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Revolutionizing Metro Construction: Exploring Advanced Precast Design and Technology for Time and Cost Savings in Pune Metro Station

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Abstract

Metro systems have become a crucial component of urban transportation infrastructure, offering efficient and sustainable mass transit solutions. However, the construction of metro stations often poses challenges in terms of time and cost overruns. This research paper aims to explore the potential of advanced precast design and technology in revolutionizing metro construction, with a specific focus on Pune Metro Station. By adopting precast construction methods, this study seeks to identify the benefits, challenges, and opportunities associated with precast technology, ultimately aiming to provide insights into improving the efficiency, cost-effectiveness, and timely completion of metro projects.

1. Introduction

1.1 Background

Pune, located in the state of Maharashtra, India, is a rapidly growing city with a population of over 3 million. With increasing urbanization and vehicular congestion, there was a pressing need for an efficient and sustainable mass transit system in the city. To address this, the Government of Maharashtra initiated the Pune Metro rail project.

The construction of metro stations in Pune poses various challenges, including the need for efficient project management, coordination with multiple stakeholders, land acquisition, environmental considerations, and ensuring minimal disruption to existing infrastructure and public life.

To overcome these challenges and expedite the construction process, innovative approaches and advanced technologies are being explored, including the use of precast design and technology. By adopting precast construction methods, the Pune Metro project aims to streamline the construction process, reduce time and cost overruns, and ensure the timely completion of metro stations.

The use of precast technology in Pune Metro construction has the potential to revolutionize the traditional construction methods and bring numerous benefits, such as faster construction, improved quality control, enhanced durability, and reduced environmental impact.

In conclusion, the Pune Metro project is a significant endeavour aimed at transforming the transportation landscape of Pune. By adopting advanced construction techniques like precast design and technology, the project seeks to overcome challenges and deliver a modern, efficient, and sustainable metro system to meet the city's growing transportation needs.

1.2 Research Objectives

- To understand the evolution of precast technology with respect to station construction.
- To compare the early precast technology with modern technology.
- To analyse the role of advancement of precast technology with respect to time savings.
- To analyse the role of advancement of precast technology with respect to cost savings.

1.3 Methodology

1.3.1 Problem Statement

"As metro cities' infrastructure work increases significantly. However, due to landscarcity and traffic congestion in metro areas, precast construction is essential. The precast Super Structure is one of the greatest options to achieve quality requirement, affordability, and time. Now a day construction industry needs to be industrialized to achieve production time and finishing of structure. Construction industry requires ecofriendly techniques to avoid pollutions caused while constructions which can be considerably controlled in precast casting yard where construction activities are runningin designated area likely outside of cities."

1.3.2 Methodology

- Study the different types of precast superstructure used in Infrastructure projects and the need of precast structure in metro cities.
- Conduct general review of construction industry and literature review to investigate the present scenario of precast superstructure in Infrastructure project.
- Physical visit to Pune metro elevated stations and casting yard and review the types of spans, types of structures and the sequence of construction. Data collection from site about the cost and time involved in each activity.
- Using the approved drawings, Examining the feasibility of Precast elements in actual case study (Pune Metro) in consideration of time (Time Duration, Manpower)and Cost (Material Cost, Erection/Placement Cost, finishing, maintenance & total cost taking suitable case study and comparison with cast in situ construction)
- Examine the feasibility of Precast elements in actual case study (Pune Metro) in consideration with quality.

2. Metro Construction Challenges

2.1 Time Overruns

Time overruns in metro construction projects have been a persistent challenge in the industry. Several factors contribute to these delays, ranging from project management issues to unforeseen complexities. Understanding these challenges is crucial for addressing them effectively and ensuring timely completion of metro construction projects. Here are some key time overrun challenges in metro construction :-

- Planning and Design Phase:
  Inadequate planning and design can lead to delays in the project right from the beginning. Insufficient feasibility studies, inaccurate project scoping, and design changes during the construction phase can significantly impact the timeline.
- Land Acquisition and Right-of-Way:
  Acquiring the necessary land and securing right-of-way for the metro alignment can be a lengthy and complex process. Delays in acquiring land or resolving disputes with landowners can halt construction progress and cause time overruns.
- Environmental Clearances and Regulatory Approvals:
  Metro projects often require obtaining various environmental clearances and regulatory approvals from government agencies. Delays in obtaining these approvals can disrupt the construction schedule and lead to project delays.
- Funding and Financing:
  Insufficient funding or delays in securing financial resources can slow down the construction process. Metro projects heavily rely on government funding or public-private partnerships, and any delays in financing can have a cascading effect on the project timeline.
- Project Management and Coordination
  Effective project management is crucial for timely completion of metro construction. Poor coordination among different stakeholders, lack of experienced project managers, and inadequate risk management can result in delays and inefficiencies.
- Utility Relocations
  Metro projects often require the relocation or diversion of existing utilities such as water lines, sewerage, electricity, and telecommunication networks. Coordinating with utility providers and carrying out these relocations can cause delays if not properly planned and executed.
- Geotechnical and Construction Challenges
  Metro construction involves dealing with various geotechnical challenges such as soil conditions, underground utilities, and difficult terrain. Unexpected ground conditions or encountering archaeological sites can significantly impact the construction timeline.
- Supply Chain Management
  Delayed procurement of construction materials, equipment, and components can disrupt the construction schedule. Issues with suppliers, logistics, and quality control can contribute to time overruns.
- Labor and Workforce Issues: Availability of skilled labor, labor strikes, and disputes can hamper construction progress. Inadequate workforce management and delays in mobilizing labor can lead to significant time delays.
- Unforeseen Risks and External Factors: External factors like natural disasters, political instability, and public protests can pose unexpected risks and cause project delays.

Addressing these time overrun challenges requires a holistic approach, including robust project planning, efficient project management, stakeholder coordination, and risk mitigation strategies. Embracing innovative construction technologies, such as precast design and off-site fabrication, can also contribute to accelerated construction and timely completion of metro projects.

2.2 Cost overruns

Cost overrun challenges in metro construction projects pose significant financial risks and can have adverse effects on project viability. Understanding and addressing these challenges are crucial for ensuring cost-effective delivery. Here are some key cost overrun challenges in metro construction :-

- Inaccurate Cost Estimation
  Poorly estimated project costs during the planning and design phase can lead to cost overruns. Factors such as inadequate assessment of project scope, underestimation of material and labor costs, and failure to account for unforeseen contingencies can result in budget deviations.
- Land Acquisition and Compensation: The cost of acquiring land for metro construction can be a substantial portion of the project budget. Delays or disputes in land acquisition and the associated compensation process can inflate costs, impacting the overall project budget.
- Construction Delays: Time overruns, as discussed previously, can lead to cost overruns. Construction delays result in extended project durations, which often require additional resources, manpower, and equipment, leading to increased costs.
- Changes in Design or Scope: Design changes during the construction phase can significantly impact costs. Modifications to the initial design due to unforeseen challenges or stakeholder demands can lead to additional expenses, including redesigning, rework, and procurement of new materials.
- Inflation and Price Fluctuations: Metro projects often span several years, and during this time, inflation and price fluctuations can occur. Escalating prices of materials, fuel, labour, and equipment can exceed the initially estimated costs, resulting in cost overruns.
- Unforeseen Site Conditions: Metro construction often encounters unforeseen site conditions, such as encountering unexpected underground utilities, difficult terrain, or encountering archaeological sites. These conditions may require additional resources, equipment, or alternative construction methods, thereby increasing costs.
- Contractual Disputes and Claims: Disputes and claims between contractors, subcontractors, and project owners can lead to cost overruns. Litigation costs, penalties, and delays caused by legal disputes can impact the project budget.
- Currency Exchange Rates and Financing Costs: For metro projects financed through foreign sources or with international contractors, fluctuations in currency exchange rates can lead to cost variations. Additionally, financing costs, including interest rates and loan repayments, can impact the project budget.
- Inadequate Risk Management: Insufficient identification, assessment, and mitigation of project risks can result in cost overruns. Lack of contingency plans for potential risks, such as natural disasters, labor strikes, or unforeseen geological conditions, can lead to additional expenses.
- Poor Project Management and Governance: Ineffective project management practices, including weak cost control mechanisms, inadequate monitoring, and governance, can contribute to cost overruns. Lack of transparency, accountability, and proper financial management can lead to financial discrepancies and increased project costs.

Addressing cost overrun challenges requires accurate cost estimation, diligent project management, effective risk management strategies, and transparent governance. Regular monitoring, proactive mitigation of risks, and robust financial control mechanisms are essential for controlling costs and ensuring the financial sustainability of metro construction projects

2.3 Sustainability Concerns

The construction of metro systems has gained popularity in urban areas around the world due to their potential to alleviate traffic congestion and reduce carbon emissions. To expedite the construction process, many metro projects are incorporating precast concrete elements. While precast construction offers several advantages, it also raises sustainability concerns that must be addressed to ensure long-term environmental and social benefits.

- Material Sourcing: One of the key sustainability concerns associated with precast metro construction is the sourcing of materials. Precast concrete requires large quantities of aggregates, cement, and steel, all of

which have significant environmental impacts during extraction, manufacturing, and transportation. It is crucial to prioritize sustainable sourcing practices, such as using recycled materials and locally available resources, to minimize carbon footprints and support local economies

- Energy Consumption: The production of precast elements involves energy-intensive processes, including transportation, curing, and assembly. Energy consumption must be carefully managed by adopting energy-efficient manufacturing techniques, utilizing renewable energy sources, and optimizing transportation logistics. Minimizing energy use not only reduces carbon emissions but also lowers operational costs, making the metro system more economically sustainable.
- Waste Generation: Precast construction can generate substantial amounts of waste, including off cuts, packaging materials, and excess concrete. Proper waste management strategies, such as recycling and reusing materials, should be implemented throughout the construction process. Recycling precast elements after the end of their lifecycle can also reduce the environmental impact of decommissioning and promote a circular economy approach.
- Transport and Logistics: Transporting precast elements from manufacturing facilities to the construction site often requires large vehicles and long-distance travel. This can contribute to congestion, road wear, and increased emissions. Optimization of logistics through route planning, using eco-friendly transportation methods, and coordinating delivery schedules can mitigate these sustainability concerns associated with transportation.
- Life Cycle Assessment: To evaluate the overall sustainability of metro construction using precast, a comprehensive life cycle assessment (LCA) should be conducted. An LCA considers the environmental impacts at each stage of the project, including material extraction, manufacturing, transportation, construction, and maintenance. It helps identify areas where improvements can be made, enabling the adoption of more sustainable practices and technologies.

3. Precast Design and Technology

Precast construction has been a part of metro and bridges construction for a long time and many bridges and metro viaducts are constructed using precast technology to achieve various benefits such as timely completion of projects, rapid construction in busy streets and environment friendly construction. But the precast technology has evolved in recent years focusing on time and cost savings in construction ensutring good quality and less impact on the environment.

4. Case Study: Pune Metro Station

4.1 Overview of Pune Metro Project

The Pune Metro project aims to develop a comprehensive metro network across the city and its surrounding areas, providing a reliable and convenient mode of transportation for its residents. The project is being implemented by the Pune Metropolitan Region Development Authority (PMRDA) and the Maharashtra Metro Rail Corporation Limited (Maha-Metro).

The metro system in Pune is designed to cater to the growing transportation demands of the city, reduce traffic congestion, and provide an eco-friendly mode of travel. It is expected to improve connectivity, reduce travel time, and enhance overall urban mobility.

The Pune Metro project consists of multiple phases, with each phase focusing on the development of new metro lines and stations. The initial phase of the project includes the construction of two metro corridors: Line 1 (PCMC to Swargate) and Line 2 (Vanaz to Ramwadi). These corridors cover key areas of Pune, such as Pimpri-Chinchwad, Shivajinagar, and Hadapsar.

4.2 Challenges Faced in Construction

- Land Acquisition: Acquiring the required land for the project can be a complex and time-consuming process. Pune being a densely populated city, acquiring land for metro stations, depots, and alignment was a huge challenge due to existing structures, legal disputes, and resettlement issues.
- Traffic Management: Pune has a high volume of traffic, and construction activities for the metro led to disruptions and congestion. Ensuring smooth traffic flow during the construction phase while simultaneously carrying out construction activities has been a significant challenge.
- Utility Relocation: The alignment of the metro often intersects with existing underground utilities such as water pipelines, sewage lines, and electrical cables. Relocating these utilities without disrupting services is a challenging task and requires coordination with multiple agencies like electricity department, municipal corporation, and water supply department etc.
- Financial Constraints: Funding and financial viability are crucial aspects of any infrastructure project. Securing adequate funds, managing cost escalations, and balancing the project's financial viability with affordable fares for commuters has been a significant challenge for the project's implementation and it required the design to be implemented in such a way that maximum cost savings can be achieved so that the burden on exchequer is reduced.
- Technical and Engineering Challenges: Constructing an elevated or underground metro system involves complex engineering tasks. Ensuring structural integrity, managing geotechnical issues, and incorporating advanced signaling and communication systems are some of the technical challenges faced during the construction of the Pune Metro.
- Environmental Concerns: Metro construction can have an impact on the environment, including noise pollution, dust generation, and disruption to ecosystems. Mitigating these environmental concerns, adhering to environmental regulations, and implementing sustainable practices are challenges.
- Timely Execution: Construction projects often face delays due to various reasons such as technical issues, funding constraints, and regulatory approvals. Ensuring timely execution of the project within the planned schedule is a critical challenge for the Pune Metro.
- Stakeholder Management: The Pune Metro project involves multiple stakeholders, including government agencies, local communities, residents, and businesses. Ensuring effective communication, addressing concerns, and maintaining stakeholder engagement throughout the construction process is a big challenge.

4.3 Precast Solutions Implemented

- Modification in design - Design modifications are carried out in order to reduce the time taken for construction and also the cost factor is taken into consideration. use of pre-stressed units helped reducing

the overall steel consumption and also reduced the dead load of the structure, hence requiring less heavy design for the same types of structures.

- T-shaped girders - The earlier designs were only I-Shaped girders for elevated metro but a new shape in form of 'T' is designed to reduce the extra time incurred for casting slab over the I-girders. With the T-shaped girders slabs are casted at yard only embedded in the girder in form of extended flanges.
- L-shaped girders - This type of shapes allows to close the ends of spans and gives finishes to the station without any additional cast-in-situ works.
- Precast pier arms and pier caps - pier arms and pier caps are generally cast-in situ and requires shuttering and supporting which in turn obstructs the traffic for several months. But use of precast pier arm and pier caps allowed faster construction without any significant blockage to traffic. the erection works are carried out in night shifts and are generally required road block for few hours, hence saving at least 40 days cycle for casting pier arm and piercap.

4.4 Results and Implications

- Faster Construction: Precast girders are manufactured off-site in controlled factory conditions. This allows for parallel construction activities, where the girders can be produced simultaneously with the foundation and other station components. Once ready, precast girders can be quickly installed, reducing construction time compared to traditional cast-in-place methods. it was observed that one day time is taken for erection of pier arm as compared to 40 days cycle for cast-in situ process.
- Cost Efficiency: Although precast girders may have higher upfront costs due to factory production, they can lead to cost savings in the long run. The faster construction process reduces labor and equipment expenses. Additionally, precast elements are typically of high quality and require less maintenance, resulting in lower life-cycle costs. manpower for shuttering and scaffolding erection is saved and also cost of shutter ply and supporting material is saved by using the precast erection.
- Improved Quality and Consistency: Precast girders are fabricated under controlled conditions, allowing for stringent quality control measures. The manufacturing process ensures consistent dimensions, strength, and durability. This results in a higher quality end product, reducing the risk of structural issues and ensuring long-term reliability.
- Minimal Disruption and Traffic Congestion: Precast girders enable rapid installation, minimizing the disruption to traffic and surrounding areas. Since precast elements are lifted and assembled into place, it reduces the need for extensive formwork and temporary supports. This helps to minimize road closures and traffic congestion during construction.
- Enhanced Safety: The use of precast girders reduces the amount of work performed at height, as most of the manufacturing and assembly is done at ground level. This improves worker safety by minimizing the risks associated with working at elevated heights.
- Flexibility and Customization: Precast girders can be manufactured in various sizes and shapes to meet the specific requirements of the metro station design. This flexibility allows for customized solutions, accommodating different architectural designs and structural demands.
- Sustainability: Precast construction methods often result in reduced material waste, as components are manufactured to precise specifications. Additionally, precast elements can be reused or recycled,

contributing to sustainability goals. The controlled manufacturing process can also incorporate sustainable practices, such as using recycled materials and reducing energy consumption.

- Accelerated Project Delivery: The use of precast girders enables faster construction, which can help expedite project completion. This is particularly beneficial for metro systems aiming to provide public transportation solutions within strict timelines, reducing traffic congestion and improving connectivity sooner.

5. Analysis and Findings

5.1 Time Savings

From the table below it can be seen that erection of one span requires 2 days of erection, 2 days of stitching the girders and 2 days of diaphragm joint construction. whereas traditional precast requires 4 days of shuttering arrangement, 2 days of reinforcement fixing, and 1 day of casting and 7 days of minimum curing time. hence saving of 8 days for erecting one span. also, if the pier arm and pier cap are cast-in situ, it takes a complete road diversion arrangement, which includes making of alternate pavement road on side of the main road. Scaffolding takes 3-4 days, shuttering takes additional 2 days, reinforcement fixing takes another 4 days, casting requires 1 day and additional 28 days are required to remove the support from below the pier arm. hence overall a cycle of 39 days for casting one pier arm, but in precast, it takes only one-two days for erection and post tensioning the pier arms. total savings of 48 days is achieved with the use of precast.

Activity at station site	Cast-in situ / traditional method	Precast erection
Scaffolding and shuttering for slab casting	4 days	-
Reinforcement fixing	2 days	-
Casting / concrete pouring	1 day	-
Curing	7 days	-
erection	-	2 days
Girder stitching	-	2 days
Girder diaphragm casting	-	2 days
Pier arm erection	-	1 day
Traffic diversion	5 days	1 day
Scaffolding	3 days	-
Shuttering	2 days	-
Reinforcement	3 days	-
Concrete pouring	1 day	-
Curing	28 days	-
TOTAL	56 days	8 days

5.2 Cost Savings

cost savings in form of scaffolding material, shuttering material and reinforcement usage is achieved with the use of precast material. though there are additional initial cost involved in the precast construction but it

recovers for itself and turns profitable when the quantum of work is high. use of same shutter mould offers great savings.

5.3 Enhanced Quality and Durability - Quality of segments so manufacture is very good and matches the standards with a little or negligible deviation from the set standards. The factory like manufacturing process ensured dimensions, strength, and durability as per codal requirements. This resulted in a higher quality end product.

5.4 Sustainability Considerations - less wastage was observed at casting yard as well as at the construction site and less concrete waste as compared to cast-in situ concrete construction.

6 Opportunities and Future Directions

6.1 Integration of BIM and Prefabrication
The use of BIM and other software helps in Design Coordination and Visualization. This allows for clash detection and identifying potential design conflicts. compatibility of prefabricated elements can be assessed using BIM models which can further encourage the use of precast elements in construction.

6.2 Standardization and Code Development
the precast activities can be standardized throughout the country and onse shape and size can be followed throughout the nation in order to make this a foremost choice for construction. the standardization will help faster completion of works due to readily availability of shutter moulds and will take less time for manufacturing.

7. Conclusion
with implementation and adoption of new design techniques preacast can be the first choice in heavy civil construction and can be used frequently with the government promoting and standardizing the designs and shapes used for particular works. the coat and time savings is enormous and it also proves to be beneficial to the commuters and local public. Less noise and air pollution is observed and hence it is good for the environment also. Precast is the future of heavy civil industry due to its benefits.

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9. Biographies

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