INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

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Research Paper

Evaluation Of Challenges in Implementation of Safety Measures During NDCT Construction

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ARTICLE INFO

Published: 18 May 2026

Keywords:

Argyreia speciosa, Argyreia nervosa, elephant creeper, Ghav-patta, Vryddhadaraka

DOI:

10.5281/zenodo.20268587

ABSTRACT

Natural draught cooling towers (NDCTs) play a crucial role in modern thermal and nuclear power generation by enabling effective heat dissipation while maintaining environmental sustainability. Among these, the hyperbolic cooling tower configuration is the most widely used due to its structural efficiency and superior airflow characteristics. The increasing height and mass of these towers introduce complex load behaviors and design challenges, making advanced analysis and construction methods essential. This paper provides an overview of the development of cooling tower technology, highlighting recent innovations in design, simulation, and construction practices, as well as the difficulties commonly encountered during implementation.Recent advances in formwork systems have enabled the casting of larger structural elements in a single operation, significantly improving productivity, quality, and cost-effectiveness compared to traditional techniques. This study presents a comparative evaluation of conventional formwork and modern jump formwork methods, emphasizing their suitability for hyperbolic NDCT construction. Particular attention is given to the identification and mitigation of risks associated with material handling and work on temporary platforms, areas that contribute to a substantial proportion of workplace incidents. The findings aim to support the development of safer and more efficient construction practices in the NDCT sector

INTRODUCTION

NDCT jump formwork refers to a temporary or permanent mold, including all supporting members, used to shape and support concrete until it gains sufficient strength to carry its own weight. It must be capable of supporting all imposed dead and live loads in addition to its own weight. Jump formwork systems used in concrete frame construction have evolved significantly since the early 1990s. Major innovations have focused on improving on-site production efficiency, health

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

and safety standards, and environmental considerations, driving the concrete construction industry toward higher efficiency and better quality. Different formwork systems offer a wide range of construction solutions that can be selected based on the specific requirements of a project.

Traditional formwork for concrete construction typically consisted of custom-made solutions requiring skilled labor. Such systems often had limited safety features, resulted in slower construction progress, and generated a high level of material waste.

Constructional components of NDCT can be broadly classified into the following categories based on their functional requirements:

- Foundation and pond basin
- Raker columns and ring beam framework
- Shell
- Grillage structures and precast louvers

This study focuses on analyzing the hazards, risks, and potential injuries associated with each activity involved in the erection and construction of hyperbolic NDCT jump formwork.

II. LITERATURE REVIEW

1. Advances in Cooling Tower and Safety Procedures (2021)

Rahul V. Fulzele, Sushant Gajbhiye

This study discusses recent theoretical and experimental developments in natural draught hyperbolic cooling towers. It analyzes key design parameters, structural behavior, and safety aspects, providing updated knowledge that supports improved design practices and future research in cooling tower technology.

2. Comparative Study of Formwork Techniques (2018)

Arbaz Kazi, Fauwaz Parkar

This paper emphasizes the importance of selecting appropriate formwork systems in construction projects. It compares different techniques based on cost, time, and efficiency, helping contractors make better decisions to improve productivity and reduce project delays.

3. Safety Inspection of Jump Form and Slip Form Systems (1983)

S.G. Fattal

This guide outlines essential safety requirements in construction, focusing on the stability of partially completed structures and the strength of early-age concrete. It highlights the importance of proper anchorage, safe access systems, and continuous safety monitoring to prevent accidents during jump form and slip form operations.

4. Construction Safety Management Framework (1991 / 2004)

Helander M.G., Evelyn Ai Lin Teo

This study proposes the 3P+I framework (Policy, Process, Personnel, Incentive) for effective safety management in construction. It identifies major causes of site accidents, including weak safety policies, unsafe practices, lack of worker training, and poor management commitment, and suggests structured approaches to improve overall site safety.

III. SUSTAINABILITY

Sustainability refers to the ability to maintain or support a process continuously over time without depleting natural or physical resources. In engineering and construction, it focuses on efficient resource utilization, environmental protection, and long-term development. It ensures that current needs are met without compromising the ability of future generations to meet their own needs. Sustainability is broadly classified into three core aspects: economic, environmental, and social.

3.1 Three Pillars of Sustainability

The concept of sustainability is based on three main pillars—economic, environmental, and social, often referred to as profit, planet, and people. Economic sustainability focuses on efficient use of resources to support long-term economic growth, including both renewable and non-renewable resources. Environmental sustainability emphasizes the protection of natural systems such as air, water, and soil, which are essential for human survival and industrial activities. Social sustainability addresses human well-being by promoting equality, improving living standards, and reducing poverty and hunger.

IV. HYPERBOLIC STRUCTURES

Hyperbolic structures are characterized by negative Gaussian curvature, meaning they curve inward rather than outward or remaining flat. These geometries provide high structural efficiency and strength, making them suitable for large-scale construction projects.

Hyperbolic paraboloids are particularly significant because they can be constructed using straight members, making them economical and easy to build. Their curved surface offers excellent stiffness, enabling them to withstand heavy loads over large spans. Similarly, hyperboloid structures are widely used in modern architecture and engineering due to their stability and aesthetic appeal, as seen in towers and high-rise structures.

There are three basic structural types: shell structures, frame structures, and solid structures, though many real-world structures combine these forms. Common examples of hyperbolic structures include natural draught cooling towers (NDCT) and chimneys.

APPLICATIONS

Hyperbolic paraboloid structures are widely used in roofing systems because their ruled surface allows construction with straight elements, simplifying design and reducing costs. Cooling towers in power plants are typically constructed as hyperboloids, as this shape provides high structural stability and efficient load distribution.

Hyperbolic forms are also useful in engineering applications such as modeling hanging cables or electrical lines between supports, where the curve represents the natural shape formed under self-weight.

V. GUIDANCE TO JUMP FORM AND SLIP FORM

5.1 Slip Form

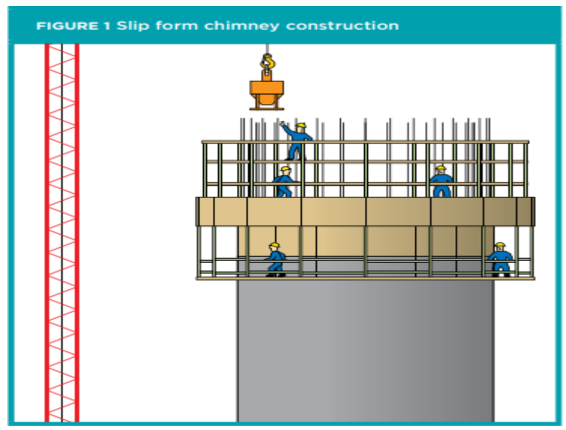

Fig 5.1: Slip Form Construction

Slip form and jump form are self-climbing formwork systems used for constructing vertical concrete structures such as silos, chimneys, and high-rise cores. These systems use hydraulic or electric mechanisms for climbing. Slip forms move continuously during concrete pouring, producing smooth, joint-free structures. They include working platforms and safety screens, and their design depends on the structure's size and shape.

5.2 Jump Form

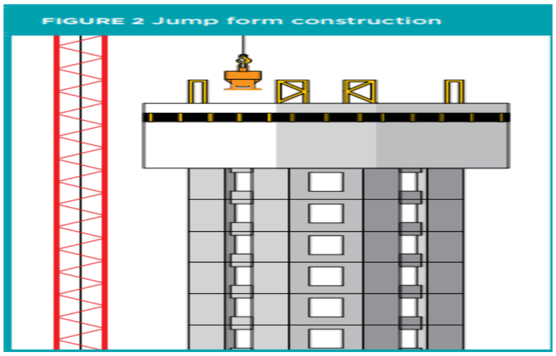

Fig 5.2: Jump Form Construction

Jump forms move in stages after each concrete pour, making them suitable for structures with multiple levels like high-rise buildings. Unlike slip forms, they create visible joints but offer better control during construction.

5.3 Design Considerations

Key factors include minimum concrete strength before climbing, load considerations (dead, live, wind), handling of eccentric loads, maintaining level alignment, fire protection, temporary power supply, worker safety (refuge and rescue systems), and proper operating manuals.

5.4 Types of Jump Form

- Normal/Climbing Form – lifted by crane
- Guided Climbing Form – crane-assisted with better control
- Self-Climbing Form – hydraulic system, no crane required
- Gliding Form – continuous movement, produces seamless structures but requires uninterrupted operation

5.5 Applications

Used in construction of:

- Shear walls
- Core walls
- Lift shafts
- Stair shafts
- Bridge pylons

5.6 Advantages of Jump Form

- Faster construction and improved productivity
- Reduced crane dependency (in some systems)
- Better surface finish and quality
- Suitable for high-rise and windy conditions
- Minimizes scaffolding and labor time
- Easy planning due to repetitive operations

5.7 Travelling Forms

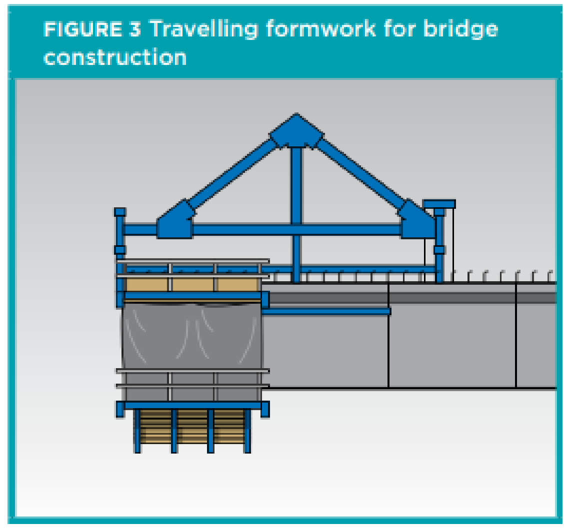

Fig 5.7: Travelling Formwork

Travelling formwork moves horizontally and is mainly used in bridge construction. It is supported by the completed structure, eliminating the need for ground support, making it ideal over rivers or roads.

5.8 Design Aspects

Design of slip, jump, and travelling forms is complex and requires experienced engineers. Important considerations include load capacity, concrete strength, environmental effects, hazard control, safe access, sufficient workspace, and emergency rescue provisions. Proper design helps minimize risks, especially when working at heights.

VI. NATURAL DRAFT COOLING TOWER

A natural draft cooling tower is a heat exchanger used to cool water by direct contact with air. It is widely used in power plants, oil refineries, and petrochemical industries to remove excess heat. The system works on natural convection, where airflow is created due to the density difference between warm air inside the tower and cooler outside air, eliminating the need for mechanical fans.

6.1 Principle

The working of a natural draft cooling tower involves key components:
• Hot water inlet – distributes hot water through spray nozzles
• Fill material – increases surface area for heat transfer
• Cold water basin – collects cooled water for reuse
• Air inlet – allows fresh air entry at the base
• Air outlet – releases warm air at the top
Cooling occurs through two mechanisms:
• Sensible heat transfer – heat exchange without phase change
• Latent heat transfer – cooling by evaporation of water
The combined effect cools the water, while warm air rises upward, creating a continuous natural draft cycle.

6.2 Types

• Counter flow towers – air moves upward against downward water flow; high efficiency but requires more height
• Cross flow towers – air flows horizontally; lower height but slightly less efficient

6.3 Applications

Used in:
• Thermal and nuclear power plants
• Oil refineries
• Petrochemical industries
• Natural gas processing plants
Preferred where large cooling capacity, low power consumption, and long-term operation are required.

6.4 Advantages and Disadvantages

Advantages:
• No fans required, reducing power and noise
• Low maintenance and operational cost
• High cooling capacity
• Minimal water loss and no air recirculation
Disadvantages:
• High initial construction cost
• Requires large space and height
• Aesthetic and permission challenges
• Performance affected by wind conditions

VII. METHODOLOGY

7.1 Procedure for Assembly, Erection and Lifting of Jump Form System

Purpose:
To provide guidelines for safe assembly, erection, and operation of the jump form system used for working on the shell in construction projects.

Pre-requirements:
• Authorized foreman and engineer
• Area clearance and barricading
• Tower crane with tested slings and shackles
• PPE (helmet, gloves, safety shoes, full body harness, safety nets)
• Pre-embedded anchors/sleeves
• Signal man and rigger

Procedure:

1. Ensure initial concrete lifts and anchor screws are in place.

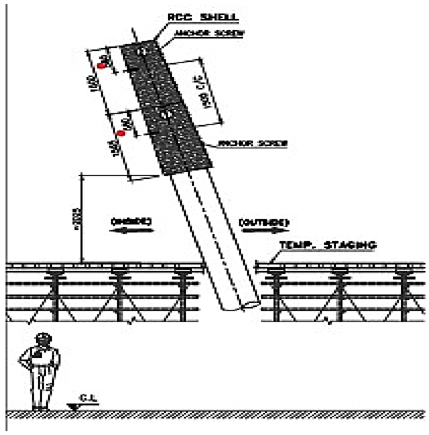

Fig 7.1

2. Assemble main rig at ground level.

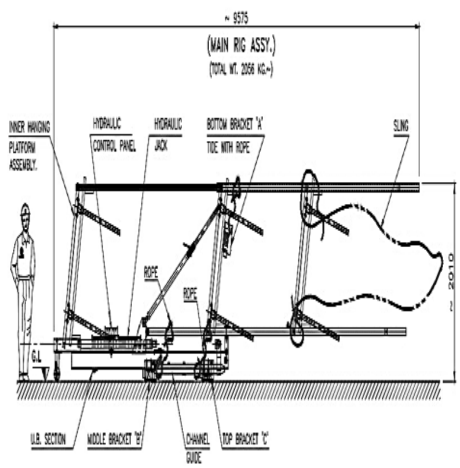

Fig 7.2

3. Lift rig assembly (approx. 2056 kg) using tower crane near RCC shell. Use rope for positioning and ensure worker safety with lifelines and harness.

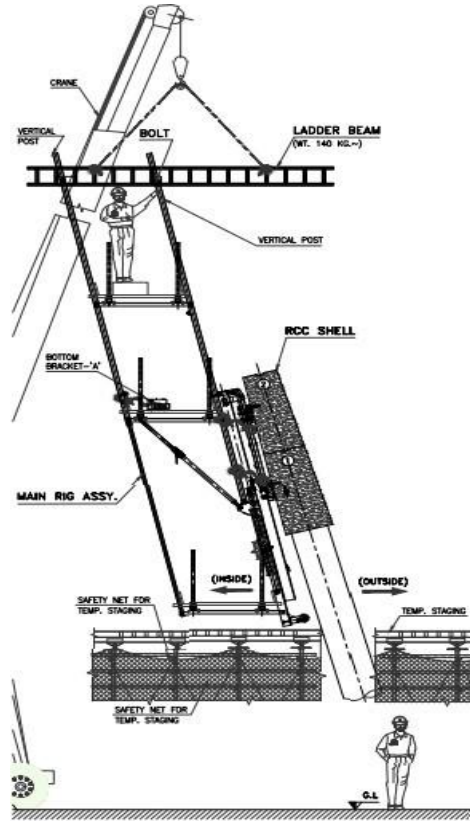

Fig 7.3

4. Fix brackets (middle and top) to anchor screws and transfer load to brackets. Release crane after securing.

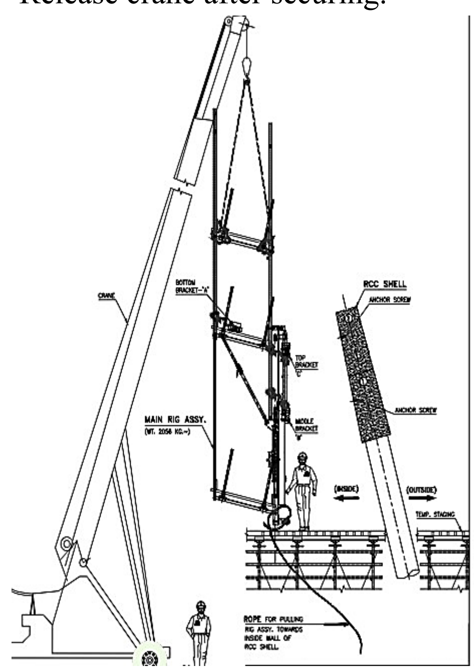

Fig 7.4

5. Lift and fix ladder beam (approx. 140 kg) to rig assembly.

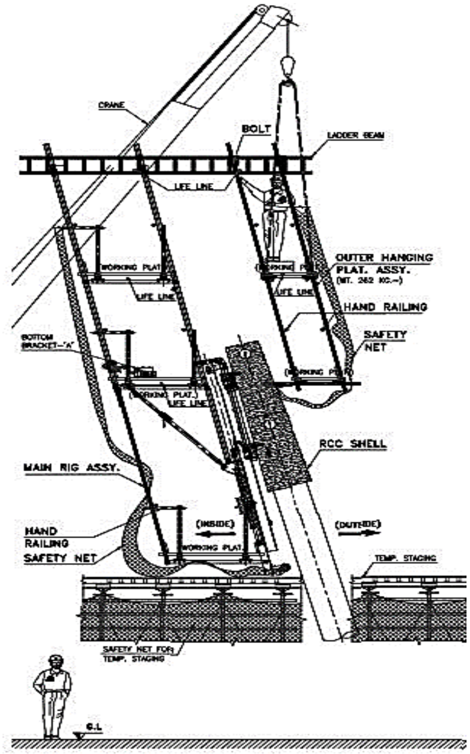

Fig 7.5

6. Assemble and install outer hanging platform (approx. 262 kg) with crane. Provide handrails and safety nets.

7. After all rigs are positioned, connect hydraulic system and fill with oil.

8. Operate hydraulic jack and engage with guide system for lifting.

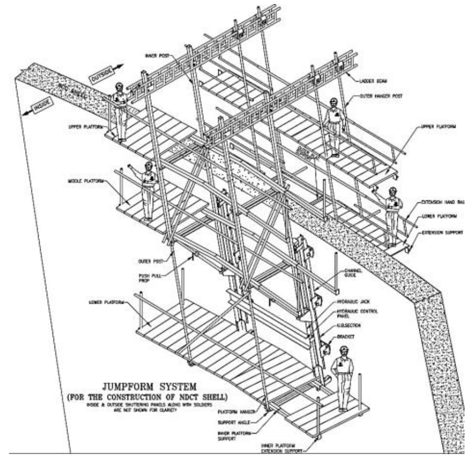

Fig 7.6

VIII. HYDRAULIC SYSTEM OF JUMP FORM

The hydraulic system is a key component of the jump form system, used for lifting the rig to higher levels during construction.

8.1 Power Pack

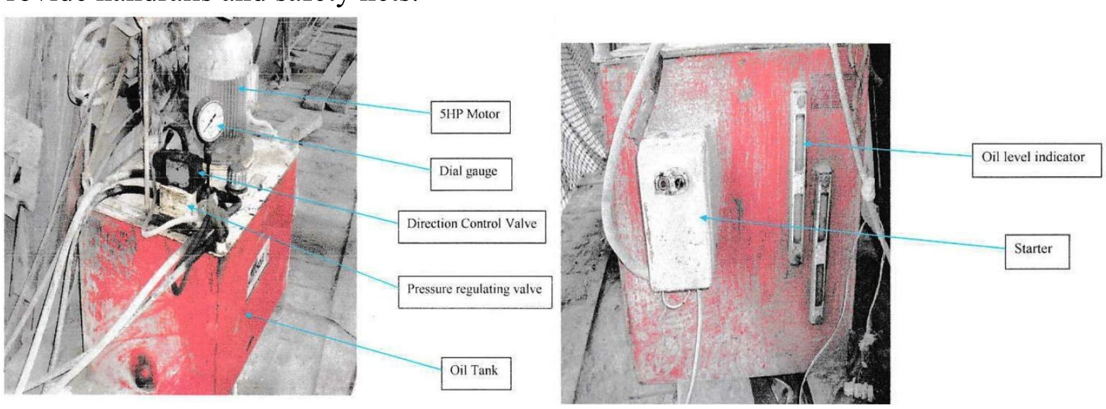

Fig 8.1 & 8.2

The power pack supplies hydraulic energy for lifting operations. One power pack can operate up to 18 rigs, with each rig lifted up to 1.5 m using hydraulic jacks.

Main Components:

- 5 HP motor (1445 RPM) – drives the pump
- 200-liter oil tank – stores hydraulic oil (Grade 68 recommended)
- Directional control valve – controls oil flow direction

• Pressure regulating valve – adjusts oil pressure
• Dial gauge – displays pressure (up to 150 bar)
• Filter – removes impurities
• Dowty pump (3028) – pumps hydraulic oil
• Oil level indicator – monitors oil level

8.2 Control Panel and Hose Connectors

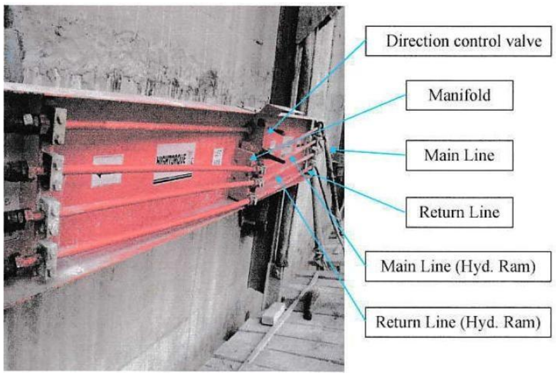

Fig 8.3

Each rig has an individual control panel for operation.

Functions:

• Directional control valve – starts/stops lifting by controlling oil flow
• Manifold with levers – operates hydraulic rams
• Main line – supplies oil from power pack to rigs
• Return line – carries oil back to the power pack

The system ensures smooth, controlled, and safe **lifting of jump form rigs during construction.**

IX. HAZARDS AND RISKS IN NDCT CONSTRUCTION BY JUMP FORM TECHNOLOGY

9.1 Material Shifting using Tower Crane

Hazards: Fall of materials, collision, overloading, wind effects
Recommendations: Proper rigging team, safe rigging practices, tag lines, good communication

9.2 Tower Crane Mast Erection

Hazards: Fall from height, electrical shock, material fall, equipment failure
Recommendations: Double fall protection, proper anchoring, training, supervision

9.3 Passenger Lift Mast Erection

Hazards: Fall from height, entanglement, electrical risks
Recommendations: Fall protection, safe platforms, training, supervision

9.4 Incomplete Working Platforms

Hazards: Fall from height, loose materials, structural issues
Recommendations: Proper handrails, safety nets, barricading, training

9.5 Improper Lifeline Provision

Hazards: Fall from height, lifeline damage, poor supervision
Recommendations: Proper lifelines, regular inspection, training, 100% tie-off

9.6 Fall of Materials

Hazards: Falling debris, fire risk, property damage
Recommendations: Safety nets, housekeeping, PPE, controlled work zones

9.7 Improper Material Storage

Hazards: Material fall, ergonomic issues, collisions
Recommendations: Proper stacking, stoppers, training, supervision

9.8 Concrete Bucket Shifting

Hazards: Concrete spillage, collision, health risks
Recommendations: Proper locking, daily inspection, communication

9.9 Tower Crane Anchoring & Guide Ropes

Hazards: Fall from height, collision with ropes
Recommendations: Fall protection, reflective markers, training

9.10 Hydraulic Jack Failure

Hazards: Structural failure, oil leakage, fire risk
Recommendations: Inspection, proper maintenance, trained personnel

9.11 Improper Access & Platforms

Hazards: Fall, structural instability
Recommendations: Safe ladders, proper platforms, regular checks

9.12 Jump Form Frame Erection

Hazards: Fall from height, collision, weather risks Recommendations: Fall protection, training, supervision

9.13 Electrical Power Failure

Hazards: Poor visibility, electrocution, fall risks Recommendations: Electrical safety devices, inspections, emergency support

9.14 Tower Crane Activity

Hazards: Crane collapse, load fall, collisions Recommendations: Skilled operators, communication, regular inspection

9.15 Mobile Crane Activity

Hazards: Equipment failure, collisions, falling loads

Recommendations: Trained crew, inspection, safe operation

9.16 Adverse Weather Conditions

Hazards: Poor visibility, wind effects, electrical risks

Recommendations: Stop work during extreme weather, proper evacuation plan

9.17 Improper Housekeeping

Hazards: Fire, slips, environmental risks Recommendations: Regular cleaning, proper storage, supervision

9.18 Safety Management Systems

Use structured systems like PDCA cycle to improve safety, reduce accidents, and ensure compliance.

9.19 Training & Site Inspections

Includes induction training, medical checks, toolbox talks, equipment inspections, and fire safety checks to ensure overall site safety.

RESULTS AND DISCUSSION

The implementation of a structured safety management system in NDCT construction using jump form technology has significantly improved overall site safety performance.

10.1 Reduction in Unsafe Acts and Conditions

Unsafe acts such as lack of PPE, improper anchoring, and unsafe material handling were reduced. Unsafe conditions like missing handrails, poor lifelines, and housekeeping issues were identified and corrected through regular inspections.

10.2 Work at Height Safety Improvement

Use of double fall protection systems (FBH + RFA), proper lifelines, and regular vertigo tests reduced fall risks and increased worker confidence.

10.3 Equipment and Lifting Safety

Improved safety in tower crane operations, concrete bucket handling, and hydraulic systems through inspections, trained operators, and proper communication minimized risks like load fall and collisions.

10.4 Housekeeping and Material Management

Planned housekeeping reduced trip hazards, fire risks, and improved material storage, leading to a safer work environment.

10.5 Environmental and Health Improvements

Dust and noise were controlled, PPE usage increased, and regular health checkups improved worker safety and well-being.

10.6 Training and Awareness

Toolbox talks, work-at-height training, and equipment safety programs increased awareness, reduced errors, and improved compliance.

10.7 Safety Management System

Implementation of the PDCA cycle ensured continuous monitoring, corrective actions, and improvement in safety performance.

10.8 Overall Result

The study confirms that proper safety planning, training, and supervision significantly reduce hazards and ensure safer working conditions in NDCT construction.

CONCLUSION

Recent advancements in the design and construction of natural draught hyperbolic cooling towers have been studied, with a focus on hazards, risks, injuries, and safety improvements. This research provides a comprehensive understanding of safety challenges in NDCT construction using jump form technology and offers updated insights for future analysis.

The study emphasizes the importance of safe work procedures, proper implementation, continuous monitoring through checklists, and detailed risk assessments. Feedback systems also play a key role in improving safety practices and ensuring effective control of construction activities.

Management involvement is critical in addressing these safety issues, as they directly impact project performance and business risk. By strengthening Health, Safety, and Environment (HSE) systems and procedures, organizations can enhance overall safety standards.

Continuous implementation and monitoring of safety measures will help achieve the ultimate goal of zero accidents and incidents in the workplace.

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HOW TO CITE: T. Karthikeyan, P. Lingeswaran, Dr. S.Prakasam, Kannakumar K, Evaluation Of Challenges in Implementation of Safety Measures During NDCT Construction, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 5, 4519-4528, https://doi.org/10.5281/zenodo.20268587