Study of Tunnel Formwork System & Comparative Analysis with Conventional Formwork

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Abstract— Winds of change are blowing across every industry in India but the construction industry is still reluctant to utilize the advanced techniques that can enhance the productivity and efficiency of the construction industry. In recent years construction industry is witnessing increased demand in multi-storey construction and repetitive modular structures are becoming an integral part of it. These structures require detailed planning in order to save cost and time. As formwork accounts for about 25- 40% of the total project cost and almost 60% of the time in concrete construction, we need to pay attention to the development in formwork techniques and replace conventional formwork with new formwork techniques like tunnel formwork. This paper aims at focusing on the benefits and limitations of tunnel formwork in contrast to conventional formwork thus changing the mindset of local construction industries that are still dependent on conventional formwork techniques.

Index Terms— Concrete, Conventional Formwork, Cost analysis, Economy, Rapid formwork, Slab cycle, Stripping time, Timber Formwork, Tunnel formwork.

1 Introduction

THE increase in population and the limitation of space has leaded the way to multi-storey or high-rise buildings. In order to make these structures sound, we need to focus on factors that impart strength to concrete and this is where formwork plays an integral role.

Formwork is a temporary structure like a die or mould, used to contain poured concrete, to give concrete the desired shape and support it until it attains sufficient strength to carry its own weight. Formwork should be capable of carrying all imposed dead and live loads apart from its own weight.

Pantheon, a former Roman temple and now a church in Rome, is the earliest example of use of mould for concreting.

Formwork should be properly designed, fabricated, and erected to achieve high quality concrete finish. If this is not done properly the desired shape and strength of concrete is not achieved.

Advanced Tunnel formwork is one of the new formwork techniques to hit Indian construction industry. It is found to be suitable for mass construction in Indian conditions. It delivers quality and speed at a rate which is higher than the speed achieved by most of the formwork systems. The labour in coordination with heavy machineries like tower crane speeds up the construction, assures quality control and durability. This reduces overall time and cost of the structure. This paper mainly focuses on advanced tunnel formwork systems, its components, working cycle, cost involved, its benefits and its limitations based on speed and economy.

2 Objective

The objective of this paper is to

1. Introduce advanced tunnel formwork systems to Indian construction industry and lay emphasis on the high quality, speedy construction and if used effectively the economicality which tunnel formwork yields.
2. Present comparative study of tunnel formwork and conventional formwork to eliminate the reasons which act as barrier for the local construction industries while opting for new formwork techniques like tunnel formwork.

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3 Literature Review

Various types of formwork systems are used in India and based on type of material, purpose of use and method of erection the formwork systems are listed as follows.

1. Conventional formwork
2. Tunnel formwork
3. Climbing formwork
4. Mivan formwork
5. Slip formwork

The above mentioned formwork techniques are the trending techniques in construction industry of which conventional formwork is the traditional formwork. In this paper the focus will be on Tunnel Formwork and Conventional Formwork.

3.1 Tunnel Formwork

Tunnel form is a box sized steel fabricated form that allows the wall and the slab to be casted in a single operation. Once reinforcement is placed, concrete for walls and slabs can be

poured in a continuous pour. An arrangement of hot air blowers accelerates the setting of the concrete and one slab is achieved in one day i.e. 24 hours slab cycle. 300-400 m2 of floor area can be poured on a daily basis.

A crew of 10 people can achieve a daily cycle of casting 1-2 apartments per day depending on the type of structure. A 10 storied building can be completed in 20-30 days maximum. For low-rise buildings e.g. 5 storeys, total weight of the building can be designed 1.10 – 1.20 tons/m2 lighter than compared to 1.30 in conventional method.

Precast element is one of the critical activity at the time of using tunnel formwork, it results in increased productivity at very short period of time which results in time and cost saving. It is particularly effective in projects suited to repetitive cellular construction involving huge symmetrical work such as residential blocks, hotels, student accommodation, barracks and prisons. Tunnel form is also used in several housing projects especially for earthquake resistant projects as the construction time is reduced.

Fig. 1. Tunnel Form System

3.2 Components and Supporting system in Tunnel Formwork

The major components in Tunnel formwork are as follows:

1. Half Tunnel. Two half tunnels when bolted together forms one unit which acts like tunnel.
2. Back Panel is attached to the two half tunnel forming one entire tunnel form.
3. Outside Wallform it is used as formwork arrangement for the end wall along with arrangements for lifting of platforms.
4. Lifting Beam is used in movement of tunnel panels.
5. Lifting Device applied for lifting of tunnel panels.
6. Roller for movement of tunnel form.
7. Kicker Form it prevents cement slurry leakage and also stabilises the form.
8. Slab Stopend is used to indicate the end for slab.
9. Slab Boxout is used as openings in slab for conduits.
10. Door Boxout is used as opening for door.
11. Window Boxout is used as opening for window.
12. Stripping Platform for easy removal of tunnel form after concreting
13. Gable End Frame it is used as a platform for movement of labours.
14. Tie- rod and cone set is driven before concreting is pour to take the lateral support of the concrete to be poured and keeping the form in place.
15. Crane and lifting equipments are used for movement of tunnel form from one floor to another.

3.3 Life Cycle of Tunnel Form

For optimising the volume of formwork, equipment & workforce overall structure is divided into a number of more or less similar construction phases and sizes correspond to daily work to cast concrete.

In order to save the time reinforcement mesh are used in place of normal steel bars. The wall and slab reinforcement is laid and kickers are placed for positioning formwork for wall. Two half tunnels are bolted on site to make one tunnel and lifted by crane to desired location. The ties are added. The concrete is poured and hot air blowers are placed for early settling of concrete. Thus concrete reaches striking strength overnight and the tunnel forms are removed the next day. The tunnel form are cleaned and oiled for reuse.

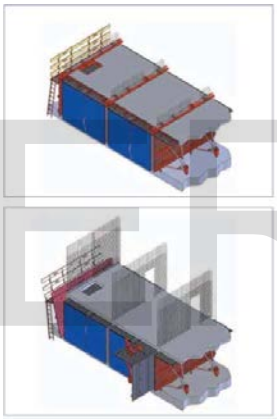

Fig. 2.(a) Laying Reinforcement Mesh

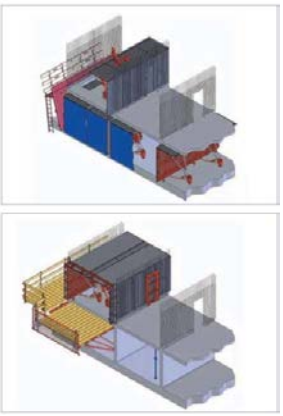

Fig.2.(b) Bolting Half Tunnels & Laying Slab Reinforcement

3.4 Consideration of Cost Involvement in Tunnel Form

For all structural systems, the construction cost is obviously expected to get higher as the number of floors. In case of tunnel formwork the past studies have shown that in the buildings of the same wall thickness, the unit cost per apartment decreases as number of floors increases.

The components which influence cost are initial cost, cost of materials or assembly, reuse cost, machinery and operational cost and daily cost expenditure on labour.

The initial cost is very high but tunnel formwork is economical in long run as the life cycle is reduced and reuse of form is possible. Reusability also reduces material, assembly and erection cost.

Due to high quality finish the cost of finishing treatment is reduced. In order to maintain the durability of formwork, formwork oil (1 litre for 20-45 m2 of formwork) is applied at regular interval and thus it is a minor cost. Machinery cost involves the operational cost and the cost of cranes. As skilled labours are involved and the work is repetitive the total time

of construction is reduced so the amount spent on daily cost on labour and supervision cost is greatly reduced.

3.5 Advantages

The overall advantages of tunnel formwork are categorized into four categories as follows.

1) Design:

1. Hi-tech all-steel system of tunnel form with 3 mm. steel surface provides durability and strength.
2. Collapsible strut provides clearance for form stripping, the composite wheel assemblies help in accurate form positioning and blockouts eliminate nailing.
3. Multiple rooms can be concreted and that provides flexibility in scheduling.
4. Proper concreting of ceiling to the wall results in lack of formation of beams.
5. Tunnel form can be adapted to special building features, like balconies. It gives freedom and variety in architectural designing.
6. The dimensional accuracy of the concrete structure allows the placement of partition walls and fixing of all other finishing material such as joinery right after casting.
7. Standard push pull props can be used at every tunnel dimension due to its telescopic nature and makes it very easy to adjust vertical and horizontal leveling. High kickers make it easier to adjust tunnel heights which eliminate levelling mistakes. Tunnel form can be adapted to higher floor level easily.

2) Quality

1. Installation of all utility conduits in the shell reduces the internal finishing work.
2. High quality and dimensional accuracy is achieved. 1/1000 deformation is allowed and can be achieved. Low depreciation and long life of building.
3. The obtained surface is smooth which minimizes much of finishing work and allows direct application of paint or wall paper after sanding off the fins at the joints connecting two forms and smoothing with paint filler.
4. Monolithic elements of the building prevent thermal cracks which are observed in the heterogeneous materials because of temperature variation.
5. Low scope of change in the original design of the building results in application of standard dimensions of doors, windows, partition wall etc.

3) Time

1. In the high temperature zones and/or by thermal treatment, with the use of ordinary cement, the normal pace is one day per cycle. Achievable cycle of production is of 1-3 days.
2. A monolithic structure with simultaneous casting of walls/cross-walls and slab results in reduction in total construction time.
3. Installation of electrical conduits, water and gas pipes in the shell reduces the internal finishing work, internal finishing proceeds in accordance with the concrete shell construction resulting in reduced total building time. Reducing minor works and overlapping activities yields into high quality and speed of implementation.

4) Cost

1. Tunnel form can be reused and this reduces the overall cost of formwork for per m2 or per housing unit.
2. The amount of rework and finishing work is reduced thus additional material, machinery and labour cost is saved.
3. High quality and early completion of project helps minimize cost in long run.
4. Tunnel form system comes with highest jobsite safety due to full perimeter platform system. This reduces cost associated with risk.

3.6 Limitations in implementation of Tunnel Form

1. High initial investment is high and it further increases for small sized projects.
2. Implementing all internal walls in the form of reinforced concrete is unnecessary which causes lack of changes in the plan and concrete increases dead load of the building.
3. Precast elements like stairs, parapets etc are used and this requires separate workshop arrangement.
4. The activities involving erection, removal and carriage of formwork, scaffolds, and placing of pre-cast components to the required place involves use of tower cranes and this increases cost. Topographic limitations can make movement of cranes difficult in some projects.
5. All activities need to be planned and executed according to the dependency to minimize time and cost. This requires efficient construction management and high cash flow.
6. Large spans of slab cannot be executed due to increased gap between the tunnel form panels. Here combination of formwork system may be adopted. Very short span of slab incorporates difficulty in removal of tunnel form at the time of stripping and suspended ceiling is needed. Basement stories are avoided as it is difficult to remove formwork.
7. Axial system plays important role and load bearing walls must be designed continuously on the same axial system to resist horizontal forces.
8. The number of labour required is less and it is more efficient as compared to that in traditional formwork. Thus proper training is required to impart skills to handle tunnel formwork.

3.7 Role of Management

Co-ordination plays an important role in process of concreting with tunnel formwork. Cost and time constraints are always impacting design and quality considerations. In order to achieve conformity with design and maximum quality with reduction in cost and time, management comes into picture.

1. Responsibility of training the labours to ensure smooth execution.
2. Building should be so planned that maximum tunnel from can be done with the help of one location of

tower crane. Positioning of the crane, precast workshop, material storage, etc are to be planned to reduce transportation time and idle time.

3. Detailed planning is required. All the activities are to be planned before the commencing of the project. This will reduce the lag time. The activities dependent on one another can be foreseen and executed in sequence this helps in providing space for ducts and facilities.
4. Alternatives should be decided beforehand incase barriers are faced in tunnel form especially in very short and very large spans of slab. This will help in speedy construction.
5. Tunnel form system comes with highest jobsite safety due to full perimeter platform system but risk management should not be ignored.

Involvement of all the sectors is needed. The designing team, execution team and architectural team need to be in sync so that tunnel formwork is executed on time.

4 Case Study

A case study was conducted at Rohan Abhilasha, Pune to highlight the benefits of tunnel formwork against conventional formwork and eliminate the hurdles faced by local construction industries, which are responsible for the hesitant nature of local construction industries towards tunnel formwork. Data required to identify the hurdles was collected by Questionnaire Survey. On basis of previous studies on conventional and tunnel formwork, and suggestions from Local Construction Professionals, major hurdles were identified. The target population included Civil Engineers from construction firms. The Questionnaire prepared was distributed amongst respondents. Respondents were required to mention the major hurdles.

TABLE 1
Construction Site Details

Details	C ase Study
Name of organization	Rohan Builders India Pvt Ltd.
Name of project	Rohan Abhilasha
Location	Wagholi- Lohgaon road, Pune
Type of project	Real estate
Area of RCC construction	32000 sq. ft.
Type of formwork	Up to 2nd parking level: Conventional formwork 3rd to 14th floor: Tunnel formwork
Contractor hired for execution	MESA Imalat.

5 Data Collection

From the questionnaire, following hurdles were identified for hesitation of local construction industries to adopt tunnel formwork in place of conventional formwork in multi-storied construction.

1. Less Awareness about new formwork techniques
2. Low skilled labour and the additional responsibility to train them for modern formwork techniques
3. High initial cost
4. Burden of additional cost due to machineries like tower crane
5. Lack of experience in tunnel formwork
6. Reluctance to adopt new technology
7. Difficulty in adoption of changes in original drawing

Data collected from Rohan Abhilasha site is as below:

1. Plan of building
2. MS Project schedule
3. Quantity estimates of material (Steel, Concrete & formwork)
4. Formwork technical manuals & user guide

For comparison of tunnel formwork with conventional formwork, average values for conventional formwork from various construction sites are selected as part of the questionnaire.

6 Data Analysis

For data analysis detailed study of the tunnel formwork system is done and is compared with conventional formwork. Summary of findings is mentioned in following table.

TABLE 2
Data Analysis

Sr. No.	Details	Tunnel Formwork	Conventional Formwork
1.	Procurement cost	₹22,000 per sq m (Initial cost is high)	₹800 per sq m
2.	Casting system	Monolithic structure of main walls and ceiling Partition walls are built afterwards	RCC framed structure
3.	Floor cycle	1-3 days	Minimum 3-4 weeks
4.	Speed of construction	Very High	Slow
5.	Type of labour	Skilled	No skilled labour required
6.	Labour cost	₹200 per sq ft	₹80- ₹100 per sq ft
7.	Staff required on site	Low	High
8.	Reusability	+500	15-25
9.	Additional machinery	Tower crane	No
10.	Accuracy	Very high	Low
11.	Design flexibility	Very low scope	High scope
Sr.	**Details**	**Tunnel**	**Conventional**

No.		Formwork	Formwork
12.	Finishing	High finished product so no need of finishing	Finishing is required
13.	Safety	Safe if crane operations are carried out safely	Safe
14.	Waste disposal	Low waste generated	High waste generated
15.	Scrap value	High	₹0
16.	Net floor Area to Gross	High. 86-88% compared to 82-84% in Conventional systems.	-
17.	Earthquake resistivity	Area of load bearing walls to the total area is 2% more than compared to 0.5% in Conventional systems.	-
18.	Cost saved	45% (Based on previous studies)	-
19.	Time saved	50% (Based on previous studies)	-
20.	Favourablility	Highly favourable for construction of more than 15 storied buildings as initial cost are reduced.	Everywhere but usually avoided for buildings greater than 20 storied.

Tunnel formwork is the solution to the repetitive modular multi-storied construction and it eliminates the common hurdles that the local construction industries face. The details are explained as follows-

1. Less Awareness about new formwork techniques: In order to maximize the quality with reduction in time and cost, constructors need to focus on innovations taking place around them. This simply needs initiatives to enhance production.
2. Low skilled labour and the additional responsibility to train them for modern formwork techniques: Internal training workshops can be conducted by the companies to improve the skills. Few labours are required as oppose to conventional formwork and thus it is cost effective in the long run.
3. High initial cost and Burden of additional cost due to machineries like tower crane: The initial cost is very high. The duration required to finish the structure is half than that required with conventional formwork and thus early returns are possible. As per the previous studies the cost of tunnel formwork is lower than conventional formwork after building of 90 housing units.
4. Lack of experience in tunnel formwork and reluctance to adopt new technology: This is more of a mental blockage than practical problem. As tunnel formwork construction has already started in India, local construction industry can share the experience. Formwork contractors are usually hired and the procedure is explained through user guide manuals.
5. Difficulty in adoption of changes in original drawing: This is one of the limitations of tunnel formwork but proper management can help in this as discussed above.

7 Conclusion

Formwork development has paralleled the growth of concrete construction from its earliest uses but still many construction companies, especially the locals, are hesitant in adopting different formwork techniques. This paper was primarily focusing on inculcating innovative techniques to enhance quality and reduce time and cost. Tunnel formwork stands to these expectations as it allows a slab cycle within 1 to 3 days and high quality which reduces finishing works. This reduces cost by 40% and time by 60% when compared to conventional formwork.

Tunnel formwork has limitations like design limitations, requirement of skilled labour, crane availability, etc but these limitations don't weigh much when compared to the long run benefits achieved by tunnel formwork. Alternatives can be used to reduce these limitations as mentioned in the paper and 100% utility can be achieved.

Tunnel formwork may not be economical for construction of buildings less than 7 storied but as the number of floors increases the overall cost is reduced. Even in 5 storeys, total weight of the building can be designed 1.10 – 1.20 tons/m2 lighter than compared to 1.30 in conventional method. Depending upon whether economy or design is important, we can adopt tunnel formwork in different types of constructions.

After studying and comparing both the systems it can be concluded that, though initial investment and per day operational cost in tunnel formwork is more than conventional formwork, the reusability and reduced slab cycle time makes tunnel formwork works economical. Rapid completion of project helps in returns from initial investment. Thus, in long run tunnel formwork is beneficial as compared to conventional formwork in repetitive modular multi-storied construction.

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