top dome	Thickness=125mm A_{st}= 300 mm^2	Thickness 110 mm A_{st}= 225 mm^2
Top Ring Beam	200 x 200 mm A_{st}= 320 mm^2	175 x 175 mm A_{st}= 320 mm^2
Cylindrical wall	Thickness=140mm A_{st}= 500 mm^2	Thickness=125mm A_{st}= 500 mm^2
Slab	Depth = 300 mm A_{st}= 1740mm^2	Depth = 270 mm A_{st}= 1675 mm^2
Bottom Ring Beam	300 x 385 mm A_{st}= 4900 mm^2	300 x 425 mm A_{st}= 3000 mm^2
Staging column	300 x 300 mm A_{sc} = 1300 mm^2	275 x 275 mm A_{sc} = 820 mm^2
Bracing	300 x 300 mm A_{st} = 950 mm^2	300 x 300 mm A_{st} = 950 mm^2
Circular Girder	400 x 425 mm A_{st} = 1970 mm^2	400 x 425 mm A_{st} = 1038 mm^2
Annular Raft Slab	Width = 1.5 m Depth =160 mm A_{st} = 450 mm^2	Width = 1.4 m Depth =150 mm A_{st} = 450 mm^2
Total cost	Rs.688490	Rs.610347
% cost saving		11.35%
Dia. of Tank= 7.6m and Height of tank=2.1 m		

Particulars	Conventional Design	Optimized Design
Top dome	Thickness=125mm A_{st}= 300 mm^2	Thickness=110 mm A_{st}= 225 mm^2
Top Ring Beam	200 x 200 mm A_{st}= 320 mm^2	190 x 190 mm A_{st}= 320 mm^2
Cylindrical wall	Thickness=125mm A_{st}= 500 mm^2	Thickness=155mm A_{st}= 500 mm^2
Slab	Depth = 300 mm A_{st}= 1740mm^2	Depth = 275mm A_{st}= 1675 mm^2
Bottom Ring Beam	300 x 400 mm A_{st}= 4900 mm^2	300 x 425mm A_{st}= 3000 mm^2
Staging column	300 x 300 mm A_{sc} = 1300 mm^2	275 x 275 mm A_{sc} = 820 mm^2
Bracing	300 x 300 mm A_{st} = 950 mm^2	300 x 300 mm A_{st} = 950 mm^2
Circular Girder	400 x 425 mm A_{st} = 1970 mm^2	400 x 425 mm A_{st} = 1970 mm^2
Annular Raft Slab	Width = 1.5 m Depth =160 mm A_{st} = 450 mm^2	Width = 1.4 m Depth =150 mm A_{st} = 450 mm^2
Total cost	Rs.699584	Rs.633474
% cost saving		9.45%
Dia. of Tank= 8m and Height of tank=2 m		

Fig 3 D/H Ratio vs. Total Cost (100 m^3)

Comparison of Results for Various Capacities of Elevated Circular Water Tank

The variation of % saving of cost with respect to various D/H ratio was plotted against different capacities of water tank (Fig. 4)

Fig 4 D/H Ratio vs. % Saving

Design Curve

The design curve is found that the optimum D/H ratio increases as the capacity of tank increases. But the variation is nonlinear in nature. The optimum D/H ratio for intermediate capacities may be interpolated from design curves

Fig 5 Design Curve Plotted for Optimum D/H Ratio vs. % Capacity

RESULTS AND DISCUSSIONS

- Concrete is a cheap and economical material in resisting compression. Therefore usage of higher grade of concrete and lower grade of steel in axially loaded column members leads to optimized design
- Beams are flexural members, should be capable of resisting both bending tension and bending compression. Therefore usage of higher grades of both concrete and steel materials will lead to optimized solution.
- For the particular capacity of tank total cost decreases with increase in D/H ratio up to certain limit after that cost of the structure increases
- For lower D/H ratio the design was influenced by minimum reinforcement ratio, minimum thickness of members and higher bending moments of cylindrical wall. Therefore the lower D/H ratios gives uneconomical design
- For higher D/H ratios the design was influenced by large bending moments of floor slab and ring beam. Therefore adaptation of higher D/H ratio leads to uneconomical design
- The optimum D/H ratio which gives minimum cost of total structure was found by running fmincon algorithm in MATLAB

CONCLUSION

The most economical design for the problem under consideration can be easily found by running fmincon SQP algorithm in MATLAB software. Apart from the final design the optimum values for preliminary analysis and suitable grades of materials like steel, concrete can also be found to attain cost optimized design. The optimization method adopted in this thesis can also be extended in future for various structures like steel structures, composite structures, prefabricates structures, prestressed concrete structures with some modifications regarding with relevant Indian Standards to cater the needs of present construction industry.

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