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TECHNO-COMMERCIAL STUDY OF 'TUNNEL FORMWORK SYSTEM' AND ITS COMPARISON WITH CONVENTIONAL AND ALUMINUM FORMWORK SYSTEMS.

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Abstract : Construction industry of India is growing tremendously. Multinational construction companies came to Indian market made the globalisation, it's now the need of time to faster and precise in construction in India. Traditional methods of construction are incapable to meet the desired speed, quality and economy of the construction. Though the traditional construction methods are convenient but unable to deliver the required housing units in desired time with desired quality, hence there is need to adopt the advanced construction technichqs available in the market as well as develop the existing techniques.

Construction is a complicated and tedious job which required exhaustive planning, monitoring, resource planning and strong cash flow. On executing all these activities hand in hand the project will be completed successfully, failure of any activity will result the overall failure of the project. In construction formwork plays a vital role and its cost is around 20 to 24% of the overall cost of the project. The desired quality, speed and economy of the project can be achieved by means of meticulous planning. To avoid the damage to the permanent structure to be constructed utmost care to be taken of formwork need to be taken. By using the tunnel formwork the contractor can cast the slabs and walls together at same time in per day cycle alongwith quality, speed, precision and ultimately the economy.

In this dissertation the will be studied in detail, and, Aluminium Formwork (Mivan Technology) with Tunnel Formwork System.

IndexTerms **- Tunnel Formwork System, comparison between established conventional formwork technologies and Aluminium Formwork (Mivan Technology) System.**

I. INTRODUCTION

1.1 Background:

Construction is a complicated and risky procedure requiring meticulous making plans, engineering, procurement, and construction control. The undertaking might be a hit only if all of those activities accomplished hand in hand. However, any person of those activities fails, the entire mission fails down. Form work plays a vital role in construction and its costs about 20-24% of entire project value of assignment. Additionally, it calls for meticulous planning, monitoring and strong cash outflow. Though, form work is a transient construction; care need to be taken to prevent harm to permanent work. whilst searching for for the pleasant technique of formwork following components are considered

- Acceptable tolerances permitted;
- Use of appropriate materials;
- Standards of workmanship;
- Cycle time.
- Care and maintenance of the formwork, to achieve maximum numbers of re-use

1.2 Basic considerations for a good quality formwork

Formwork acts as mould to assist the concrete of structures till the concrete gains its early sustainable strength. Formwork should be supporting to all structures as designed. Following are the characteristics of the good form work. :

- Durability
- Strength
- Watertightness
- Precision
- Convenient to achieve floor cycle
- Maximum repetitions
- Ease for handling
- Economical

Durability: Formwork should durable and able to fabricate in any desired shape as per drawing.
Strength: Formwork should strong enough to sustain the designed load of green concrete along with the weight of the labours and machineries used during concreting. Also, it should safely absorb the vibrations of vibrators used for concreting.
Watertightness: Formwork should watertight enough to avoid the leakage of cement slurry at the time of concrete and achieve the desired form finish of the structure's surface.
Precision: Formwork should have minimum tolerance i.e. upto acceptable limit and capable of delivering the structures of desired sizes as per drawings as per casting. Hence, there should be provisions for levelling, adjustments etc.
Convenient to achieve floor cycle: Formwork should be convenient to operate for the labour so that the desired floor cycles can be achieved.
Maximum repetitions: The formwork should be capable of achieving maximum repetitions without compromising the speed, quality of work and the finishing of the structure.
Ease for handling: Formwork should facilitate the ease of handling during shuttering, concreting, de-shuttering shifting etc. to achieve the desired speed of construction.
Economical: Since the formwork is generally costing around 20-24% of entire project cost, it should be economical to enough to maintain the desired profit margin of the project.

1.3 Objective of the study:

Following are the objectives of the proposed work:

1. Detailed study of Tunnel Formwork System – with case study
2. To examine the construction price of constructing using Tunnel Formwork System.
3. The Comparison of Conventional Formwork, Aluminium Formwork and Tunnel Formwork with respect to cost, quality and speed.
4. To analyse the various criteria to select Tunnel Formwork System.
5. To put together Improvement Plan for evaluation of traditional Formwork, Aluminium Formwork, Tunnel Formwork primarily based on the parameters like design standards, cost of shuttering material, repetition of shuttering, flexibility to cast diverse RCC design, salvage cost and reusability of shuttering cloth for subsequent project.
6. To prepare cost comparison amongst traditional, Aluminium Formwork and Tunnel formwork like Labour price in sq m, Material Cost per sqm, administration cost and at last Final Construction Cost in sqm.
7. To exercising Breakeven point of the whole area to be built in project to in utilize the Tunnel formwork system.

1.4 Methodology:

1. Collection & study of Literature and evaluate relating to the Project work.
2. An in-depth case study of work at Wagholi, Pune, where Tunnel Formwork System is used.
3. Prepare a day wise Bar chart of slab cycle achieved using the use of Tunnel Formwork System.
4. Categorize the essential machineries required to achieve slab cycle and criteria to choose the proper capacity of machinery.
5. Exercise the actual labour cost per sqm of slab area.
6. Compare and finalize the actual investment cost per sqm. for various shuttering material required for the total project.
7. Analyse the cost incurred for various finishing items.
8. Analyse the cash flow of project.
9. Analyse the overhead cost of project.

2 STUDY OF VARIOUS FORMWORK SYSTEMS

2.1 General

In this chapter the Various types of formwork systems are being used in India has been described. In detail. Further focuses on Tunnel Form System, its advantages-disadvantages, Components of formwork system, details of cycle of slab and wall casting. Miscellaneous methodologies adopted to achieve cycle time are also discussed.

2.2 Formwork planning:

The planning can be done in three stages.

Stage-1

The required details and extreme conditions have to be gathered and defined. In case of similar projects the checklist is helpful to obtain the desired information to complete the project. For planning important information consist of duration of project, lead time of the major material required for the construction project and the final drawings. Extreme conditions consist of whether a crane capacity, accessibility to the project location, space available to store the formwork materials etc.

Stage-2

The experience of the planning team has governed selection of type of formwork to be used alongwith the cost of the materials. The database of previous project during last few years gathered can be useful for calculation of the cost effectiveness of the system. Also, the communication among planning team and formwork team plays vital role in the successfully achieved the planned goals.

Stage-3

All engineering design tasks comes under this stage. This is most time-consuming stage. The design should allow for changes arising at later phases of the project. In most of the projects the standard sizes maintained to utilize the formwork with minimum modification to make if cost and time effective. Planning is restricted to indicate the arrangement of elements from the system. The emphasis should be on maximum repetition of materials available and procuring less materials.

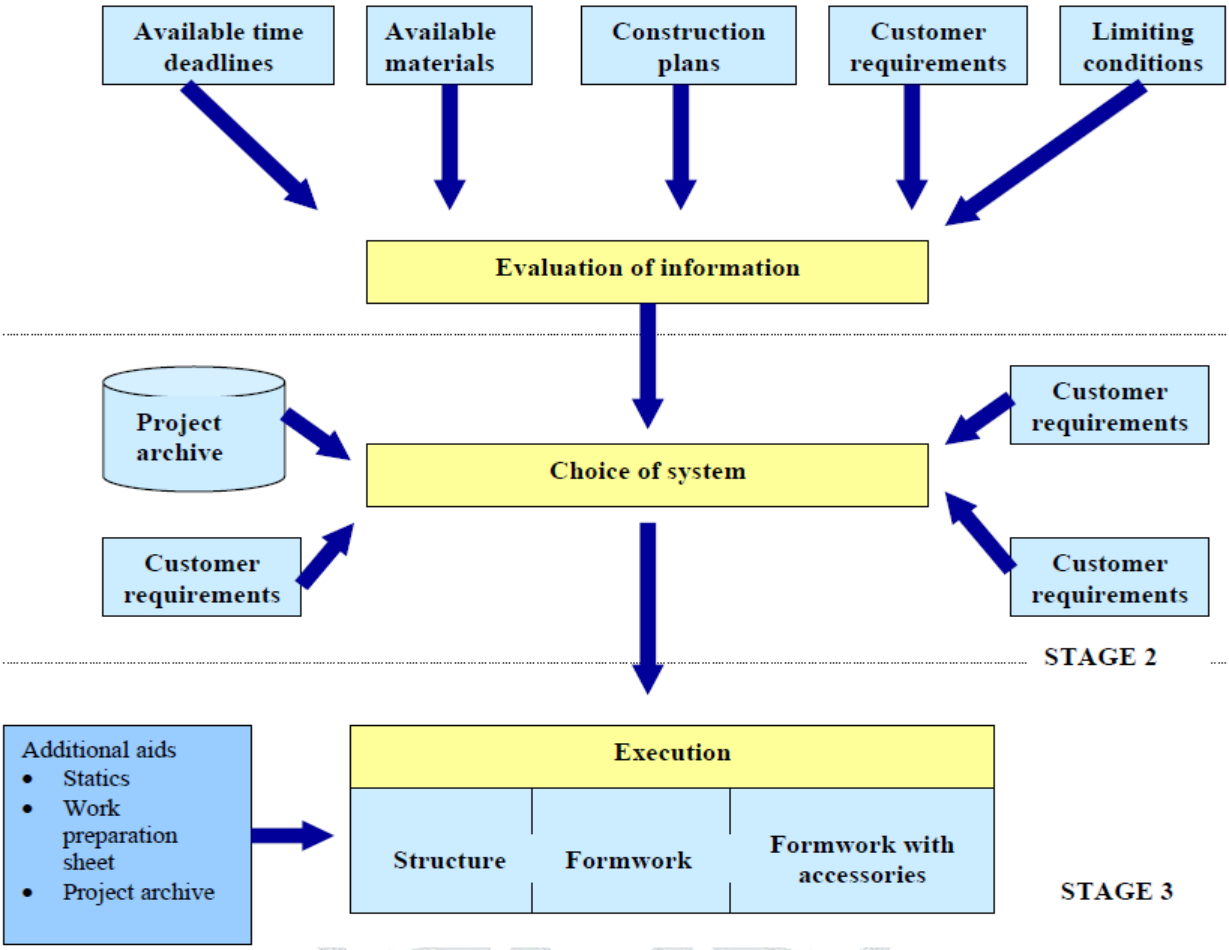

Fig 1: Formwork Planning Process

2.3 Other aspects of formwork management

Planning is important aspects of Formwork Management. In the absence of efficient system to implement the planned activities the planning will be failed totally. In addition to above the Formwork Management should focus on the following aspects also:

2.3.1 Material Mobilization

The site team work out the requirement of Formwork materials and submit to their Regional Office. The Regional Office will take check the release program of formwork material of sites under the region and if formwork materials is not available within the region the regional office will submit the same to Head Office (Formwork department).

2.3.2 Operation Assistance

During the execution of project the formwork, engineers should ensure the installation of formwork as designed and guide in modifications of the arrangement to avoid the difficulty or to improve the ease of work at site. Also, the formwork, engineers should ensure that optimum utilization of formwork material as planned. Timely decluttering of formwork material to be done by tracking the concreting dates and required curing time to achieve the planned floor cycle. Avoid the procurement the additional quantity formwork material.

2.3.3 Demobilization

Alongwith the procurement schedule the release program of formwork material to be prepared well in advance before actual release the formwork. For any large mobilization, the release program should be submitted three months in advance and Regional Office and Head offices. Planning of formwork materials for new projects, is dependant of demobilization of existing projects. Procurement of new material can be avoided by monitoring the demobilization.

2.3.4 Repair and maintenance
Repairs and maintenance of Formwork material is to be done time to time. Unfortunately, most of the time formwork material became unusable and laying at site in the absence of timely repair and maintenance which results in increase in inventory cost.

2.3.5 Accountability of formwork
Due to improper housekeeping and improper handling of the formwork, small size accessories of formwork will be lost the work will be delayed in the absence of such accessories. All projects on the verge of completion should reconcile the formwork material i.e. receipt at site, dispatch from site and stock at site as per records and physical stock at site to identify the losses if any.

2.3.6 Training
Detailed training of formwork system has to be given to all staff and workers at site. Due to the training given to staff and workmen the optimum utilization of formwork system can be achieved with less damages. The training shall be arranged at site in consultation with Regional and Head offices.

2.4 Existing trend in formwork systems.
There are various types of formwork systems are available in market as per the requirement. In general, formwork used for column/walls (vertical members) is called wallforms and the forwork used slabs, beams (horizontal members) are called slabforms or floorforms. Based on requirement following formwork systems are described.

2.4.1. Conventional formwork system
In conventional formwork the panels of required sizes connected to each other using walling. The role of waling is providing the support to panels to take the load of concrete after pouring. First, one side of formwork is fixed correctly aligned, plumbed and strutted. The reinforcement cages has been placed as per drawing thereafter another side is fixed. Generally, panels are made of plywood and wooden chavi. The Plywood is screwed on to studs on a wooden chaavi frame. This allows to remove the plywood from the frame and reuse from the other side to have maximum repetitions. Generally, wallforms are leads the damage of sharp edges and corners hence it should be carefully handled. Utmost care should be taken for comers and attached piers as the increased pressures of concrete could cause the open up of formwork which resulted in slurry leakages and honeycombing of on concrete finishes.

2.4.2. Climbing formwork system
Method of casting walls can be done using climbing formwork, the climbing of formwork can be achieved manually or by means of cranes. The set of walls formwork is deployed for casting of walls in repetitive manner. After every casting cycle the wall forms are removed and shifted to the upper level manually or by using the crane for the next lift till the required height has been casted. This type of formworks are used commonly for silos, chimnies, multi storied buildings, bridges, telephone towers, control towers etc. Due to the stages in this system, the resource levelling can be achieved. Repetitions of Anchor accessories, reduce the cost of material. While using trolley mounted formwork, the space for repairing and finishing of concrete surface will be generated at the time of removal of panels from concrete face will provide. Formwork & its assembly uplifted as a single unit, hence it will reduce the crane duration, manpower and time. Vertical and horizontal alignments of the forwork can be done using given provisions of adjustments.

2.4.3. Slipform or Sliding formwork
Slip form means a constantly moving formwork, at the speed of concrete has achieved required initial strength to withstand itself. Hence, the slip form concreting technique is a faster and economical construction method which can be used for construction projects such as silos bridge column chimneys, water towers, shaft lining and lift shaft cores etc. The technique is based on hydraulic jacks which are used to lift the forms gradually. It's a repetitive process wherein wet concrete is added to old concrete after fixing the Steel or post tensioned cables. Normal speed of slipform is 3to 6 m everyday. The slipform is specially designed for individual project considering architectural and structural demands of the project.

2.4.4. Permanent formwork
Permanent formwork or stay-in-place form is the form which is left in the structure after casting as an integral part. Permanent formwork is used as surface finish of the structure. There are two types of permanent form work i.e. participating and non-participating.
The material having sufficient strength and durability like fabricated steel, polyvinyl chloride (pvc), carbon/epoxy thin shell, galvanized coiled sheet steel are used as permanent formwork.
The disadvantages of this type of formwork is higher initial cost of design and installation, non-availability of skilled workmen for installation and maintenance etc. However, advantages of this type of formwork is greater durability, precise form design, low cost of transportation and installation, , maximum flexibility and versatility.

2.4.5. Special forms
This is Special Formworks are designed and manufactured specially for a particular structure / building as per the requirement of drawings. Necessity of such type of special forms is depends on various situations such as high dimension accuracy is required as per the contract provisions, the required shape of the structure to be constructed is irregular and the preparation of formwork at site for such shape is time consuming and costlier. where the self-sufficient formwork is required. where formwork to design especially considering the pressure developed inside the formwork due to the speed of concreting, grade of concrete type of admixtures used. where a significant number of re-uses is considered.

2.4.6 ALUFORM / Aluminium formwork system

Aluminium Formwork is convenient, speedy, flexible and low cost system. The unique advantage of this formwork is that all the concrete of the structure consisting columns, walls, slabs, beams, stairs, windows, balconies and various decorative features can be casted exactly as per the architectural drawings. Due to higher dimensional accuracy of the structure in this system, there will be the uniform sizes of door & window openings. and locations of services. Plastering/Gypsum work can be omitted due to smooth form finish is obtained.

In this system the Aluminium Formwork used to construct the framed structure, load bearing structures, multi storey buildings wherein all the slab and walls are casted simultaneously. These enhance the productivity and also provide the extremely strong monolithic concrete structure with form finish surface. Machined aluminium formwork components with low tolerance can deliver the consistent concrete shapes and finishes at every floor casted. This system accommodate the plumbing, electrical fittings and services at the same time of casting of structure.

Since, the aluminium formwork system is convenient the readily available less skilled labours can erect the formwork after appropriate training. Also the shifting of the panels of aluminium formwork can be done manually as the higher weight of one panel is about 25 kg and the special crane is not required for this formwork.

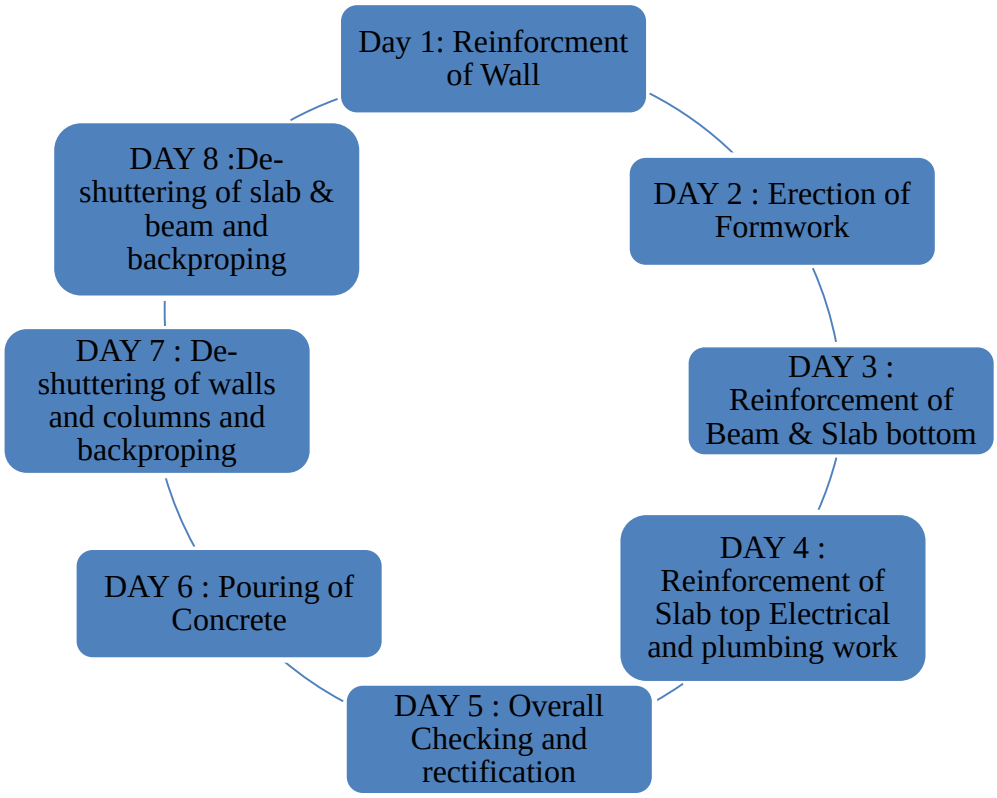

Figure 2: Cycle showing daywise activities involved in ALUFORM system.

2.4.6.1 Advantages & disadvantages of ALUFORM system.

Advantages.

1. Due to faster construction lower the overhead cost.
2. Strong Monolithic structure.
3. No requirement of Plywood and timber
4. Walls and slabs casted simultaneously.
5. Less skilled labour required are readily available at lower cost.
6. Earthquake resistance structures.
7. All architectural design can be casted using this type of formwork.
8. This formwork deliver the strong concrete structure.
9. Customization in design to suit project requirements.
10. Higher speed of construction.
11. High quality finish.
12. Due to elimination of plastering activity construction time and cost saved.
13. In the case of low cost mass housing having large number of repetition, this system is best suited.

Disadvantages

1. Higher Initial Cost.
2. Never allowed the modifications in later stage, like brick work constructions.
3. Chances of loss/theft of Aluminium panels/ accessories due to which set is incomplete and unable to pour the concrete.
4. Not suitable for small project.

2.4.7. TUNNEL form

The tunnel formwork is a room sized fabricated formwork using structural steel able to cast the rcc walls and slabs of floor monolithically. Further the structural steel formwork being heat up by means of hot air blowers to accelerate the concrete curing

to gain the early strength required for deshuttering. Tunnel forwork is economical in case of large number of typical units to be constructed.

The construction cycle by using tunnel form involves fixing of steel, plumbing and electrical services, installation of tunnel forms, pouring the Concrete, heat the tunnelform by using hot air blowers and closing the open sides of tunnel forms. Next day after initial strength achieved by poured concrete the forms are removed and placed on the next pour using cranes. The tunnel form is best suited for larger units with identical floor layout at every floor.

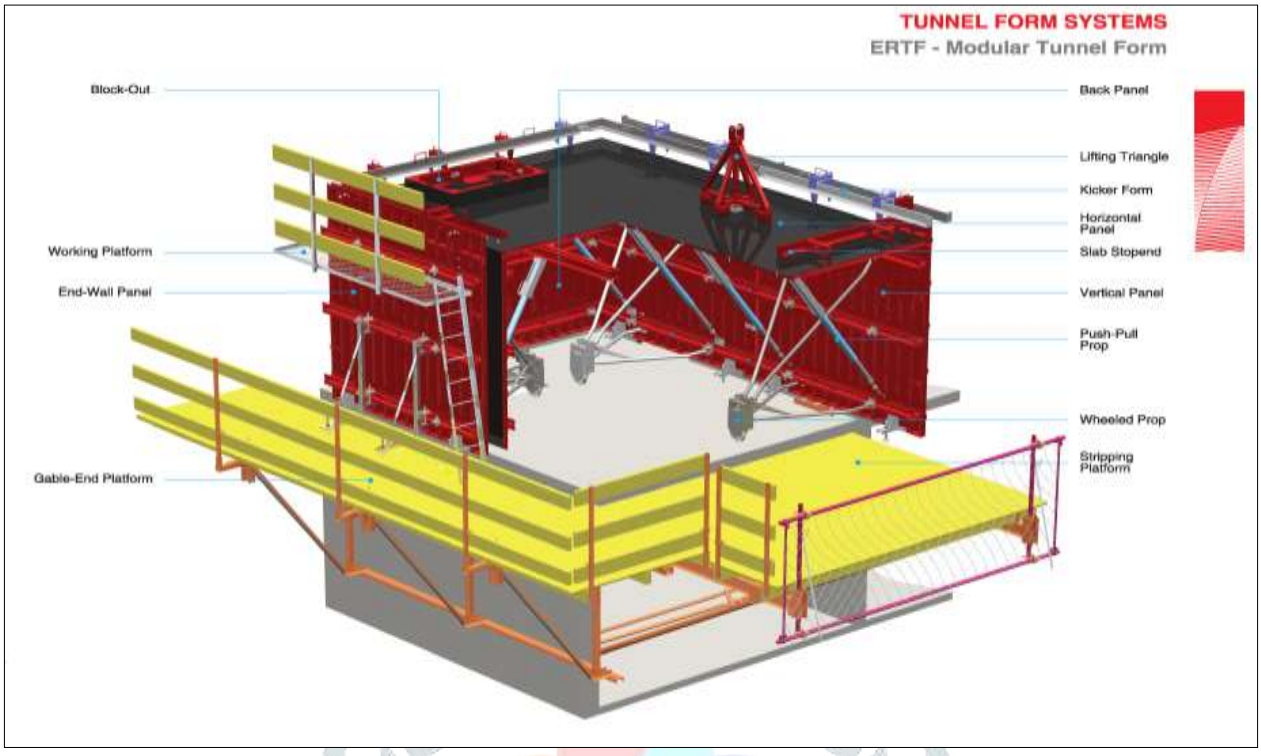

Fig 3: Figure showing cross section of TUNNEL form.

2.4.7.1 Sequence of assembly, erection & shifting.

Sequence of assembly

1. Connection of vertical panel & vertical panel extension
2. Connection of deck panel & deck panel extension
3. Installation of foldable prop to vertical panel
4. Installation of wheel connector
5. Connection of deck panel & vertical panel
6. Installation of foldable prop to deck panel
7. Installation of wheel supports to vertical panel & wheel connector
8. Installation of tunnel driving wheel to wheel connector
9. Installation of roof keys to deck panel extension
10. Installation of vertical panel jack
11. Dimension and alignment check
12. Installation of back panel to half tunnel formwork
13. Permanent connection of two half tunnels.
14. Marking boxouts and stopends.

Sequence of shifting & erection.

1. Moving and setting 1st half tunnel set
2. Levelling 1st half tunnel sets
3. Installation of tie rods and cones
4. carrying and installation of wall boxout
5. Installation of plumbing/ electrical conduit on wall
6. Moving and setting 2st half tunnel set
7. Leveling 2nd half tunnel set
8. Installation of slab stop ends
9. Tightening of roof keys
10. Tightening of bottom and mid tie rods
11. Cleaning and oiling deck panels

12. Slab reinforcement (Lowest level)
13. Installation of plumbing/ electrical conduit on slab
14. Slab reinforcement (highest level)
15. Moving and setting outside wall form
16. Installation of slab boxout
17. Installation of kicker spacers
18. installation of kicker forms and clamps
19. tightening of top tie rods
20. Alignment of half tunnels
21. Moving idle landing platform

2.4.7.2 Advantages & disadvantages of TUNNEL form

Advantages of Tunnel FormWork System (time)

1. Floor to floor cycle of 1-3 days can be achieved.
2. Due to high speed construction of rcc floors the speed of finishing activities can be accelerated.
3. Completion of project can be achieved in shorter duration than any other formwork system.
4. Due to higher speed, effects of climatic conditions on work is minimized.

Advantages of Tunnel FormWork System (quality)

1. Casting of walls and slab with higher precision
2. Form finish of walls and slab surface achieved.
3. Uniform dimensions for windows doors can be maintained.

Advantages of Tunnel FormWork System (cost)

1. Due to highest repetition of the tunnel formwork the cost of formwork per sqm can be minimized.
2. Since, the form finish of walls and slab surface achieved, the cost of finishing activities like plaster, gypsum etc can be reduced.
3. Low overhead due to completion of project in smaller duration. It also provides early financial gains.
4. Due to large number of identical units/ floros / buildings the repetitive nature of works results in minimization of labor costs.

Disadvantages.

1. Initial Capital Cost of tunnel formwork system increases formwork cost per sqm for small scale projects.
2. Consistent and higher cash outflow required to cater the speed of construction.
3. Due to higher construction speed the role of management is important any gap in communication and co-ordination issues will cause significant delays in schedule.
4. Skilled workmen with higher cost is required
5. The cost of heavy equipment's like cranes, batching plants etc. is higher.
6. Tunnel formwork system is not suitable for the structures having larger spans such as commercial buildings like theater, malls etc.
7. Sunk cannot be constructed using tunnel forms as it will be impossible to remove the tunnel formwork.
8. Unbale to cast the basement floors as it is impossible to remove the tunnel formwork.
9. Every activity in tunnel formwork system viz. erection, removal shifting of tunnel forms is dependent on Tower cranes only. Any breakdown in tower crane will results in standstill of work.
10. The allocated casting unit is required for the construction of precast components like stairs, parapets, and end walls.

3 CASE STUDY : ABHILASHA [TUNNEL FORMWORK]

3.1 Scope of Work

The main scope of this project is to analyse the time and cost required for Tunnel Formwork System and Aluminium Formwork System. Tunnel formwork system is being used by various Builders in the market. The case study taken for project will enable me to get preliminary idea about various parameters to be considered during time and cost analysis, factors affecting on it, difficulties in use in these techniques. Data required for project is taken for 2 wings A1 and A2 of block A.

3.2 DETAILS OF CONSTRUCTION PROJECT UNDER CASE STUDY

1	Name of project	**Abhilasha**
2	Architect	**Mindspace, Banglore**
3	RCC consultant	**J+W Consultant**
4	Plot area	**1,20,800 sqmt**
5	Project area ▪ Slab area ▪ Sale area	 **31.3 Lac Sqft** **20.5 Lac Sqft (Slab/Sale ratio: 1.53)**
6	Project cost ▪ Cost per slab area ▪ Cost per sale area	**INR 353 Cr (Approx)** **1129 Rs/Sqft** **1727 Rs/Sqft**
7	Project start date	**June, 1, 2014**

8	Project period	**3-4 years (Depending on sale requirement/ construction speed and no. of tunnel formwork sets used)**
9	No of flats	**2292 units (Proposed)**
10	No of buildings	**7 blocks, 25 buildings**
11	No of floors	**2 Parking+ 12 floors(14 slabs)**
12	Building height	**36.0 m(Above parking slab)+ 6 m (Parking slab)**

Table 1: Silent features of project (Abhilasha)

Name of Work: Abhilasha
Location: Behind Ultratech concrete plant, Wagholi-Lohagaon road, Wagholi, Pune
Basic considerations in execution of project

- 4 Half Sets of Tunnel Formwork considered. 1st pair of 2 Half sets to be procured immediately with onsite delivery by 1st Sep2014. 2nd pair of 2 Half Sets to be procured after six months with onsite delivery by 1st Jan 2014
- One crane is mandatory for each half set.
- Time Duration considered for Plinth+Podium Slab is 3 months.
- Time Duration considered for Balance Finishing Activities post RCC work of TunnelFormwork is 6 months.
  2 Batching Plants+Concrete Pump Sets considered one each for 2 Half Sets.

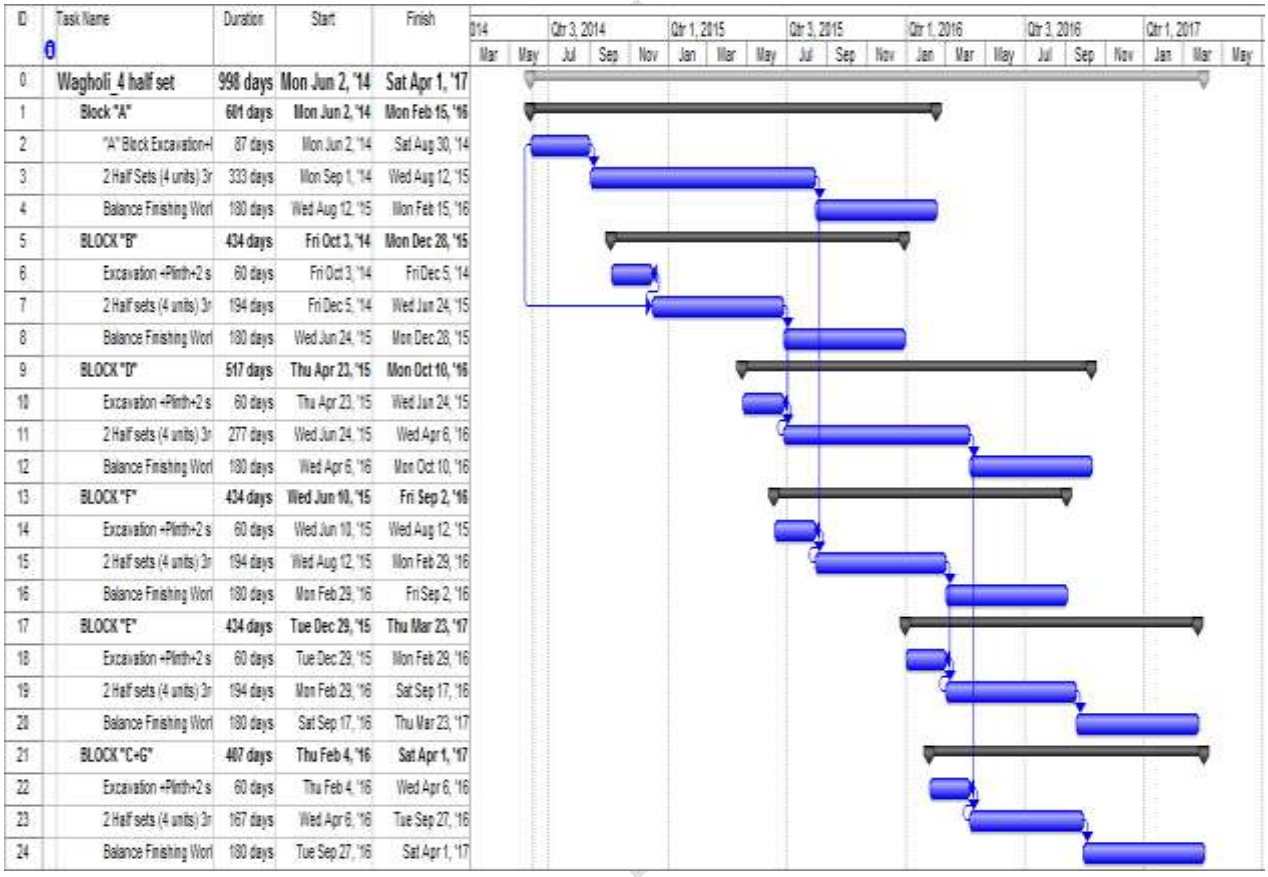

Fig 4: Bar chart showing phase wise schedule of project.

3.3 Estimated budgetary cost

Cost Head	Sr No	Item of Work	% of work	Budgeted Cost (Crore)	Rate (Rs/sqft) Slab Area	Rate (Rs/sqft) Sale Area
(A)	1	Excavation	1%	2.58	8.23	12.6
Bldg. Cost	2	RCC	54%	138.74	442.96	677.7
	2a)	Steel (@ 3.75 kg/sft)	22%	56.38	180	
	2b)	Concrete (@ 3370Rs/cum)	20%	51.05	163	
	2c)	Tunnel Form Shuttering	12%	22	100	
	3	Pre Cast Wall (Horz) L+M	1%	1.92	6.12	9.4

	4	Trimix	1%	2.8	8.94	13.7
	5	WATERPROOFING WORK	2%	5.91	18.88	28.9
	6	TILING WORK	13%	32.17	102.72	157.2
	7	DOOR WORK	2%	4.69	14.97	22.9
(A)	8	AL./ UPVC WORK	4%	9.83	31.39	48
Bldg. Cost	9	FABRICATION WORK	1%	3.78	12.07	18.5
	10	INTERNAL PAINTING WORK	2%	5.88	18.76	28.7
	11	EXTERNAL PAINTING WORK	2%	5.38	17.19	26.3
	12	PLUMBING WORK	6%	14.29	45.62	69.8
	13	ELECTRICAL WORK	4%	10.25	32.74	50.1
	14	SERVICES	7%	18.59	59.36	90.8
		TOTAL =	**100%**		**820**	**1255**
(B) Develop. & Other Work	1	Development & Other Work	PRELIMINARY FIGURES CONSIDERED (For CASHFLOW Purpose) Detail Figures would work out after receipt of landscape drawings and decisions.		50	76.5
(C) Overheads						
	1	Staff salary				
					25	38.3
	2	Consultant			60	91.8
	3	Municipal charges			150	229.5
	4	Marketing			20	30.6
	5	Mock flat & sale office			4	6.1
				TOTAL =	**309**	**473**
Total Cost= A+B+C					**1129**	**1727**
TOTAL PROJECT COST =					**353 crores(Approx)**	

Table 3: Estimated budgetary cost of project

3.4 Estimated quantity details showing slab area, concrete volume, shuttering area & reinforcement

Sr. No.	Items	Slab Area	Concrete (CUM)	Shuttering (SQM)	Total Steel (KG)
3rd slab	**First Floor**	**1,172.38**	**325.40**	**3,145.47**	**38,412.93**
1	Shear Wall		164.25	1725	26,928
2	N.S. Wall		18.952	204	-
3	Slab		108.1	900	4,791
4	Beam		34.098	316	6,693
	Second Floor	**1,117.54**	**318.75**	**3,088.59**	**32,535.51**
1	Shear Wall		164.25	1725	21,588
2	N.S. Wall		18.952	204	-
3	Slab		103.04	858	4,567
4	Beam		32.50	301	6,380
	Third Floor	**1,172.38**	**325.40**	**3,145.47**	**33,120.01**
1	Shear Wall		164.25	1725.3	21,635
2	N.S. Wall		18.952	204.24	-
3	Slab		108.10	899.99	4,791
4	Beam		34.10	315.94	6,693
	Fourth Floor	**1,117.54**	**318.75**	**3,088.59**	**31,760.74**
1	Shear Wall		164.25	1725.3	20,813
2	N.S. Wall		18.952	204.24	-
3	Slab		103.04	857.89	4,567
4	Beam		32.50	301.17	6,380
	Fifth Floor	**1,172.38**	**325.40**	**3,145.47**	**32,297.95**
1	Shear Wall		164.25	1725.3	20,813
2	N.S. Wall		18.952	204.24	-

Sr. No.	Items	Slab Area	Concrete (CUM)	Shuttering (SQM)	Total Steel (KG)
3	Slab		108.10	899.99	4,791
4	Beam		34.10	315.94	6,693
	Sixth Floor	**1,117.54**	**318.75**	**3,088.59**	**31,313.43**
1	Shear Wall		164.25	1725.3	20,366
2	N.S. Wall		18.952	204.24	-
3	Slab		103.04	857.89	4,567
4	Beam		32.50	301.17	6,380
	Seventh Floor	**1,172.38**	**325.40**	**3,145.47**	**31,850.64**
1	Shear Wall		164.25	1725.3	20,366
2	N.S. Wall		18.952	204.24	-
3	Slab		108.10	899.99	4,791
4	Beam		34.10	315.94	6,693
	Eight Floor	**1,117.41**	**318.73**	**3,088.46**	**31,312.16**
1	Shear Wall		164.25	1725.3	20,366
2	N.S. Wall		18.952	204.24	-
3	Slab		103.03	857.79	4,567
4	Beam		32.50	301.13	6,379
	Ninth Floor	**1,172.38**	**325.40**	**3,145.47**	**31,850.64**
1	Shear Wall		164.25	1725.3	20,366
2	N.S. Wall		18.952	204.24	-
3	Slab		108.10	899.99	4,791
4	Beam		34.10	315.94	6,693
	Tenth Floor	**1,117.54**	**318.75**	**3,088.59**	**31,313.43**
1	Shear Wall		164.25	1725.3	20,366
2	N.S. Wall		18.952	204.24	-
3	Slab		103.04	857.89	4,567
4	Beam		32.50	301.17	6,380
	Eleventh Floor	**1,091.14**	**315.55**	**3,061.21**	**27,710.02**
1	Shear Wall		164.25	1725.3	17,021
2	N.S. Wall		18.952	204.24	-
3	Slab		100.61	837.62	4,459
4	Beam		31.74	294.05	6,229
	Twelfth Floor	**974.12**	**281.71**	**2,732.91**	**24,738.25**
1	Shear Wall		146.63	1,540.27	15,196
2	N.S. Wall		16.92	182.34	-
3	Slab		89.82	747.79	3,981
4	Beam		28.33	262.52	5,561
	Thirteenth Floor	**53.19**	**15.38**	**149.23**	**1,350.79**
1	Shear Wall		8.01	84.10	830
2	N.S. Wall		0.92	9.96	-
3	Slab		4.90	40.83	217
4	Beam		1.55	14.33	304
	Grand Total	**13,568**	**3,833**	**37,114**	**3,79,567**
	CONSTANTS	**1,46,004 sqft**	**0.026 cum/sqft**	**0.254 sqm/sqft**	**2.60 kg/sqft**

Table 4: Estimated quantity details showing slab area, concrete volume, shuttering area & reinforcement

3.5 Tunnel Form Assembly report

Tunnel Form assembly Report(Internal wall)						
Tunnel No.	Tunnel Size				Total	Completed on Date
	Length	Breadth	Height	Sqm		
1	10093		2743	27.69	48.85	29/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
2	10093		2743	27.69	46.28	29/8/2015
	10093	1449		14.62		
		1449	2743	3.97		
3	10093		2743	27.69	48.85	29/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
4	10093		2743	27.69	48.85	29/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
5	8843		2743	24.26	43.36	2-9-15
	8843	1649		14.58		
		1649	2743	4.52		
6	8843		2743	24.26	41.04	31/8/2015
	8843	1449		12.81		
		1449	2743	3.97		
7	8843		2743	24.26	41.04	31/8/2015
	8843	1449		12.81		
		1449	2743	3.97		
8	8843		2743	24.26	43.36	31/8/2015
	8843	1649		14.58		
		1649	2743	4.52		
9	10093		2743	27.69	48.85	28/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
10	10093		2743	27.69	48.85	31/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
11	10093		2743	27.69	46.28	31/8/2015
	10093	1449		14.62		
		1449	2743	3.97		
12	10093		2743	27.69	48.85	1-9-15
	10093	1649		16.64		
		1649	2743	4.52		
13	10093		2743	27.69	48.85	4-9-15
	10093	1649		16.64		
		1649	2743	4.52		
14	10093		2743	27.69	46.28	1-9-15
	10093	1449		14.62		
		1449	2743	3.97		
15(RG-350mm)	10093		2743	27.69	48.85	3-9-15
	10093	1649		16.64		
		1649	2743	4.52		

Tunnel Form assembly Report(Internal wall)						
Tunnel No.	**Tunnel Size**				**Total**	**Completed on**
16	10093		2743	27.69	48.85	31/8/2015
	10093	1649		16.64		
		1649	2743	4.52		
17	8843		2743	24.26	43.36	2-9-15
	8843	1649		14.58		
		1649	2743	4.52		
18	8843		2743	24.26	41.04	2-9-15
	8843	1449		12.81		
		1449	2743	3.97		
19	8843		2743	24.26	41.04	3-9-15
	8843	1449		12.81		
		1449	2743	3.97		
20	8843		2743	24.26	43.36	4-9-15
	8843	1649		14.58		
		1649	2743	4.52		
21	10093		2743	27.69	48.85	2-9-15
	10093	1649		16.64		
		1649	2743	4.52		
22(RG-350mm)	10093		2743	27.69	48.85	2-9-15
	10093	1649		16.64		
		1649	2743	4.52		
23	10093		2743	27.69	46.28	3-9-15
	10093	1449		14.62		
		1449	2743	3.97		
24	10093		2743	27.69	48.85	4-9-15
	10093	1649		16.64		
		1649	2743	4.52		
25	3843		2743	10.54	21.73	31/8/2015
	3843	1699		6.53		
		1699	2743	4.66		
26	3843		2743	10.54	21.40	4-9-15
	3843	1649		6.34		
		1649	2743	4.52		
27	2993		2743	8.21	17.09	3-9-15
	2993	1549		4.64		
		1549	2743	4.25		
28	2993		2743	8.21	14.80	3-9-15
	2993	1149		3.44		
		1149	2743	3.15		
29	5093		2743	13.97	22.97	4-9-15
	5093	1149		5.85		
		1149	2743	3.15		
30	5093		2743	13.97	21.41	4-9-15
	5093	949		4.83		
		949	2743	2.60		
31	2500		2743	6.86	9.73	4-9-15
	2500	1149		2.87		
				0.00		
32	2500		2743	6.86	9.23	4-9-15
	2500	949		2.37		
				0.00		

Tunnel Form assembly Report(Internal wall)						
Tunnel No.	**Tunnel Size**				**Total**	**Completed on**
33	2593		2743	7.11	15.38	31/8/2015
	2593	1549		4.02		
		1549	2743	4.25		
34	2593		2743	7.11	15.91	1-9-15
	2593	1649		4.28		
		1649	2743	4.52		
35	2593		2743	7.11	18.05	31/8/2015
	2593	2049		5.31		
		2049	2743	5.62		
36	2593		2743	7.11	18.05	31/8/2015
	2593	2049		5.31		
		2049	2743	5.62		
36 tunnel			**total**	**1314.73**	**1314.73**	**8 days**

Lift Panels	**Tunnel Size**				**Total**	**Completed on Date**
	Length	**Breadth**	**Nos**	**Sqm**		
	10600	3000		31.80	31.80	09-05-2015
	3250	3000		9.75	9.75	09-05-2015
			total	**41.55**	**41.55**	**1day**

Outer Plate form No.	**Tunnel Size**				**Total**	**Completed on Date**
	Length	**Breadth**	**Nos**	**Sqm**		
102	10600	3000	1	31.80	31.80	09-05-2015
107	3250	3000	1	9.75	9.75	09-05-2015
108	3250	3000	1	9.75	9.75	09-05-2015
120	1250	3000	1	3.75	3.75	09-05-2015
109	2500	3000	1	7.50	7.50	09-05-2015
116	2500	3000	1	7.50	7.50	09-05-2015
117	2500	3000	1	7.50	7.50	09-05-2015
118	2500	3000	1	7.50	7.50	09-05-2015
119	2500	3000	1	7.50	7.50	09-05-2015
115	2500	3000	1	7.50	7.50	09-05-2015
114	2500	3000	1	7.50	7.50	09-05-2015
110	2500	3000	1	7.50	7.50	09-05-2015
105	5000	3000	1	15.00	15.00	09-05-2015
106	5000	3000	1	15.00	15.00	09-05-2015
103	7500	3000	1	22.50	22.50	09-05-2015
104	5000	3000	1	15.00	15.00	09-05-2015
16 Outer Panels			**Total**	**182.55**	**182.55**	**1day**

Table 6: Tunnel formwork assembly report

Total formwork area = Area of Half tunnel + Area of lift panels + Area of outer platform.
= 1314.73 + 41.55 + 182.55
= 1538.83 m^2

3.6 List of personnel engaged on site

No	Name, SURNAME	Job Describtion	Nationality
1	RAMAZAN KARA	STEEL FIXER FOREMEN	Turk
2	SHREENAND DABIR	ENGINEER	INDIAN
3	VIJAY GOFANE	Supervisor	INDIAN
Electricians			
1	RAMESH SINGH	Fabricator	INDIAN
2	TAPASAR	Fabricator	INDIAN
3	PINTU	Fabricator	INDIAN
4	RAJU KUMAR	Fabricator	INDIAN
5	AJAY BHAGAT	Fabricator	INDIAN
6	JAY KUMAR	Fabricator	INDIAN
7	RAJ KUMAR	Fabricator	INDIAN
8	RAMESH KUMAR	Fabricator	INDIAN
9	AJAY KUMAR	Fabricator	INDIAN
10	DHARMENDER	Fabricator	INDIAN
11	DAYASHANKAR	Fabricator	INDIAN
12	ANIL SINGH	Fabricator	INDIAN
13	JITENDER SINGH	Fabricator	INDIAN
14	SEAR SINGH	Fabricator	INDIAN
15	MAHANDAR SINGH	Fabricator	INDIAN
16	RAMRAJ	Fabricator	INDIAN
17	SACHINE	HELPER	INDIAN
18	ANAND	HELPER	INDIAN
19	DIPAK	HELPER	INDIAN
20	MOWSAM	HELPER	INDIAN
21	NITIN	HELPER	INDIAN
22	RAJESH KUMAR	HELPER	INDIAN
23	SONU KUMAR	HELPER	INDIAN
24	RAJENDRA RAU	HELPER	INDIAN

Table 6: Labour report for building A2

3.7 Photos

Photo 1: Erection of Tunnel formwork

Photo 2: Half tunnel

Photo 3: 3rd Slab erection activity

Photo 4: Support panels of tunnel formwork

Photo 5: Slab after deshuttering formwork

Photo 6: Construction of 14th slab

4.0 Techno-Commercial Analysis of Tunnelform System

4.1 General: Data was collected to calculate various costs, time required for completion of 1 floor (one cycle time) & hence to compare cost & time of TUNNEL FORMWORK & ALUFORM. Process is divided in 4 stages.

Stage 1: Productivity calculations

Stage 2: Cost calculations

Stage 3: Time calculations

Stage 4: Cost & Time comparison.

4.2 Productivity calculations: Productivity is an important factor of time & cost calculations. Higher productivity will resulted in lesser the time required for activity and ultimately lesser the overall cost.

$$\text{Productivity} = \frac{\text{Work done in one day (in m}^2\text{)}}{\text{Total man hours}}$$

4.2.1 Assembly productivity of tunnel formwork

Sr No	Detail of operation	No of workers	Category	No of hours
1	Connection of deck panel and extension	10+1	Skilled fabricators+ Crane operator	88
2	Connection of vertical panel and extension			
3	Installation of foldable prop to vertical extension			
4	Installation of wheel connector			
5	Connection of deck panel and vertical panel			
6	Installation of foldable prop to deck panel			
7	Installation of wheel support			
8	Installation of roof keys to deck panel extension			
9	Installation of vertical panel jack			
10	Dimension and alignment check			

Table 7: Assembly productivity of tunnel formwork

Total man hours= 88 hours
Work done = 4x[(10.1 x 2.7)+(10.1 x 1.7)+(1.6 x 2.7)]= 4 x 48.85=195.4
Productivity= 196/88 = 2.22 say 2.2 m^2 per worker per day

4.2.2 Tunnel Form Erection productivity

Sr. No	Detail of operation	No of labours	Type of labour	No of hours
1	Moving & setting 1st half tunnel formwork			
2	Moving & Setting 2nd half tunnel formwork			
3	Fixing 1st & 2nd tunnel formwork by roof keys & tie rods	16	Skilled	128
4	Cleaning & oiling			
5	Installation of slab reinforcement	1	Crane operator	8
6	Alignment & checking			
7	Installation of gas heaters & curtains			

Table 8: Tunnel Form Erection productivity

Total man hours: 200 hrs
Work done 1set of tunnel formwork: 1538.83 m^2
Productivity: 1538.83/ 200 = 7.69 say 7.7 m^2/ day/ worker

4.2.3 Tunnel formwork striking/ Deshuttering productivity

Sr. No	Detail of operation	No of labours	Type of labour	No of hours
1	Removing tie rods & roof keys			
2	Removing heaters & curtains	16	Skilled	128
2	Removing half tunnel set	1	Crane operator	8
3	Cleaning, oiling & back propping			

Table 9: Tunnel formwork striking/ Deshuttering productivity

Total man hours: 136
Work done: 1538.83
Productivity: 1538.83/136 = 11.3 m^2/ day/ worker

4.3 Cost calculation [Tunnel formwork]:

Cost calculation considering Total area to cast using Tunnel formwork : 25 Lac sqft

Detail	Cost	Cost/sqft of Project Slab area
Tunnel formwork (2 sets) (3500 SQM of contact area)	INR 8 Cr	INR 32
Tower Crane (3 No. 10 T)	INR 4 Cr	INR 16
Batching Plant (75 cum/ hr)	INR 1.5 Cr	INR 6
Rebar mesh welding machine	INR 0.5 Cr	INR 2
Boom Placer and other related machineries	INR 1 Cr	INR 4
TOTAL INVESTMENT =	**15 Cr.**	**INR 60**
Labour cost (initially 6 months)	USD 25/sqm	INR 155
Labour cost (after 6 months)	USD 12 to 15 /sqm	INR 90
Extra cost for Concrete (M35, M40)	For additional quantity of cement & admixture	INR 12-15

4.4 Break even area to be constructed using Tunnel Formwork:

Average area of 2 BHK Flat – 800 sqft
Minimum Flats per floor – 4 Nos
Area of casting of one pour using one set of Tunnel Form – 2 Flats i.e. 1600 sqft
No of Repetitions of formwork – 500 nos

Breakeven area of project / projects for optimum utilization of Tunnelform one set
= 500 x 1600 = 8,00,000 sqft

So the Tunnelform Shuttering should be consider for the Mass projects having more than or equal to 8 lakh sqft construction area.

4.5 Comparison of Tunnel formwork with Aluminum & Conventional System:

Activity	Conventional Formwork	Aluminium Formwork	Tunnel Formwork
Initial Capital Cost	Less	High	Very high due to other heavy machinery
Casting Structure	Column, Beam & Slab framed structure individually casted.	Monolithic structure (walls and slab.)	Monolithic structure (main walls and slab) Internal walls were constructed later stage.
Precision and Quality of construction	Less	Good	Good
Need of Internal/external Plastering	Required	Not required	Not required.
Change in Design	Any change in design can be incorporated before casting	Changes in design can be incorporated by time-consuming panel modifications.	Difficult to incorporate changes in design after manufacture of tunnel formwork.
Construction Speed	Slow	Fast	Very Fast
Floor to Floor Cycle time (RCC)	15- 20 days	10 -15 days	1-3 days
Number of repetition of formwork	10 to 15	100 to 150	500 +
Advantages	Convenient and low budget	High Cost, less manpower, moderate faster, high reusability with modifications, suits for mass housing projects having multi storey buildings.	High Cost, less manpower, moderate faster, high reusability with modifications, suits for mass housing projects having multi storey buildings.
Disadvantages/ Limitations	Low speed, Less quality of work, Less durable	Medium lifespan, skilled/unskilled manpower required, reasonably high investment	Long lifespan, skilled manpower required, Very High investment, Work only with tower crane
Material Cost of formwork	Approx. Rs 600 to 700 per sqft (Formwork area)	Approx Rs 7000 to 9000 per sqft (Formwork area)	Approx Rs 11000 to 13000 per sqft (Formwork area)
Labour Cost of Formwork	Approx Rs 100 to 150 per sqft	Approx Rs 200 to 275 per sqft	Approx Rs 300 to 350 per sqft

5 CONCLUSIONS

From the study of formwork systems and data analysis of case study it is concluded that:

1) Though tunnel formwork system have the higher initial cost per sq.m, it can be utilized for more number of repetitions. The tunnel formwork system is best suitable for the project wherein number of repetitions of the tunnel formwork is more than 500.

2) Higher capacity tower cranes and other heavy machinery and site management plays vital role in successfully implementation of tunnel formwork. Also, Consistent and higher cash outflow required to cater the speed of construction.

3) The role of management is important, any gap in communication and co-ordination issues will cause significant delays in schedule.

4) Ultimately, the TUNNEL formwork system is fastest formwork system and best suited for projects with a construction area more than 8 lakh sqft and having large number of identical units, floors and buildings.

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