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Parametric Optimization of Intze water tanks with respect to the latest guidelines of IS 3370:2021.

Sukanya Saxena* & Krishna Kant Pathak

Department of Civil Engineering Indian Institute of Technology (B.H.U) Varanasi 221 005 India

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This study has systematically explored the design parameters of Intze water tanks through a parametric investigation, considering cylindrical height-to-diameter ratios (H/D) and conical dome angles (θ) in pursuit of an optimized cost-efficient design. The selected Intze water tanks have had capacities ranging from 200 to 1200 kiloliters, with H/D ranging from 0.2 to 1.0. The angles considered for the conical dome with the vertical axis have included 45°, 50°, and 55°. An in-house software program, developed in C++, has used Heuristic optimization methods and integrated features for analysis, design, and estimation. The design approach has followed the limit state method, incorporating crack width calculations for all water-retaining members. The research findings have indicated specific design preferences, such as the preference for an H/D ratio of 0.8 for the 200-kL tank and a consistent recommendation of a 0.3 H/D ratio for capacities between 400 kL and 800 kL. Notably, there has been a deliberate shift in design for capacities ranging from 800 kL to 1200 kL, favoring lower H/D ratios between 0.2 and 0.3. The study has also identified cost-efficient strategies, with the utilization of a 50° conical dome angle proving to be cost-effective for the 200-kL tank, while a 45° angle has been recommended for capacities ranging from 400 kL to 1200 kL. The research highlights that optimizing H/D ratios and θ values can significantly reduce material usage and costs in water tank construction, offering substantial savings in large-scale projects.

Keywords: Elevated water tanks, Intze tanks, RCC structures, Seismic loads, Wind loads, Limit state method of design

1 Introduction

Water, often regarded as the essence of life, plays a pivotal role in sustaining civilizations. Access to potable water is crucial for human survival and the development of communities. Efficient storage methods are vital to ensure a continuous and reliable water supply. Among the various storage options, elevated water tanks stand out for their practical advantages. Positioned at a height, these tanks utilize gravity to provide consistent water pressure, enabling efficient distribution across urban & rural communities. The decision to choose a water tank's shape is influenced by several factors. The elevated Intze water tank structure minimizes the footprint, maximizing the use of available land. In essence, the choice of an elevated water tank is a strategic decision, balancing efficiency, space utilization, and structural integrity to meet the vital needs of water storage for thriving civilizations.

Water tanks are currently under construction throughout the country, incurring substantial costs. This study aims to explore cost reduction possibilities for these structures through parametric optimization. Even a marginal decrease in the construction expenses can yield significant impacts, given the large number of tanks being built. The focus here is on identifying ways to enhance cost efficiency in water tank projects, acknowledging the potential for substantial overall savings considering the extensive construction endeavors nationwide.

The substantial cost associated with water tanks necessitates a focused effort to minimize structural expenses while adhering to the stringent parameters outlined in IS 3370:2021. This study aims to achieve cost reduction by examining expenses at various H/D ratios and diverse angles of conical domes.For the study In- house software program is developed in the language C++. The software program incorporates predefined minimum dimensions and stress limits in line with the latest code recommendations.

The literature survey examines RCC elevated water tank construction, focusing on strategies for optimizing designs and reducing structural costs. Titiksh[1] conducted a parametric study on a cylindrical water tank with a capacity of 350 kL, exploring

*Corresponding author
(E-mail:sukanyasaxena.rs.civ22@itbhu.ac.in)

various H/D ratios to achieve the minimum cost of the structure. The analysis was performed using Staad. Pro software in accordance with the guidelines of IS 3370:2009. However, limitations of this study include its exclusive focus on a 350 kL tank, the absence of variation in the angle of the conical dome, and the reliance on the previous IS 3370:2009 code rather than the updated 2021 version. Saxena *et al.*[2,3]conducted studies on Intze water tank of using nonlinear optimization by computational techniques to get minimum cost of the structure. Thevendran and Thambiratnam[4-7]conducted analyses on water tanks, specifically focusing on the minimum weight criteria for cylindrical and conical tanks, determining the optimal shape of tanks, and minimizing material costs using BS 8007 and employing the Beam on Elastic Foundation analogy. In these investigations, the radius and height of the tanks remain constant, while the thickness is varied to ensure stresses align with allowable values. The structural shape is modified by introducing one or two slopes in the construction. Tan, G. H. et al.[8] conducted study on minimum weight design using BS 5337 using Finite element method and numerical method. Reddy, G. S. *et al*.[9] used machine learning for optimization of Intze water tank to obtain the minimum cost of the tanks with compliance to the Standards provisions. Workeluel, N et al.[10]conducted a comparative study on analysis of Intze tanks using American, Ethiopian, European and Indian standard codes using SAP software revealing that the Indian Standard code yielded the most optimum cost among the considered standards. A few seismic studies are also done in this field to find out seismic response of the structure and to find out the most optimum staging configurations for optimum design[11-12]. Sangiorgio, V. *et al*.[13] conducted tanks performance and degradation analysis over various tanks in Spain. Leakage is one of the primary reasons for the tank deterioration. All these investigations aimed to achieve the most optimal solution for the cost of constructing water tank structures. In all cases of the aforementioned study, circular water tanks were utilized as the type of tank, except in the initial study.The preceding studies were focused on codes from earlier editions, such as IS 3370:2009 or IS 3370:1965 which were based on the Working stress Method of design. The angle of the conical dome remained constant across previous studies. However, in this study, the angle of the conical dome was adjusted within the range of 45 to 55 degrees. There was a need for the study to be done using the latest standards. The study has been done using latest standards[14-19].For the Seismic design, IIT GSDMA[20]guidelines ais also refereed. Standard texts used for the study are mentioned in references [21-24].

RCC water tanks are essential but come with economic challenges due to substantial material consumption. Global initiatives have sought to mitigate R.C.C water tank costs through diverse approaches, including nonlinear optimization, parametric studies, and weight reduction via computational techniques like machine learning, or numerical methods[1-13].This study introduces several novelties compared to earlier research on water tank design. Unlike previous studies that focused on circular or conical tanks, this research considers Intze tanks with varying capacities (200, 400, 600, 800, 1000, and 1200 kL). It explores a range of height-to-diameter (H/D) ratios from 0.2 to 1, and adjusts the conical dome angle within 45° to 55°, offering a more flexible design approach. The study uses the recent IS 3370:2021 standard, which applies the Limit State Method of design, replacing older standards based on the Working Stress Method. A new software tool, developed for this research, automates dimension sizing based on structural requirements and uses a Heuristic Optimization algorithm to optimize the design, with validation confirmed by existing tank data and manual calculations. The software also assesses the optimal number of columns to minimize cost and incorporates criteria to reduce steel usage while checking crack width for tightness Class I (0.2 mm) to ensure leak-proof characteristics. Additionally, the study includes estimation and costing using CPWD DAR 2021 rates, and conducts wind and seismic analyses in accordance with IS 875 (Part 3): 2015 and IS 1893 (Part I & II): 2016. This comprehensive approach, integrating design, costing, and resilience factors, provides an optimized, cost-efficient, and robust solution for Intze water tank construction.

2 Materials and Methods

This study involves the design of Intze tanks, where the exploration of varying H/D ratios and conical dome angles is conducted to ascertain the most efficient design parameters. For this study, six tanks with distinct capacities (200, 400, 600, 800, 1000, and 1200 kL) were deliberately selected to represent low, medium, and high-capacity categories. The cylindrical height-to-diameter ratio varies from 0.2 to 1 in increments of 0.1, and the angle of the conical dome from the vertical is set at 45, 50, and 55 degrees for this study. The study adheres to the latest Indian standards, incorporating IS 3370:2021 for the design of water-retaining structures, as well as incorporating all other current codes for staging, foundation designs, and wind and seismic analysis. The design approach follows the limit state method, incorporating crack width calculations for all water-retaining members. An in-house software program, developed in C++ language, integrates features for analysis, design, and estimation. The program includes built-in data from the latest Indian standards and CPWD Schedule of Rates. The primary goal of the study was to identify the most effective design parameters, aiming to achieve the minimum cost of the structure. This process involves streamlining the implementation process for designers. By pinpointing and establishing optimal design criteria, the study provides a practical framework directly applicable to designers' projects. This contribution enhances overall efficiency and effectiveness in the planning and implementation of structural elements. The design of water tanks involves three stages: 1) Tank body design, 2) Staging design (columns & braces), and 3) Foundation design (Annular Raft Foundation). The Intze tank body includes three joints: top (top dome, ring beam, cylindrical wall), middle (balcony beam, cylindrical wall, conical dome), and bottom (conical dome, bottom dome, bottom ring beam). Following the tank body design, staging and foundation designs are carried out, incorporating wind and seismic analyses per Indian Standards. A C++ software program has been developed to streamline these design and analysis processes, as shown in the flowchart in Fig. 1.

2.1 Design of the tank body

Water tank designs follow the guidelines outlined in IS 3370:2021, specifically adopting the Limit State Design. Crack width calculations are mandatory to be performed as per Annexure A & B of IS 3370. Adjustments to member sizes and reinforcement spacing are implemented wherever crack widths exceed permissible limits, effectively controlling crack widths in the design process. Limiting Crack Width is taken as per 0.2 mm as per clause number 4.4.3.3. Tightness Class 1. Maximum Tensile stress in concrete is taken as 1.3 N/mm² & for steel is 435 N/mm² (Fe 500 is used in this study). Study adopts Membrane analysis approach.

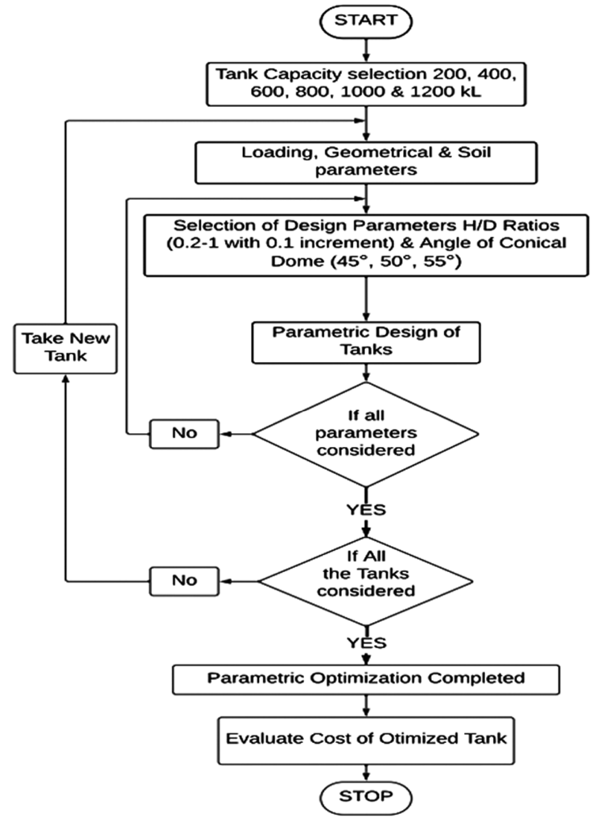

Fig. 1 — Flow chart for parametric optimization.

2.2. Design of staging and foundations

Water tanks are structures of high importance. It is mandatory to perform the Seismic and wind force calculations in both empty and fully filled case conditions. Seismic & wind calculations are to be done in accordance with IS 1893: 2016 Part I and Part II along with IITK-GSDMA guidelines & IS 875:2015 Part III respectively. Annular raft footing is preferred and is designed as per IS foundation IS 11089 –1984, their Design is done as per IS 456:2000 (Reaffirmed 2021). Careful considerations are to be made while checking the soil properties.

2.3 Software for tank design

The software is structured into modules covering Input, Dimensioning, Analysis, and Design of the tank body, Wind and seismic analysis, Analysis and Design of staging & foundation, Estimation, and Costing. The flow chart for the software workflow process is given in Fig. 2. The C++ software program developed encompasses several features as given below-

2.3.1 Input & analysis

The software offers a complete analysis and design solution for Intze water tanks in a single process,

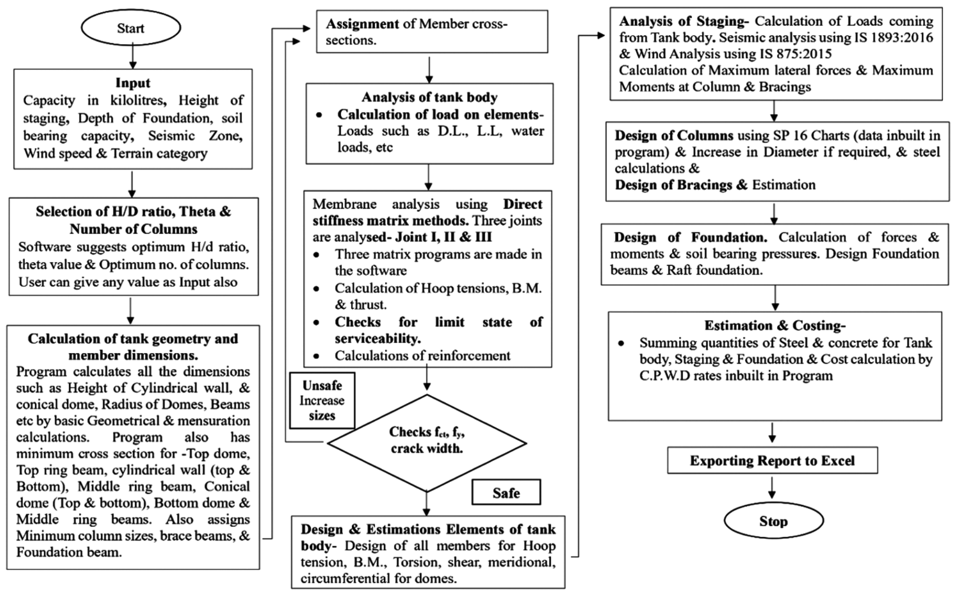

Fig. 2 — Systematic flowchart detailing the software's operation.

incorporating all relevant Indian standard codes. Users input parameters such as tank capacity (in kiloliters), height of staging, safe soil bearing capacity, foundation depth, seismic zone, location, and terrain category. Based on these inputs, the software recommends optimal H/D ratios and conical dome angles (theta), though users can provide their own values if desired. It calculates the optimum dimensions for various structural members, including the height and diameter of cylindrical walls and domes (top, bottom, and conical), as well as the radius and height of the conical dome. The software automates dimension determination, optimizing cross-section sizes through a 5 cm increment for members identified as unsafe at the minimum dimension, utilizing a heuristic optimization algorithm. Additionally, the tool includes a crack width check for all elements in contact with water, ensuring the structural integrity and leak-proof characteristics of the tank.

2.3.2 Design specifications

The software provides comprehensive design coverage for all key components of the Intze water tank, including the top dome, ring beams, circular wall, conical dome, middle ring beams, bottom ring beams, columns, braces, bottom dome, and more. It accurately computes member dimensions and steel reinforcement, ensuring a precise and optimized tank design. The program also incorporates seismic design calculations for Zones II, III, IV, and V, including seismic response time. Wind load calculations are performed in accordance with IS 875: 2015, ensuring compliance with the latest standards. Additionally, the software integrates the design of annular raft footing, providing a complete structural solution for the water tank.

2.3.3 Software algorithm

The software computes member dimensions and preliminary cross-sections based on input parameters using a Membrane analysis method with Heuristic Optimization. It employs the Direct Stiffness method in C++ to calculate forces like bending moments, outward thrusts, and hoop tension, followed by member design using the Limit State Method. Elements are evaluated for stress, exposure, and crack width, with incremental modifications applied if members are unsafe. Staging and foundation loads are analyzed for wind and seismic criteria. The software estimates concrete volume and steel quantities for all tank members and calculates total material costs using the latest CPWD Schedule of Rates (DAR VOL 1, Updated Dec 2021). The program ensures comprehensive design and cost calculation in a single run, with an intuitive user interface.

2.3.4 Software validation

A pilot manual test was conducted with over 50 designs for tanks ranging from 100 kL to 1500 kL, considering various seismic zones, wind speeds, and soil capacities. Positive results led to software development, with outcomes cross-verified by the software.

2.4 Application

In this study, a comprehensive exploration is undertaken with the selection of nine distinct H/D ratios ranging from 0.2 to 1. Additionally, three varied angles of the conical dome—45°, 50°& 55°are chosen for thorough investigation. For this study, a targeted selection involves six tanks of different capacities, specifically chosen with volumes of 200, 400, 600, 800, 1000, and 1200 kL. Watertank properties are detailed in Table 1. The latest CPWD DAR 2021 rates are taken and are used for the estimation of cost of Concrete& Steel. The water tanks are designed using the software program, enabling the attainment of optimal and minimum required cross-sections. The software automates dimension sizing based on structural needs, optimizing the overall structure by introducing a 5 cm increment for unsafe members & systematically evaluates the optimal number of columns for each tank, aiming to minimize the overall structure cost.

3 Results and Discussion

A comprehensive analysis was conducted to evaluate the economic and structural aspects of Intze tanks across capacities ranging from 200 to 1200 kiloliters. Each tank was meticulously designed using specialized software, accounting for variations in H/D ratios and conical dome angles. The assessment included a detailed examination of costs associated with the water tank, tank body, staging, and foundation. The results pointed out the important effects of changing these design aspects, giving valuable insights for each tank category. The detailed cost comparisons among different tank configurations are shown as below-

3.1 Optimal design parameters for 200 kl intze tanks

Figure 3 shows the Optimal design parameters for 200 kL Intze water tank.

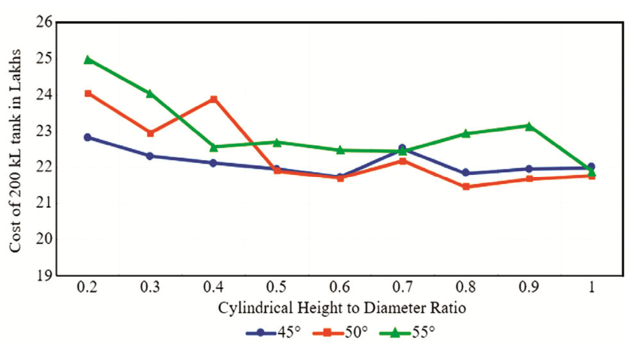

Fig. 3 — Cost of 200 kL tanks with varying H/D ratios & angle of conical dome.

The results highlight that for a 200 kL Intze water tank, categorized as low capacity, the optimal H/D ratio falls within the range of 0.8-0.9, with the most efficient point identified at an H/D ratio of 0.8, as shown in Fig. 3. The least cost is observed when the angle of the conical dome is set at 50°. The highest cost occurs at an H/D ratio of 0.2. Increasing the H/D ratio leads to a steep decrease in the cost of the structure, as a lower H/D ratio results in a higher tank diameter and lower height, thus increasing the cost of the structure, staging, and foundation. In nearly all cases, θ = 55° results in the highest costs. The lowest costs are observed at θ = 50° for H/D ratios between 0.5 and 1, and at θ = 45° for H/D ratios between 0.2 and 0.5. Notably, within the H/D ratio range of 0.5-0.6, both 45° and 50° angles of the conical dome maintain low costs. However, opting for θ = 55° is not advisable, as it result in a higher cost compared to both 45° &50°.

3.2 Optimal design parameters for 400 kl intze tanks

Figure 4 shows the Optimal design parameters for 400 kL Intze water tank.

The results highlight that for a 400 kL Intze water tank, classified as medium capacity, optimal efficiency is achieved at an H/D ratio of 0.3. The minimum cost is observed when the conical dome angle is set at 45°. Costs remain low within the H/D ratio range of 0.6-0.7 at a 45° angle, as well as at H/D ratios of 0.4-0.5 with θ = 50°. The highest costs are observed at θ = 55°. However, selecting θ = 55° is not recommended due to its significantly higher cost compared to both 45° and 50° angles.

3.3 Optimal design parameters for 600 kl intze tank

Figure 5 shows the Optimal design parameters for 600 kL Intze water tank.

The results highlight that for a 600 kL Intze water tank, categorized as medium capacity, the optimal

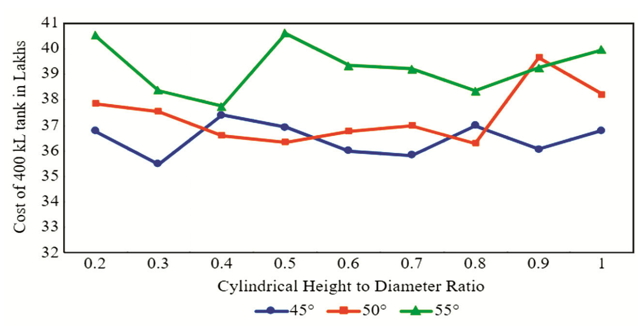

Fig. 4 — Cost of 400 kL tanks with varying H/D ratios & angle of conical dome.

H/D ratio falls within the range of 0.3-0.5, with the most efficient point identified at an H/D ratio of 0.3. The least cost is observed when the angle of the conical dome is set at 45°. Significantly, costs remain low within the H/D ratio range of 0.3-0.4 at a 50° angle, as well as at H/D ratios of 0.7-0.8 with θ = 55°, though these costs are higher than those achieved with θ = 45°. However, opting for θ = 50° and θ = 55° is not advisable as they result in higher costs compared to 45°.

3.4 Optimal design parameters for 800 kl intze tank

Figure 6 shows the Optimal design parameters for 800 kL Intze water tank.

The results highlight that for 800 kL Intze water tanks, categorized as medium capacity, the optimal H/D ratio falls within the range of 0.2-0.3, with the most efficient point identified at an H/D ratio of 0.3. The least cost is observed when the angle of the conical dome is set at 45°. Significantly, costs remain low within the H/D ratio range of 0.5 at a 50° angle. Higher costs are observed at H/D ratios of 0.6 or above, making them unsuitable for 800 kL tanks. Additionally, opting for θ = 50° and θ = 55° is not advisable as these result in higher costs compared to the 45° angle.

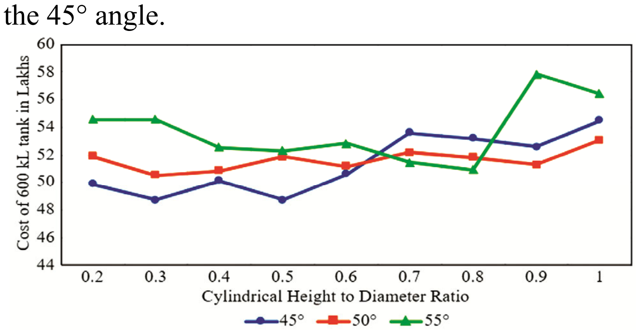

Fig. 5 — Cost of 600 kL tanks with varying H/D ratios & angle of conical dome.

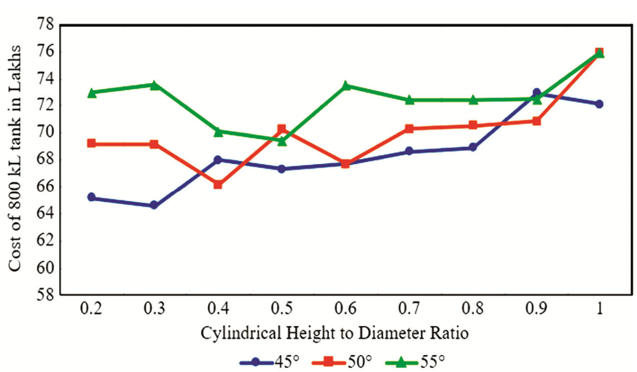

Fig. 6 — Cost of 800 kL tanks with varying H/D ratios & angle of conical dome.

3.5 Optimal design parameters for 1000 kl intze tank

Figure 7 shows the Optimal design parameters for 1000 kL Intze water tank.

The results indicate that for 1000 kL Intze water tanks, the optimal H/D ratio lies between 0.2 and 0.4, with the most efficient point at H/D = 0.4, as shown in Fig. 7. The cost difference between H/D ratios of 0.4 and 0.2 is minimal, around 0.2 lakhs. The lowest cost is achieved with a conical dome angle of 45°. However, angles of 50° and 55° lead to higher costs, making them less favorable.

3.6 Optimal design parameters for 1200 kl intze tank

Figure 8 shows the Optimal design parameters for 1200 kL Intze water tank.

The results highlight that for 1200 kL Intze water tanks, the optimal H/D ratio falls between 0.2 and 0.3, with the most efficient point identified at H/D = 0.2, as shown in Fig. 9. The least cost is observed when the conical dome angle is set to 45°. Higher costs are associated with all dome angles when the H/D ratio is 0.5 or above. Interestingly, at θ = 50° and H/D = 0.4, the cost of the tank is the same as that at θ = 45°. However, θ = 55° is not advisable for 1200 kL tanks. Furthermore, it is notable that the optimal H/D ratio tends to shift towards lower values in this study.

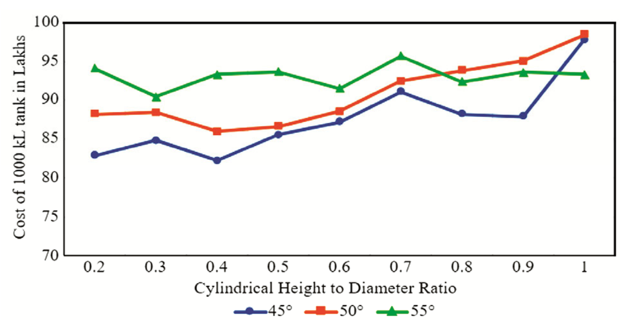

Fig. 7 — Cost of 1000 kL tanks with varying H/D ratios & angle of conical dome.

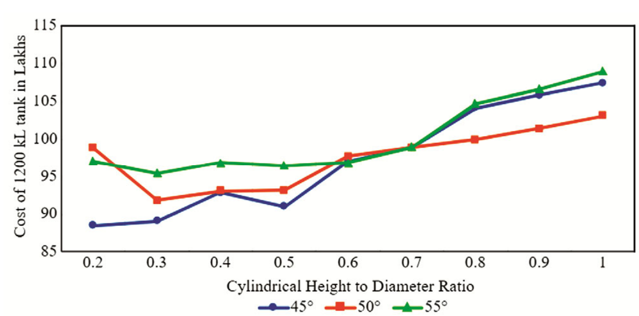

Fig. 8 — Cost of 1200 kL tanks with varying H/D ratios & angle of conical dome.

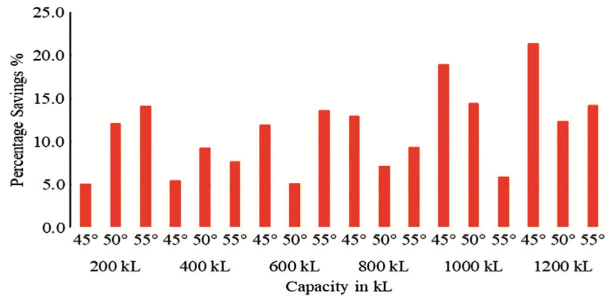

Fig. 9 — Percentage savings across various capacities at optimum H/D ratio & angle of conical dome.

3.7 Optimal H/D ratio, optimum angle of conical dome & percentage savings for the intze water tanks

The results highlight that a consistent optimal conical dome angle of 45° is observed across all capacities (400, 600, 800, 1000, and 1200 kL), except for the 200 kL tank, where the optimal angle is 50°. The most efficient H/D ratios vary, with values of 0.8 for 200 kL, 0.3 for 400, 600, and 800 kL, 0.4 for 1000 kL, and 0.2 for 1200 kL. These findings provide valuable insights for designing efficient and cost-effective Intze water tanks. Percentage savings across H/D ratios from 0.2 to 1, shown in Fig. 9, reveal that the maximum cost occurs at higher H/D ratios, while the minimum cost is achieved at the optimal H/D ratio. Significant cost savings, ranging from 5% to 18.9%, can be realized by carefully selecting H/D ratios and conical dome angles for different tank capacities.

4 Conclusion

Following are the salient conclusions of this study-

a The H/D values and Angle of conical dome values are indeed significant parameters in the analysis of water tanks. They play a crucial role in determining the structural design and have a substantial impact on the overall cost of the structure. Proper selection and optimization of these parameters can lead to cost savings and efficient design solutions for water tanks.

b For a 200 kL Intze Water Tank, categorized as low capacity, the optimal H/D ratio falls within the range of 0.8-0.9, with the most efficient point identified at an H/D ratio of 0.8. The least cost is observed when the angle of the conical dome is set at 50°.

c As the capacity of the water tank increases, a shift in the optimum H/D ratio is observed, moving towards lower values around 0.3 or less. This implies that for larger water tanks, the most cost-effective design tends to have a relatively shorter height in proportion to the diameter of the tank.

d The optimal angle for the conical dome is 45° for all tanks, except the 200 kL tank.

e To achieve cost savings for tanks with a capacity of 200 kL or less, the angle of the conical dome can be increased. This adjustment in the conical dome angle serves to enhance cost efficiency for smaller capacity tanks.

f However, opting for θ = 55° is not advisable as it results in a higher cost compared to 45° and 50° angles.

g The developed software program is user-friendly, serving as an excellent tool that is both precise and timesaving. Moreover, its adaptability is noteworthy, allowing for easy modifications, especially if there is revision in provisions of standard codes or regular updates of schedule of rates by concerned departments.

h In conclusion, this study emphasizes the importance of cutting costs in building water tanks across the country. By optimizing parameters, even small savings can make a significant impact, considering the widespread construction efforts. The focus is on finding ways to make water tank projects more cost-efficient and achieve substantial overall savings.

References

1 Titiksh A, Asian J Civ Eng, 20(2) (2019) 187.
2 Saxena M, Sharma S P, & Mohan C, *Eng Optim*9(2) (1985)143.
3 Saxena M, Sharma S P & Mohan C, *Eng Optim*, 10 (1987) 279.
4 Thevendran V & Thambiratnam D P, *NumTech for Eng Anal & Design*, (1987) 163.
5 Thevendran V & Thambiratnam D P, *Computstruc*, 26 (1987) 805.
6 Thevendran V & Thambiratnam D P, *Computstruc*, 29 (1988) 699.
7 Thevendran V & Thambiratnam D P, *Int J Num Meth Eng*, 23 (1986) 1679.
8 Tan G H, Thevendran V, Das Gupta N C & Thambiratnam D P, *Computstruc*, 48 (1993) 803.
9 Reddy G S, Komaravolu A, Devi K, Saduwale S &Obulesh A, *Int Conf Rec Adv Civ Eng*, (2022) 437.
10 Workeluel N, Saha P, Matiyas S & Mohanty T, *Mater Today: Proc*, (2023).
11 11Moslemi M, Kianoush M R & Pogorzelski W, *Eng Struct*, 33 (2011) 2074.
12 Nirmal S, Pawar P M & Jadhav R P, *Techno-Societal 2016*, (2022) 195.
13 Sangiorgio V, Uva G, Adam J M & Scarcelli L, *Eng Fail Anal*, 115 (2020).
14 IS: 3370 (Part I-IV), *Code of Practice for Concrete Structures for the Storage of Liquids*,BIS, New Delhi, (2021).

15 IS: 3370 (Part I-IV), *Code of Practice for Concrete Structures for the Storage of Liquids*,BIS, New Delhi, (2009).
16 IS: 1893 (Part I-II), *Criteria for Earthquake Resistant Design of Structures*, BIS, New Delhi, (2016).
17 IS 13356, *Precast Ferrocement Water Tanks up to 10000 Liters Capacity*, BIS, New Delhi, (1992).
18 IS: 875, *Code of Practice for Design Loads,* BIS, New Delhi, (2015).
19 IS: 456, *Plain and Reinforced Concrete – Code of Practice*, BIS, New Delhi, (2000).
20 Jain S K, *J Struct Eng*, 22 (1995) 73.
21 Krishna J & Jain O P, *Plain and Reinforced Concrete Volume-II*, Nem Chand Books, (2017).
22 Raju N Krishna, *Advanced Reinforced Concrete Design (IS 456-2000)*, CBS, (2005).
23 Jain S K & Jaiswal O R, *IITK-GSDMA Guidelines for Seismic Design of Liquid Storage Tanks*, NICEE, Kanpur, (2007).
24 24Balagurusamy E, *Computing Fundamentals and C Programming*, McGraw Hill Education, (2017).