Design Optimization of Water-Tank using Artificial Intelligence

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Abstract - *Water-Tanks are structures used for storing water for supplying it to various household, commercial buildings through Water-Pipeline, thus forming an integral part of the Water Distribution System. Water-Tank consists of a storage tank called as Reservoir made of either Steel shells or Reinforced Cement Concrete RCC or composite material. To meet the water requirements for the exponential growing population of India we need to build more Water-tanks in a more efficient and optimal way. The construction of Water-tank is a mammoth task which requires large amount of steel and concrete. The reduction of the amount of steel and concrete to be used in construction of water-tank poses a major challenge for the researchers. This study presents Design Optimization of Reinforced Concrete Circular Water-Tank using Artificial Intelligence. The Water-Tank is designed using IS 3370 which is Indian Standard Code for Design of Liquid Storage Structures. The Concrete and Steel used in Design of WaterTank is taken as M30 and Fe 500 respectively. The Seismic Design of the Water-Tank is done using IS 1893 which is Indian Standard Code for Seismic Design of Structures. The Wind Loads on Water-Tank are calculated using IS 875 Part 3 which is the Indian Standard Code for Design of Structures against Wind Loads. This complete Design of Water-Tank against the Seismic and Wind Loads is coded in Python language. The Total Cost of steel and concrete used in construction of Water-Tank is calculated using the DSR (Delhi Schedule of Rates) 2021. Then we apply the Artificial Intelligence technique using a Meta-Heuristic Algorithm named Simulated Annealing to our program on Design of Water-Tank and Optimize different Parameters such as Ratio of Depth to Diameter of Water-Tank, Thickness of Top-Dome, Thickness of Water-Tank Wall, Thickness of Base-Slab, Depth of Bottom Ring Beam, Width of Bottom Ring Beam, Diameter of Column, Depth of Bracing and Width of Bracing. This reduces the overall Material Cost of Reinforced Concrete Water-Tank which is calculated and presented in the Results.*

Key Words: Water-Tank, Optimization, Artificial Intelligence, Simulated Annealing, Design Parameters, Material Cost

1.INTRODUCTION

Water-Tanks are structures used for storing water for supplying it to various households, and commercial buildings through Water-Pipeline. Analysis and design of such tanks are independent of the chemical nature of the product. They are designed as crack-free structures to eliminate any leakage. While designing liquid retaining structures recommendations of the "Code of Practice for the storage of Liquids- IS3370 (Part I to IV)" should be considered.

2. LITERATURE REVIEW:

: *2.1 Martínez-Martín et al. (2022):* This study emphasizes the optimization of the design of reinforced concrete elevated water tanks under seismic loads, highlighting the significance of structural resilience in earthquake-prone regions.

2.2 Zulfiqar et al. (2022): The investigation into an optimum ring baffle design for enhancing the structural strength of tanks subjected to resonant seismic sloshing contributes to the seismic optimization of water tanks.

2.3 Saghi et al. (2020): This study discusses the optimization of baffled rectangular and prismatic storage tanks against the sloshing phenomenon, providing insights into the mitigation of seismic-induced sloshing.

3. Volume Minimization and Efficiency: *3.1 Nakic et al. (2022):* Introducing a novel procedure for minimizing the volume of water tanks in water supply systems, this study addresses the optimization of water storage capacity while maintaining efficiency.

3.2 Younis et al. (2020): The evaluation of the cost-effectiveness of reinforcement alternatives for concrete water chlorination tanks contributes to the optimization of material usage and structural performance.

4. Baffle Design Optimization: *4.1 Jiang et al. (2020):* The exploration of optimal design based on analytical solutions for storage tanks with inerter isolation systems showcases advancements in baffle design optimization for improved structural performance.

4.2 Zhao et al. (2017): The discussion on seismic mitigation performance and optimization design of nuclear power plant water tanks with internal ring baffles offers insights into baffle optimization strategies.

5. Cost Optimization and Material Selection: *5.1 Elansary et al. (2018):* The presentation of the optimum design of composite conical tanks under hydrostatic pressure contributes to understanding cost-effective material selection in water tank construction.

5.2 Hallmann et al. (2018): The discussion on heuristics and simulation for water tank optimization provides insights into cost-effective design approaches through computational methodologies.

3. Objectives-The aim of this work is to optimize the cost of circular overhead water tank during design stage using meta-heuristic optimization considering the following parameters: 1. Cost of Concrete as per DSR of 2021 2. Cost of Reinforcement bars as per DSR of 2021 3. Considering the seismic effect on water tank as per IS 1893:2016 4. Designing as per IS 3370:2009 guidelines

4. Methodology- The following Design Constraints have been considered while designing of Water-Tank:

1. Grade of Steel = Fe 500
2. Grade of Concrete = M30
3. Water-Tank is assumed to be flat base
4. Importance Factor for Water-Tank is 1.5

The entire Design of Water-Tank is based on IS 3370 guidelines. This design is coded into Python language. Different inputs have been taken from users which are as follows:

1. Capacity of Water-Tank in Litres
2. Staging Height in meters
3. Seismic Zone
4. Type of Soil
5. Type of Terrain
6. Wind speed in metres/second

The different parts of the Water-Tank that are designed are as follows:

1. Design of Top-Dome:
   (i) Meridional Force (T1) in kN
   (ii) Hoop Tension (T2) in KN
2. Design of Top-Ring Beam
3. Design of Water-Tank Wall
4. Design of Base-Slab
5. Design of Bottom-Ring Beam
6. Design of Staging:
   (i) Wind Loads
   (ii) Seismic Loads

The Water-Tank has been optimized using a Meta-heuristic Algorithm named Simulated Annealing.

The different parameters that are optimized are as follows:

1. Ratio of Depth of reservoir of Water-Tank to Diameter of Tank (h/D Ratio)
2. Thickness of Top-Dome
3. Thickness of Water-Tank Wall
4. Thickness of Base Slab
5. Depth of Bottom Ring Beam
6. Width of Bottom Ring Beam
7. Diameter of Column
8. Depth of Bracing
9. Width of Bracing

5. PYTHON CODES FOR INPUT PARAMETERS:

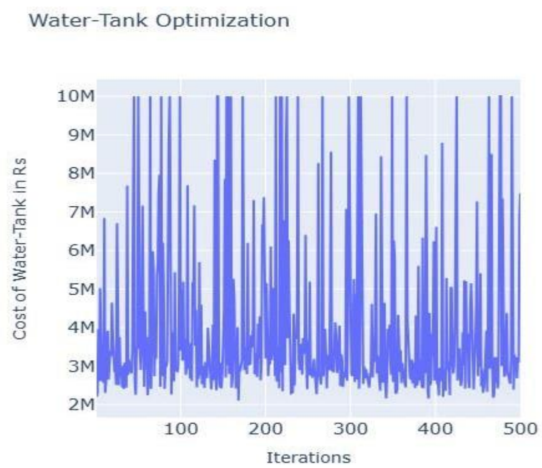
CASE 1:

Capacity of Water-Tank = 5 Lakh Litres

Staging height = 16 m

CODE:

```
sl, bf= cirtank_opti(500000,16,"3","hard","ter3",47)
minC= min(bf)
loc= bf.index(minC) locsl= loc*9
data= sl[locsl:locsl]
```



GRAPH 1:

COST:

Original Cost = Rs 2939936

Cost after Optimization = Rs 2105094

Reduction in Cost = 28.39 %

CASE 2:

Capacity of Water-Tank = 5 Lakh Litres

Staging height = 18 m

CODE:

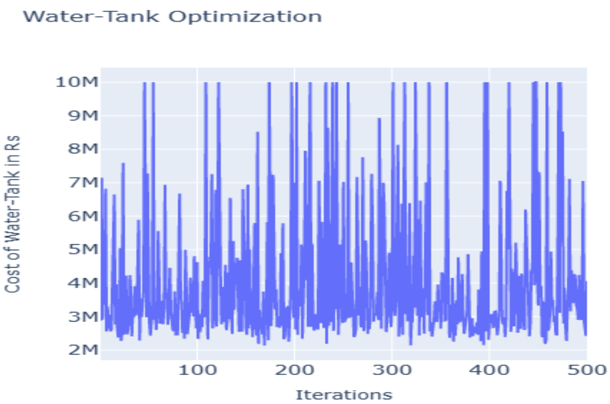
```
sl, bf= cirtank_opti(500000,18,"3","hard","ter3",47)
minC= min(bf)
loc= bf.index(minC) locsl= loc*9
data= sl[locsl:locsl+9]
```

COST:

Original Cost = Rs 3007124

Reduction in Cost = 29.06 %

Cost after Optimization = Rs 2133034



GRAPH 2:

6. CONCLUSIONS

The Cost Optimization performed on the Circular Water-Tank using Simulated Annealing Algorithm shows an average reduction in Material Cost of Water-Tanks of different Capacity and Staging Height by 28.34 %.

The Optimized values of Ratio of Depth to Diameter of Tank of reservoir of Water-Tank (h/D Ratio) increases with increase in Water-Tank Capacity by 12.21 % and Staging Height by 2.89 % of Water-Tanks. The Optimized values of Thickness of Top-Dome increases with increase in Water-Tank Capacity by 19.745 % and Staging Height by 6.22 % of Water-Tanks. The Optimized values of Thickness of Water-Tank wall increases with increase in Water-Tank Capacity by 11.19 % and Staging Height by 4.03 % of Water-Tanks.

The Optimized values of Thickness Base-Slab increases with increase in Water-Tank Capacity by 19.96 % and Staging Height by 5.64 % of Water-Tanks. The Optimized values of Depth of Bottom Ring Beam increases with increase in Water-Tank Capacity by 23.47 % and Staging Height by 5.91 % of Water-Tanks. The Optimized values of Width of Bottom Ring Beam increases with increase in Water-Tank Capacity by 12.20 % and Staging Height by 3.35 % of Water-Tanks.

The Optimized values of Diameter of Column increases with increase in Water-Tank Capacity by 22.35 % and Staging Height by 4.51 % of Water-Tanks. The Optimized values of Depth of Bracings increases with increase in Water-Tank Capacity by 13.235 % and Staging Height by 3.56 % of Water-Tanks. The Optimized values of Width of Bracings increases with increase in Water-Tank Capacity by 18.77 % and Staging Height by 5.85 % of Water-Tanks.

The values of Material Cost of Water-Tank before Optimization increases with increase in Water-Tank Capacity by 15.99 % and Staging Height by 2.10 % of Water-Tanks. The values of Material Cost of Water-Tank after Optimization increases with increase in Water-Tank Capacity by 18.13 % and Staging Height by 1.23 % of Water-Tanks. The Results show that the increase in Water-Tank Capacity has greater role in increasing the Optimized values and Material Cost of Water-Tank before and after Optimization as compared to Staging Height.

On executing the program again and again for same case, we get different values of Optimized Material Cost of the Water-Tank because during each execution, the program selects any random value of each Optimizing Parameter from range specified in the program and calculates the Material Cost for that combination.

REFERENCES

[1] 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 (Switzerland)*, *12*(11). https://doi.org/10.3390/app12115635

[2] Nakic, D., Djurin, B., Hunt, J., & Dadar, S. (2022). A Novel Procedure for Minimizing the Volume of Water Tanks in Water Supply Systems. *Water (Switzerland)*, *14*(11), 1– 16. https://doi.org/10.3390/w14111731

[3] Zulfiqar, Y., Hyder, M. J., Jehanzeb, A., Ahmad, H. W., Zulfiqar, A., Masood Chaudry, U., & Jun, T. S. (2022). Numerical Investigation of an Optimum Ring Baffle Design to Optimize the Structural Strength of a Tank Subjected to Resonant Seismic Sloshing. *Structural Engineering International*. https://doi.org/10.1080/10168664.2022.2029690

[4] Saghi, H., Ning, D. zhi, Cong, P. wen, & Zhao, M. (2020). Optimization of Baffled Rectangular and Prismatic Storage Tank Against the Sloshing Phenomenon. *China Ocean*

ngineering, *34*(5), 664–676. https://doi.org/10.1007/s13344-020-0059-8

[5] Younis, A., Ebead, U., Suraneni, P., & Nanni, A. (2020). Cost effectiveness of reinforcement alternatives for a concrete water chlorination tank. *Journal of Building Engineering*, *27*(October 2019). https://doi.org/10.1016/j.jobe.2019.100992

[6] Jiang, Y., Zhao, Z., Zhang, R., De Domenico, D., & Pan, C. (2020). Optimal design based on analytical solution for storage tank with inerter isolation system. *Soil Dynamics and Earthquake Engineering*, *129*(October 2019), 105924. https://doi.org/10.1016/j.soildyn.2019.105924

[7] Topology, S., Of, O., Tanks, W., & Genetic, U. (2019). *IMECE2003-4 3925 SURFACE TOPOLOGY OPTIMIZATION OF WATER TANKS USING GENETIC*. 1–7.

[8] Shaikh, H. M., & Kulkarni, N. R. (2018). SWOT on Execution of Optimization Techniques for Liquid Level Control in a Tank. *3rd International Conference and Workshops on Recent Advances and Innovations in Engineering, ICRAIE 2018, 2018(November), 1–4. https://doi.org/10.1109/ICRAIE.2018.8710418*

[9] Hallmann, C., Burmeister, S., Wissing, M., & Suhl, L. (2018). Heuristics and simulation for water tank optimization. In *Communications in Computer and Information Science* (Vol. 889). Springer International Publishing. https://doi.org/10.1007/978-3-319-96271-9_5

[10] Elansary, A. A., Nassef, A. O., & Damatty, A. A. E. (2018). Optimum design of composite conical tanks under hydrostatic pressure. *Advances in Structural Engineering*, *21*(13), 2030–2044. https://doi.org/10.1177/1369433218764976

[11] Zhao, C., Chen, J., Wang, J., Yu, N., & Xu, Q. (2017). Seismic mitigation performance and optimization design of NPP water tank with internal ring baffles under earthquake loads. *Nuclear Engineering and Design*, *318*, 182–201. https://doi.org/10.1016/j.nucengdes.2017.04.023

[12] Azabi, T. M., El Ansary, A. M., & El Damatty, A. A. (2016). Cost analysis of conical tanks; Comparison between reinforced concrete and steel. *Proceedings, Annual Conference - Canadian Society for Civil Engineering*, *4*(June), 2841–2850.

[13] Sanjuan-Delmás, D., Hernando-Canovas, E., Pujadas, P., de la Fuente, A., Gabarrell, X., Rieradevall, J., & Josa, A. (2015). Environmental and geometric optimisation of cylindrical drinking water storage tanks. *International Journal of Life Cycle Assessment*, *20*(12), 1612–1624. https://doi.org/10.1007/s11367-015-0963-y

[14] Elkholy, S. A., Elsayed, A. A., El-Ariss, B., & Sadek, S. A. (2015). Towards optimal finite element modeling for the analysis of liquid storage tanks. *Civil-Comp Proceedings*, *September*. https://doi.org/10.4203/ccp.108.104

[15] Okoye, C. O., Solyali, O., & Akintuƞ, B. (2015). Optimal sizing of storage tanks in domestic rainwater harvesting systems: A linear programming approach. *Resources, Conservation and Recycling*, *104*, 131–140. https://doi.org/10.1016/j.resconrec.2015.08.015

[16] El Ansary, A. M., Nassef, A. O., & El Damatty, A. A. (2013). Optimum design of stiffened liquid-filled steel conical tanks. *Proceedings, Annual Conference - Canadian Society for Civil Engineering*, *3*(January), 2810–2819.

[17] Hilo, S. J., & Wan Badaruzzaman, W. H. (2011). *Cost Optimisation of Water Tanks Designed According To the Aci and Euro Codes*. *September 2015*. https://doi.org/10.13140/RG.2.1.2102.8329

[18] Barakat, S. A., & Altoubat, S. (2009). Application of evolutionary global optimization techniques in the design of RC water tanks. *Engineering Structures*, *31*(2), 332–344. https://doi.org/10.1016/j.engstruct.2008.09.006

[19] Basile, N., Fuamba, M., & Barbeau, B. (2009). Optimization of water tank design and location in water distribution systems. *Proceedings of the 10th Annual Water Distribution Systems Analysis Conference, WDSA 2008*, 361–373. https://doi.org/10.1061/41024(340)32

[20] Tan, G. H., Thevendran, V., Das Gupta, N. C., & Thambiratnam, D. P. (1993). Design of reinforced concrete cylindrical water tanks for minimum material cost. *Computers and Structures*, *48*(5), 803–810. https://doi.org/10.1016/0045-7949(93)90501-4

[21] Thevendran, V., & Thambiratnam, D. P. (1988). Minimum weight design of conical concrete water tanks. *Computers and Structures*, *29*(4), 699–704. https://doi.org/10.1016/0045-7949(88)90382-3

[22] Mohan, C., & Sharma, S. P. (1987). Cost optimization of intze tanks on shafts using nonlinear programming. *Engineering Optimization*, *10*(4), 279–288. https://doi.org/10.1080/03052158708902543

[23] Thevendran, V., & Thambiratnam, D. P. (1987). Optimal shapes of cylindrical concrete water tanks. *Computers and Structures*, *26*(5), 805–810. https://doi.org/10.1016/0045-7949(87)90029-0

[24] Thevendran, V., & Thambiratnam, D. P. (1986). Minimum weight design of cylindrical water tanks. *International Journal for Numerical Methods in Engineering*, *23*(9), 1679–1691. https://doi.org/10.1002/nme.1620230908

[25] Mohan, C., & Sharma, S. P. (1985). Use of nonlinear optimization techniques in determining the optimal design of intze tanks on shafts. *Engineering Optimization*, *9*(2), 143–153. https://doi.org/10.1080/03052158508902510

[26] IS 3370 (Part 2): 2009: Indian Standard Code for Design of Reinforced Concrete Structures for Liquid Storage.

[27] IS 3370 (Part 4): 1967: Indian Standard Code of Design Tables for Liquid Storage Structures.

[28] IS 1893 (Part 1): 2016: Indian Standard Code for Earthquake Resistant Design of Structures for general provisions.

[29] IS 1893 (Part 2): 2014: Indian Standard Code for Earthquake Resistant Design of Structures for Liquid Retaining Tanks.

[30] IS 875 (Part 3): 2015: Indian Standard Code for Design Loads other than Earthquake Loads which are Wind Loads for Buildings and Structures.

[31] DSR 2021: Delhi Schedule of Rates 2021 Volume 1.