

OVERHEAD WATER TANK CONSTRUCTION: AN INNOVATIVE STRATEGY

Mainak Mallik

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Abstract

The construction of an overhead water tank leads to extensive scaffolding and formwork for the full height of the tank. A steel mill in Sadat City, Egypt, required a tank with a total capacity of 275 m³ at a staging height of 36.75 meters above ground level, so it was built using the “Slip Forming and Heavy Lifting Technique”. It comprises twin chambers, each having a capacity of 75 m³ and 200 m³, supported by a circular shaft. A comparison between the methods of “slip-forming and heavy lifting techniques” and “conventional methods of construction” has been presented. “Slip Forming and Heavy Lifting Technique” is the need of the hour to provide an economical solution to the requirement of a time-bound finish to any project.

Keywords: Heavy Lifting Technique; Overhead Water Tank; Slip Form Shuttering

Introduction

In today’s world, saving water is crucial due to the growing population’s increasing demand for it. Water is essential for various purposes like drinking, farming, industries, and firefighting. Properly managing water storage is vital to meet these needs effectively (Kapadia *et al.*, 2017), in industries, whether it is a steel plant or a power plant, liquid storage tanks are commonly used for the retention of water, chemicals, petroleum products, etc., as well as for the storage of water in public water distribution systems. The shape of the raised tanks may be either rectangular or round. These tanks are elevated so that, after they are filled, the water will flow to the intended region by gravity. The staging for the tanks may be a simple slab or a spherical dome with or without a central aperture, with the latter being the more typical design. When the tank’s size is significant, a network of beams over columns

support the foundation slab. If staging includes columns, ring beams support them not only at the top and bottom but also at various points along their height. In this instance, the effective length of the columns is determined by the distance between the centers of neighboring bracings. Depending on the position of the tank, it may be exposed to wind pressure and seismic stresses. In some cases, staging is also provided in the form of a circular shaft. All over the world, the Intze tank is one of the most popular forms of construction for overhead water tanks.

The traditional method for building this type of overhead water tank is to first build the foundation, then build the tank bowl’s supporting structure—either in the form of a circular shaft, column, or beam—up to the staging height, and finally build the tank bowls. This will lead to extensive scaffolding

Department of Civil Engineering, National Institute of Technology, Arunachal Pradesh, India. E-mail: mainak.mallik@gmail.com*
* Corresponding author

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and formwork for the full height of the tank. An OH tank is constructed in just under ten months.

The construction of the tank bowl, however, is the most critical one because of the height between the cantilevered slab of the tank bowl and the ground. As shown in Figure 1, temporary H-shaped steel elements placed vertically on the ground initially supported the cantilevered portion of the tank bowl (Jeng *et al.*, 2000). Generally, the height of the staging of an OH tank varies from 20 m to 30 m for domestic purposes, but it may go up to 40 m for industrial purposes. The stability of the scaffolding system turned out to be crucial due to the huge unsupported length and the likelihood that the temporary joints of these members would not be rigid. The cost of the scaffolding system was discovered to be extremely high and to be as much as one-fifth of the whole building cost, which was excessively exorbitant. Furthermore, because the prior system's stability issue was so serious, there may be cause for concern regarding the possibility of its failure. To overcome this, an alternate scaffolding system (Jeng *et al.*, 2000), Figure 2, was suggested, but it also has some drawbacks, like the



Figure 1. Ground Support: Conventional Scaffolding Systems (Jeng *et al.*, 2000)

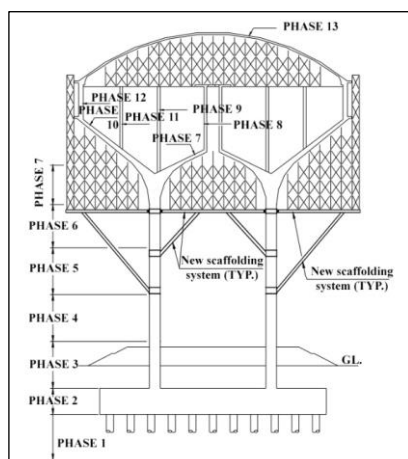


Figure 2. Shaft Support: Conventional Scaffolding Systems (Jeng *et al.*, 2000)

fact that if you use the central shaft as a supporting member, there will be a waiting period till it attains its full strength.

In the past, during earthquakes like the ones in Bhuj, Gujarat in 2001 and Jabalpur in 1997, circular shafts with thin shells didn't hold up well. These thin shell shafts, when functioning as columns or pedestals, were at risk because they lacked both flexibility and additional routes for bearing loads, unlike framed structures. Consequently, structures using these elements were assigned lower response reduction factors compared to those designed with more ductile and energy-absorbing capacities, like building frames (Landge and Murnal, 2014). In order to overcome all these problems, a method has been adopted for the construction of an overhead tank to supply the water requirements of a steel melting shop located in Sadat City, Egypt, where tanks were built using a combination of slip-forming and heavy lifting techniques. In this methodology, the slip-forming technique has been adopted for the construction of the shaft after the footing of the tank is cast using the conventional method. The tank bowl is then cast around the shaft at ground level, lifted along the shaft using a heavy lifting technique, and then set in place using a specific arrangement. It is obvious that the original diameter inside the tank bowl has been designed to be larger than the shaft diameter so that it can be lifted along the shaft, keeping in mind that the capacity of the tank bowl is as per requirement. In view of this innovative approach, which is not only cost-effective but also time-saving, the client and the architect accepted these challenges as well as changes without any reservation (Mallik, 2017).

Materials and Methods

There are six major steps, starting from the construction of the footing to the casting of the top slab of the tank bowl, based on which the total construction of the overhead water tank has been carried out.

STAGE-I

Step-I: As per normal practice the first step is the construction of the raft foundation, followed by circular shaft construction up to 2.0 above ground level, as shown in Figure 3.

Step II: In the year 1942, the Swedish company Byggbättring (Royam, 1972; VSL, 1956) invented the slip-forming technique. By using a system of mechanical locknut hydraulic jacks connected to a hydraulic power source, large-scale structures' vertical walls can all be constructed at

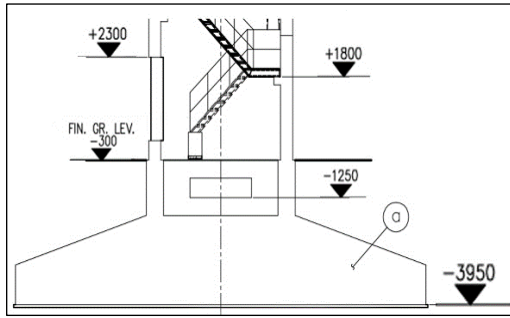


Figure 3. Construction of footing and tank shaft

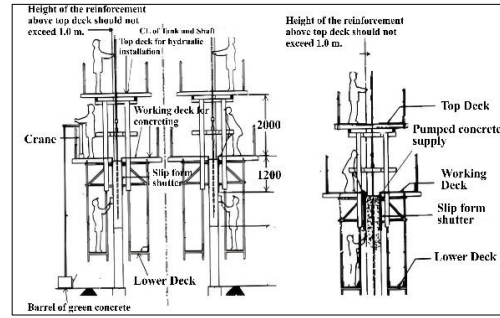


Figure 4. Typical arrangement and procedure of slip-forming technique

once. Scaffolding is not required. The sequence of work is as follows: placing the formwork along the shaft wall, pouring the concrete, and then raising the same formwork to pour freshly mixed concrete on top of the earlier concrete after giving it time to cure. Until the staging height is achieved, these sequences keep repeating. There are two options for carrying out the construction work: either without any breaks, using day and night shifts to complete the shaft construction, or with breaks during intermittently continuous nighttime work. Slip-forming equipment is known to be made up of self-climbing formwork and steel reinforcements that are placed as the forms move up.

Three platforms in the form of the top deck, working deck, and lower deck are arranged as shown in Figure 4. It takes only 7 days to construct a staging height of 40m with a sliding speed of 15 to 25 cm per hour. With concrete being poured all the time, the slid movement of the formwork has been carried out using hydraulic jacks. The formwork, which is usually 1.20 meters high, moves 4 meters in 24 hours, so the concrete at the bottom is only 4 to 6 hours old. It is strong enough to hold without molds, but it hasn't hardened enough to stick to the molds. If it did, the concrete would pull away from the molds as it rose. The height of the reinforcement should not exceed 4 meters above the top deck. This method has been used to build buildings, water towers, bridge piers, and chimneys with great success. The shaft wall building has gone on until the staging height has been reached.

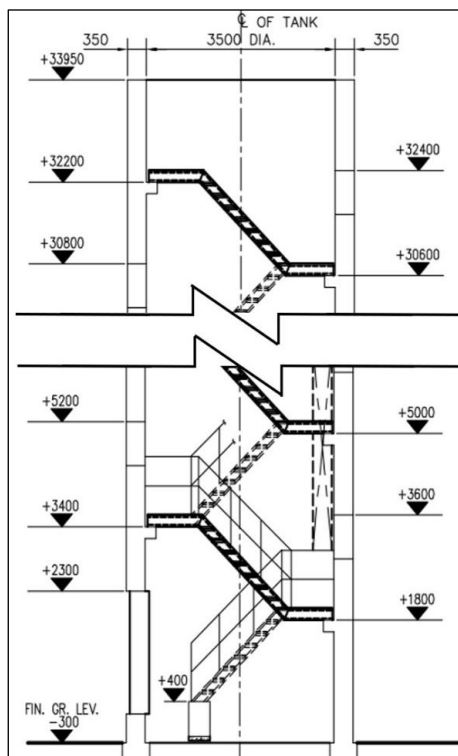


Figure 5. Placing of pre-fabricated structural staircase

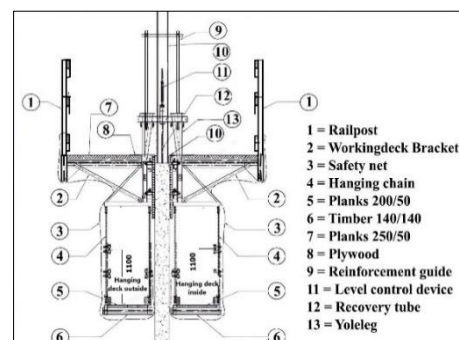


Figure 6. Typical detail of jack for holding and lifting of slip form shuttering (Constro System, 1987)

STAGE-II

Step I: 12 numbers of supporting columns have been constructed by the conventional on the top of the final staging height at a spacing of 300 mm, required for placing lifting jacks as shown in Figure 7 and Figure 8.

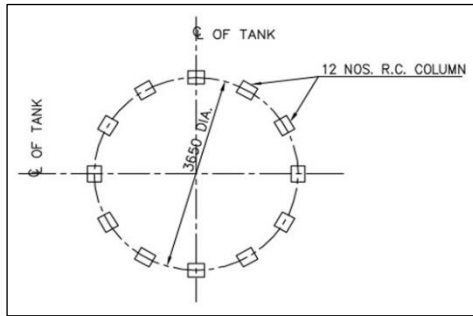


Figure 7. Construction of columns

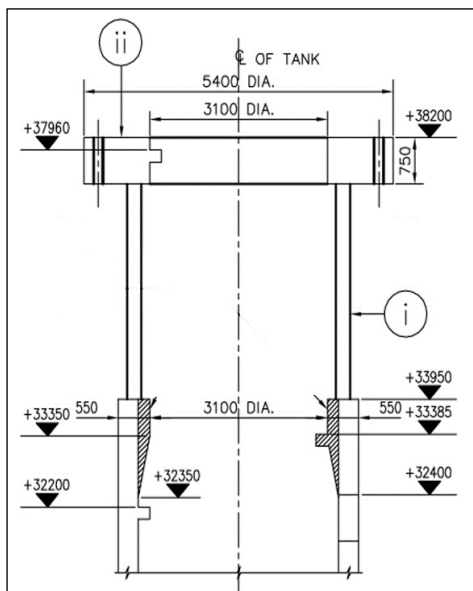


Figure 8. Decking platform for jack support

Step II: Construction of a circular resting on the column has been done. The purpose of this is to place the lifting jacks (each having a capacity of 70 tons). At equal intervals, 24 embedded steel pipes with a 150-mm diameter were placed on the deck slab.

STAGE-III

Step I: Twelve numbers of short columns supported on a ring beam have been cast. The ring beam profile is made in such a way that it can be placed on the sloped profile of the raft and has been cast encircling the shaft.

Step II: The circular shaft was encircled by the tank bowl, which was cast at ground level and supported by twelve columns resting on a ring beam built above the foundation at the step, as shown in Figure 9 and Figure 10.

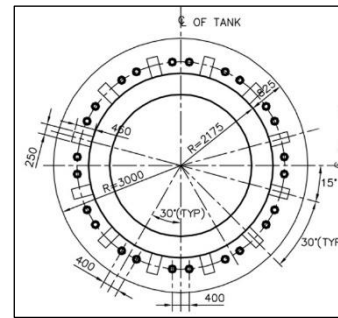


Figure 9. Displays a circular shaft encircled by a tank bowl

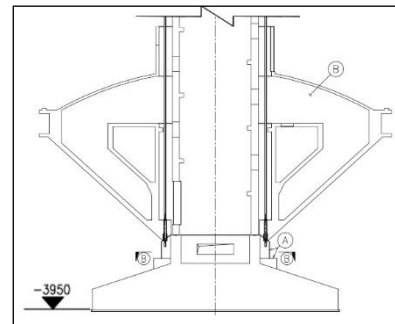


Figure 10. Displays a column resting on a ring beam

Step III: The lifting beam is equipped with twenty-four 150-mm-diameter embedded steel pipes. Two telescopic tie rods, one for each jack, have been installed and are fastened to the lifting beam through these pipes at the bottom and top of the circular deck. The whole tank bowl was suspended with the help of these tie rods.

STAGE-IV

It is that stage when the whole tank bowl constructed at ground level is lifted up to the final level. The tank bowl was lifted in a controlled manner by means of twelve jacks, which were connected to a common manifold at the top of the circular beam. The whole lifting operation was continued until the tank bowl was positioned at the desired level, as shown in Figure 11.

STAGE-V

In this stage, the knee beam that joins the tank bowl with the circular shaft is built after the tank bowl has been set in its final position, as shown in Figure 12.

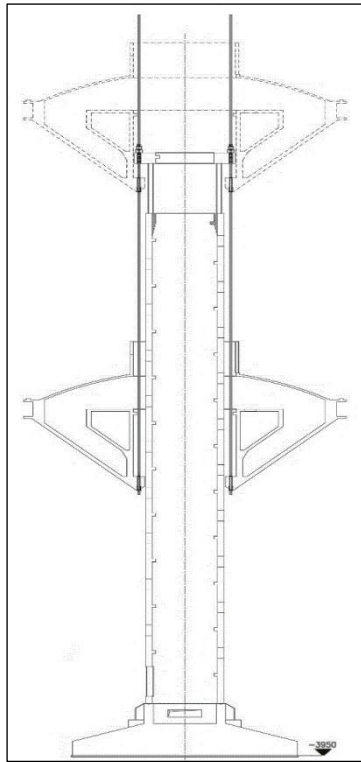


Figure 11. Display lifting of the tank bowl

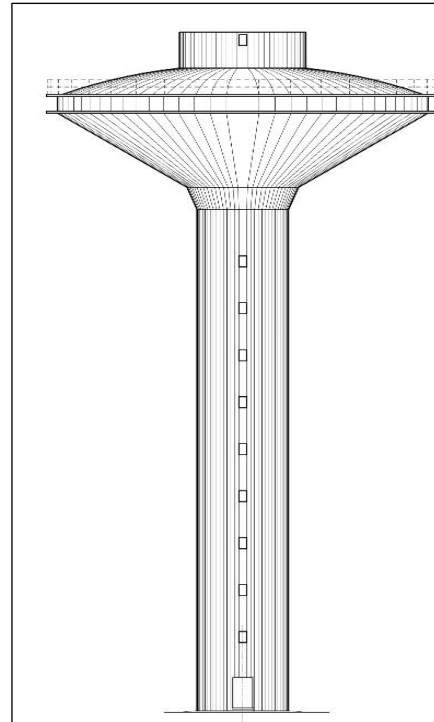


Figure 13. Elevation and sectional view of the completed tank

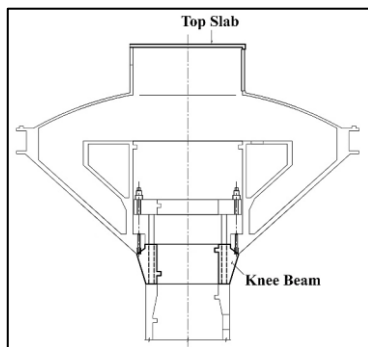


Figure 12. Display construction of knee beam and top slab

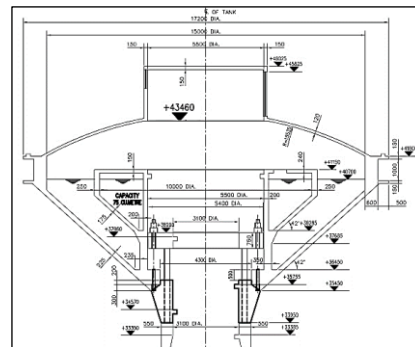


Figure 14. Sectional Elevation of tank bowl

STAGE-VI

In this stage, the lifting mechanism has been taken down, and the pipes and cables have been installed. To finish the building, top slabs were cast once the service lines were finished, as shown in Figure 13 and Figure 14.

Design Methodology

Geometrical Properties: The details of the outer chamber and inner chamber are given in Table 1.

Analysis: - STAAD Pro (Dattatray and Kamble, 2022) software was used for the modeling

Table 1. Details of Outer and Inner chamber

Details of Outer Chamber	Details of Inner Chamber
Capacity - 20 m ³	Capacity - 75 m ³
Top Diameter - 15 m	Top Diameter - 10 m
Bottom Diameter - 6.2 m	Bottom Diameter - 5.9 m
Height - 5.35 m	Height - 2.765 m

and analysis of the tank, considering the following breakdown of the structure:

- The annular shaft up to the staging height.
- The tank is filled to the top with the tank bowl in place under operating and non-operating conditions.
- The design and detailing of the various tank bowl components, together with the central

shaft, deck slab, and other supporting facilities of the tank, were completed to fit the construction and erection mechanism of the entire structure.

- Along with being built to withstand water loads, the structure was also tested for wind and seismic loads that were typical at the Egyptian location of Sadat City. According to the requirements of the Egyptian code, the various factors for design against wind load and seismic load were taken into consideration (Permanent Committee, 2007).

The following are the key parameters taken into account during design calculations:

- The design utilised high-yield deformed bars of grade St 36/52 with yield stresses of 360 N/mm² and ultimate stresses of 520 N/mm², together with M30 grade concrete. However, the tensile stress of untreated steel is restricted to 100 N/mm² for fracture management.
- The main purpose of conical tanks was to manage membrane forces brought on by hydrostatic pressure and self-weight. For seismic stress conditions, the impact of hydrodynamic pressure on the tank wall has also been taken into account.
- By restricting the tensile stress of the concrete to 2.0 N/mm² and reducing the stress in the steel, as is typically used for water retention structures, the walls were built as uncracked sections.

In order to control cracks and limit the bar diameter of the reinforcement, the following formula has been adopted (Permanent Committee, 2007):

$$\Phi \leq r \left(\frac{\mu_z}{f_s} \right)^2 \times 10^6$$

where,

f = largest bar diameter

r = coefficient to take the bond properties of the steel.

$$f_s = 100 \frac{A_{st}}{A_{ct}}$$

A_{st} = area of tension reinforcement.

A_{ct} = area of concrete section at the tension zone.

f_s = tensile stress in reinforcement resulting from working loads.

The structure was checked against wind load for the following intensity along the height of the tank taken as depicted in Table 2:

Table 2. Variations in Wind Pressure with Height

Height (m)	Intensity of wind pressure (kN/m ²)
0-10	0.75
10-20	0.825
20-30	0.975
30-50	1.125

calculating the base shear (V) due to seismic load is as follows: The formula (Permanent Committee, 2007) adapted for:

$$V = Z.I.K.C.S.W$$

where,

Z = Seismic intensity factor = 0.2 (Zone 2 map for Sadat City).

I = Importance factor = 1.25 for emergency services.

K = Structural system and ductility co-efficient = 1.33 for cores, shear walls, or braced frame system.

$$C = \text{Structure co-efficient} = \frac{1}{15} \sqrt{T}$$

Where,

T = Fundamental Natural Period

S = Soil coefficient, which depends on the type of soil below the foundation = 1.15 for medium-density soil.

W = Total weight of structure design of jack supporting deck slab and jacking system.

- When lifting the tank bowl, lifting beams should be examined for areas of significant stress.
- Checking the impact of a focused load during the raising of the tank bowl on the circular deck slab at +38.2m level and the supporting columns.
- The structure has been detailed to meet the needs of building and erection. Additionally, the design and finishing of the tank were completed according to the terms outlined in (Permanent Committee, 2007).
- During the construction of the jack supporting platform and the knee beam connecting the tank bowl to the main shaft, it is crucial to follow the specific details outlined in Figure 15 (a), Figure 15 (b), and Figure 16, which highlight essential structural components.

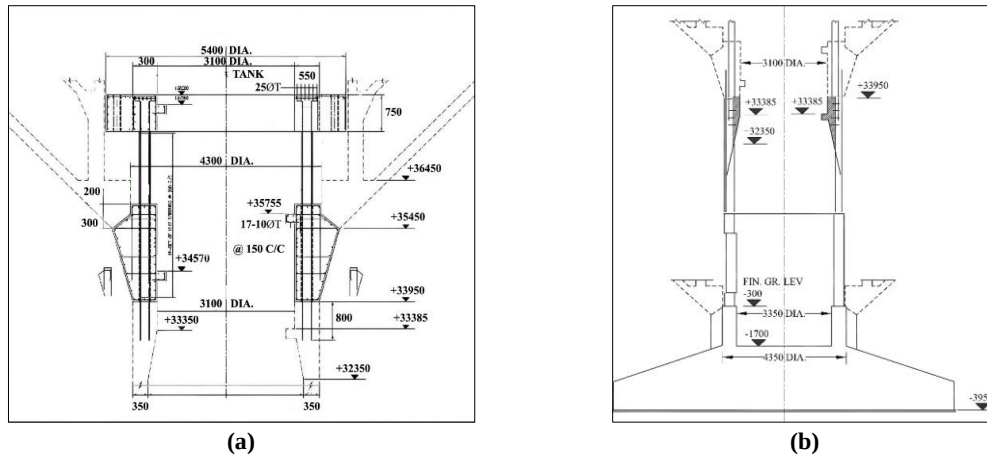


Figure 15. (a). Display the details of additional reinforcement in the knee beam and jack-supported column slab and (b). Display the details of additional reinforcement in the knee beam and jack-supported column slab

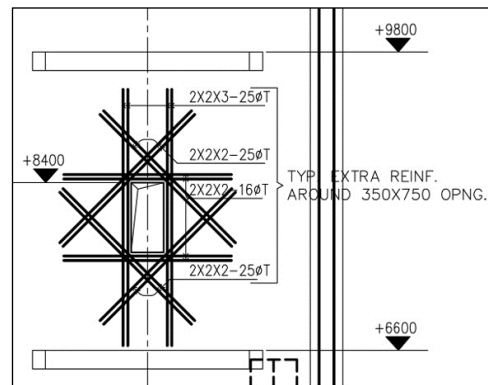


Figure 16. (a). Display the detail of additional reinforcement around openings

- Based on the design output the details of the several components of the tank are given in

Table 3-Summary of design of different components of tank bowl.

Table 3. Summary of different tank bowl

Component	Thickness (mm)/ Width × Depth	Reinforcement provided	$\theta_{\max}$ (allowable) (mm)	Allowable Spacing (mm)	Tensile stress in concrete (N/mm ²)
Top Dome	120	12ΦT@200c/c (ring) 10 ΦT @200c/c (radial)	32.97 22.75	200c/c	0.781
Outer Ring Beam	600 × 1300	31-20 ΦT 10 ΦT @200c/c	43.68	$p_{t,\min.} = 0.4\%$	1.1
Outer conical dome	225	16 ΦT @200c/c (ring) 12 ΦT @200c/c (radial)	49.78 17.5	200c/c	0.99
Inner top slab platform	150	10 ΦT @200c/c (T & B) Both ways	18.2	200c/c	2.008
Inner ring beam	250 × 1200	16-20 ΦT 10 ΦT @200c/c	22.4	200c/c	0.38
Inner conical dome	175	12 ΦT @125c/c (ring) 12 ΦT @200c/c (radial)	36.16 22.6	200c/c	0.71

Time Schedule: The time required for construction was considerably reduced as compared to conventional approaches to construction. Table 4 shows the savings in time required for the construction of the tank as compared to conventional construction methods.

Table 4. Display the savings in time for different methodology of construction

Methodology of construction	Saving in time
- Slip Form method of shaft construction & conventional method of tank bowl construction	20%
- Slip Form method of shaft construction & heavy lifting of tank bowl constructed at bottom	50%

Results and Discussion

In the construction of a 275 m³ capacity tank, towering 36.75 meters high, the slip-forming and heavy-lifting techniques played a crucial role. This innovative approach utilized twin chambers—one with a 75 m³ capacity and the other with a 200 m³ capacity supported by a circular shaft, revolutionizing the project's design structure. Throughout the tank's construction, extensive scaffolding and formwork were employed, showcasing the technique's efficiency. By permitting the formwork to ascend continuously, it was able to adhere to strict time constraints. This technique proved to be a cost-effective approach to constructing such enormous edifices, in addition to its timely efficacy.

Conventional construction methods, on the other hand, could have necessitated long and labor-intensive processes, potentially raising costs due to substantial scaffolding requirements. Furthermore, their viability within time-sensitive project deadlines remains an important consideration, emphasizing the benefit of the selected innovative method.

The Slip Forming and Heavy Lifting Technique redefines the dynamics of building. Its speed and efficiency are its defining characteristics, enabling quick building by preventing pauses for formwork adjustments and preserving a constant upward movement. By cutting labour expenses and overall construction time, this efficiency greatly improves the project's economic feasibility and increases its cost-effectiveness. Furthermore, its expertise in building towering constructions-like overhead tanks underlines its supremacy over less effective conventional techniques in this particular field.

Nonetheless, conventional methods remain applicable in specific situations or for smaller-scale undertakings. These traditional methods, which have a strong foundation in construction history, endure because they are flexible and have well-established learning curves. Considering the comfort and familiarity ingrained in traditional procedures, making the switch to fresh ways may present early hurdles. Employing creative ideas is still crucial for improving construction procedures, even when there may be more initial challenges.

Conclusions

Nowadays, new ventures generally start with high-interest bank loans due to scheduling restrictions. We recommend combining heavy lifting techniques with slip form to speed above-water tank installation. This approach requires design modifications without compromising robustness. Our mission is to transform the building industry by employing innovative methods like slip-forming and heavy lifting while prioritising efficiency and affordability. But efficacy depends on raising the skills of our labour force via training programmes. The application of hybrid approaches—which blends contemporary and conventional methods is another fascinating idea. These hybrids optimize prices and efficiency for a range of jobs by offering comprehensive solutions. Cutting-edge technologies and time-tested techniques are combined in this way to maximize the advantages of building from an economical and practical standpoint.

Acknowledgement

The work was completed in its entirety in accordance with Indian standards. There is no piracy in the study effort; in fact, some information has been gathered to enhance my research, and the specifics of those data are cited in the footnotes.

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