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Critical Evaluation of Super Structure Construction for Metro Corridor

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ABSTRACT

To keep cities and metropolises accessible it is seen more and more that the infrastructure is elevated high above the ground. An elevated metro system is comparatively cheaper than an underground metro system and the construction project duration is also less. The physical barrier caused by the realization of an elevated system is also less than that of a metro system at ground level. With Metro Rail construction rapidly growing in our country it is therefore necessary to decide which practices are best selected for its construction. India is facing a serious problem of cost and time overruns due to adoption of poor construction methodologies in infrastructure projects, which is very unfortunate part of the construction industry. Construction of Superstructure in a significant part of elevated viaduct construction and constitutes a major portion of cost, time and resources required for development of the project. Various different construction methodologies are available for construction of both Pier cap and Girder which have been critically evaluated selecting five major parameters for comparison. This document attempts to compare different methods on basis of aforementioned criteria and identify the best possible technique for superstructure construction.

Keywords

Metro, Construction, Methodologies, Girder, Superstructure, Pier Cap, Construction.

INTRODUCTION

Infrastructure projects are essential for the development of a country, so it is necessary that proper construction methodologies are adopted during the execution of the work. Rail based 'Mass Rapid Transit System' has been broadly acknowledged as a solution for most of the traffic and pollution problems. Further in India, metro projects are under construction in many major cities such as Delhi, Kolkata, Ahmedabad, Mumbai, Bengaluru, Chennai, Hyderabad, Jaipur, and Nagpur. Also for the construction of same element, various feasible technologies are being adopted based on the constraints in the project such as precast and cast in-situ.

NEED FOR STUDY

India is facing a serious problem of cost and time overruns due to adoption of poor construction methodologies in infrastructure projects, which is very unfortunate part of the construction industry. Proper construction methodologies along with economical execution of work is a significant factor apart from the time constraints in the construction of Metro projects.

OBJECTIVE

The study aims at solving the dilemma of the selection of suitable construction methodology out of various available construction methodology adopted in elevated metro corridor through critical comparison of the available construction methodologies in elevated metro corridor.

LIMITATIONS

- Metro projects of India only have been taken as a case study keeping in mind the time frame of the study.
- Scope of work has been limited to the comparison of different methodologies for elements of super structure only.
- Further scope of work has been restricted to RCC structures only.
- All the data and information obtained from the site are assumed to be authentic based on personal observation.
- Design aspects of the elements have not been taken into consideration looking towards the parameters on which comparison is to be done.

RESEARCH METHODOLOGY

Literature study includes study of topic related reference books, research papers, journals, detailed progress reports of metro projects and various infrastructure projects thesis. From literature study, various technologies adopted for construction of elevated viaduct structural elements have been identified. Methodologies include both cast in-situ and precast elements. Once the technologies adopted for construction of elevated viaduct structural elements have been identified, then case studies have been selected from the elevated metro projects in India. Various parameters have been taken into consideration for case study selection so that the analysis could be done properly and all the major available technology could be covered. After identification of various methodologies and cases of ongoing projects, contractors and clients of various metro projects have been approached for the permission for site visits and data collection.

In order to maintain the authenticity of the data collection, various sites have been visited personally for observation of the construction methodology and data collection. Visits have been made to various ongoing metro construction projects for the data collection purpose and for gaining the in-depth knowledge of the construction methodology. Data collection sheet have been prepared and all the data required for the analysis purpose have been collected through site officials and personal observation on site. Starting from basic site details to the element details along with the manpower, timescale and rates have been collected for analysis purpose. Through site visits along with the help of site officials, a thorough understanding of the construction methodology have been developed. All the construction activities have been properly observed and understood so that an accurate analysis could be done.

Parameters for analysis have been identified at literature stage only through opinion survey. Thus this prepares a common ground at which various methodologies would be compared and most efficient methodology would be identified. After critical evaluation of all the construction methodologies taken into study based on the selected five parameters, most efficient method have been identified for each parameter.

LITERATURE STUDY

There are various different methods available for the construction of elements of elevated metro corridor. Determining the method of construction to be adopted, requires taking into account the span length, the existing site constraints, project duration, project cost, etc. Furthermore the construction schedule, the contractor’s equipment or the size of the project may also be determining factors to prefer one method over another. The advantages and disadvantages of various approaches must be analyzed early in the conceptual design phase to determine the best one. This section discusses the suitability, feasibility and the construction sequence of each method.

- Cast-in-situ construction
- Span-by-Span Precast Construction
- Balanced cantilever Construction
- Incremental Launching Construction

CASE STUDY

Various possible construction methodologies for the selected elements have been identified and for case study, ongoing metro project sites in India have been selected.

Table 1. Case Study Details

Element	Case study	Construction Methodology
GIRDER	Case study-1	Full Span Precast Girder
	Case study-2	Segmental Precast Girder
	Case study-3	Full Span Cast In-Situ Box Girder
	Case study-4	Composite (Cast In-Situ Deck Slab + Precast I- girder)

Table 2. Element Details

Details	Case Study-1	Case Study-2	Case Study-3	Case Study-4
Construction Methodology	Full Span Precast Girder	Segmental Precast Girder	Full Span Cast In-Situ Box Girder	Composite (Cast In-Situ Deck Slab + Precast I-girder)
Length of Girder	25.6 m	3 m	31 m	21 m
Width of Girder	5.05 m	8.8 m	4.63 m	8.61 m
Concrete Grade	M55	M50	M50	M45
Concrete Qty.	58.5 CuM	14.54 CuM	95.2 CuM	42.03 CuM
Reinforcement Quantity	10.07 MT	3.64 MT	14.34 MT	17.57 MT

PARAMETERS FOR EVALUATION

1) Time Analysis
2) Rate Analysis
3) Risk Analysis
4) Manpower Required
5) Level of Mechanization
6) Sustainability
7) Constructability

CONSTRUCTION METHODOLOGY

FULL SPAN PRECAST U GIRDER

The casting bed includes pedestals, thrust block, abutments for stressing etc. which are made as per GFC drawings. The area is neatly dressed and compacted with roller and after that the M-15 grade levelling is laid. For lifting and shifting of girders and other required materials 2 x 100 MT gantry crane is erected with its rail foundation. In all two long line pre-casting beds are provided for precast U-girder spans.

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Fig 1: Full Span Precast U-girder Casting bed

The rebar cage is tied with already treated, cut and bent bars by using cutting and bending machines at the centralized reinforcement yard .The bars are then shifted to the respective rebar jigs where the same are tied by using Galvanized Iron (GI) binding wire in the required position according to approved drawings. The debonding pipes are fitted inside the rebar cage and held in position using suitable chairs hooks and GI binding wire. After joint inspection, reinforcement cage is lifted with two gantry cranes by using a spreader beam .The cages are lifted and placed in pre-casting shutter moulds with a structural frame holding the cage in a manner to prevent any distortion while lifting and placing.

After lowering reinforcement cages in shuttering mould, HT strands are threaded through rebar cages and debonding tubes from anchor end passing through all U-Girder cages and respective debonding tubes. At strand holding structural beam these are anchored withthe help of master barrel and wedge sets. After feeding and anchoring all strands as above, one by one strand are stressed from anchor end at 5% to 10% of design load against anchor end and locked with the help of master barrels and wedges for slack removal. Then all H.T strands are stressed from stressing end with the help of central holed jack sets operated by a single hydraulic pump to their design load. Load applied v/s extension of strands is measured and recorded.

After aligning rebar cages and fixing clear cover blocks, already cleaned inner shuttering sets are fed in the rebar cages. The inner shuttering sets so fed in are joined and alignedto the line and level required. Safe lifting is ensured. Inserts for launching girder handling, rain water drain, OHE-MAST, foundation bolts, earthing, cable racks etc. are fixed beforeconcreting. Bottom slab from one end towards other end over full width and length of at span/3.After bottom slab concrete achieves initial setting time both side beams from the same end of bottom slab towards the other end layer by layer in 3 layers are poured. However this length is determined by concrete poured initially in bottom slab, so that slope of concrete in web does not exceed beyond the bottom slab concrete already poured.

During step 2, the condition of bottom slab already poured is monitored carefully and in case the bottom slab starts initially setting, then the bottom slab is extended by 1.5 to 2.0 m as a painting pour to avoid cold joint. Take up pouring in bottom slab from existing location towards the other end over full width and balance length.

During step 3, the condition of both side beams already poured is to be monitored carefully and in case the beams start initially setting, then the beams are extended by 1.5 to 2.0 m as a painting pour to avoid cold joint. Both side beam concrete, up to the span end is done.Curing is done continuous over a minimum of 14 days period after concreting. Curing by either ponding / spraying / jetting water is attended un-interruptedly. Top of the bottom slab is to be ponded with water.

SEGMENTAL PRECAST GIRDER

The reinforcement cage of the pier head segment is done on the reinforcement jig, specially fabricated for tying of the reinforcement cage of box segments.First of all the bottom bars are laid on the jig and cover blocks of 50mm are laid at the bottom. Then the side curved bars are laid and the side stirrups are placed and the side bars are inserted along with the cover bocks of 50mm. Then the bars of the deck slab are placed and then the bars of middle portion are inserted. Then the helical bar used for the support of HDPE pipes are inserted.Then the earthing is done using a mild steel strip and GI strip the earthing drawings.After the whole cage is ready, it is placed to the mould using a 15 Ton capacity Gantry crane.

Casting of the pier head segments on both sides is done at the short line casting bed and then the match casting of other segments is done at the long line bed. The buffing of the mould is done and releasing agent is applied to it. Then the reinforcement cage is brought from the jig and placed above the mould and profiling is done. Rubber bit is attached on the outer bulk heads of both the sides and are inserted to the bottom trolley using 16 mm bolts. The inner formwork is inserted and necessary propping is done. Steel block of appropriate size is placed for maintaining drainage whole if required.Profiling is done for the post tensioning of the span. HDPE pipes are used for profiling of the segments. HDPE pipes are inserted after the reinforcement cage is placed on the mould.

Concreting is done with the help of transit mixer and concrete pump.Hose pipe of 150 mm diameter is arranged at the top of the segment.Temperature is checked, slump test is done and total 12 no. of cubes are filled for cube test.Concreting is started and first concreting of the soffit is done.Then the concreting of both the webs is done up to certain levels alternatively. Then the concreting of the deck slab along with the cantilever portions is done. Level of the concrete is done using muster. De-shuttering of the segment is done after 24 hours only if the strength obtained by cube test is more than 20 MPa. Then the pier head segment is lifted from the lifting holes using the gantry crane and placed on the respective long line casting bed where the further segments of the span are to be constructed.Curing of the segment is done for 14 days from the date of casting. Soon after the de shuttering, curing compound is applied on the surfaces and gunny bags are kept in the inner surface.

Fig 2: Segmental Precast Girder Casting

FULL SPAN CAST IN-SITU BOX GIRDER

Initially the bottom ground surface is cleaned and levelled to lay out the scaffolding (cup lock system) according to the level to be achieved at the top of the segment. Bottom blocks are placed after the line out of size 250*250*150 mm. Transportation of the elements is by creating an h-frame so that the arrangement is easy and efficient. The stacking of the formwork is in the form of box carriages near the work area. Two jacks one at bottom and other at top to get the exact height of the segment top. Cross bracing is done every 3 m of the length for extra support. After that walers are fixed all along the span and across the span for support of bottom span shuttering. Making of the safety walkway and railing at soffit slab level is done. Lastly checking of the exact height of the staging is done by the surveyor at site using total stations.

After the staging is done the shuttering for the fixing of the slab bottomand checking the alignment and levelling is done including bearing fixation and grouting.The level of the soffit is checked and then the shuttering fixation for the web outer position including shutter modification at both the ends isdone.The fixation starts from the both the end of the span and then brought up tothe center adjusting the plate size at thecenter.Shuttering fixation for the end panel is done after the profiling and reinforcement caging of thespan**.**

Finally the shutter fixation for web inner portion includingshutter modification at both theends.Shuttering of full span includes the checks for the same by the PMCconsultant and the site engineer for the proper alignment of theshuttering.After that first pour of concreting is done and after curing period of about 2 days the shuttering of the deck slab is started after the staging of thebottom.Shuttering fixing for deck slab bottom with extra supports at hunch portion including shutter modification at bothends**.** Outside shuttering fixing for deck slab is done later on for the completion of shuttering the final checking is done by the engineer-in-charge and PMC consultant.

Fig 3: Full Span Cast In-situ Box Girder Construction

The co-ordinates for the sheathing pipes are marked on the soffit formwork with paint. Majority of the bottom reinforcement is placed, except for the supportive reinforcement. The final Y-co-ordinates for the sheathing pipes are derived after deducting the radius of the pipe from the given Y-co-ordinates. These are then marked on a reinforcement bar with chalk. Using a tube filled with water, these levels are then transferred onto the web reinforcement bars. The marking is initially done with chalk and is then redone with paint. Then chairs, support bars and helical anchorage reinforcement are placed as per markings done. The sheathing pipes are then slowly inserted from either of the end diaphragms. Care is taken that the pipes rest on the supporting reinforcement and there is no undesired bend in the pipes. Then the remaining reinforcement is placed, except for the supportive reinforcement.

After the checking of the formwork is done, the concretingprocess starts. Concreting is done in two stages. The arrangement of concreting is done with the connection of transit mixer and boom placer near the span which is been casted and later on thevibrators are used for more homogeneousmixture. The second stage is done after curing and shuttering of the deck slab bottom with extra support at haunch portion including shutter modification at both the ends.

COMPOSITE (CAST IN-SITU DECK SLAB + PRECAST I- GIRDER)

The casting bed includes pedestals, thrust block, abutments for stressing etc. which are made as per GFC drawings. The area is neatly dressed and compacted with roller and after that M-15 grade concrete leveling is laid. For lifting and shifting of girders and other required materials 2x 100MT gantry crane is erected with its rail foundation.

Formwork is prefabricated as per GFC. The formwork should be sufficiently strong and rigid to withstand without distortion, the effect of placing and compacting concrete as well as of prestressing. Jack & turn buckles are provided to support the shuttering of I- girder. After fixing of shutter the verticality, alignment, sizes is checked. De-Shuttering is done after 24 hours of concreting.

Fabrication of reinforcement is done as per approved BBS in rebar yard using bar bending and bar cutting machines. The rebar's are manually fixed as per GFC drawing and approved BBS for I- girder and shifted to casting beds. 40mm cover blocks are made as per specification and provided at spacing as required.

The concrete required is produced as per the approved design mix at the centralized batching plant and transported by transit mixers to the pouring location. Before pouring concrete slump (120-160mm) is checked

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at pouring location. Concrete casting for I-girder is done in three layers and in one pour. Sufficient compaction is done by means of needle vibrators and shutter vibrators placed at 3m interval. Both ends of de-bonding tube are effectively sealed against ingress of cement slurry using epoxy putty or relevant materials.

Stressing isdoneafter7daysorafterthe concreteattainsstrengthof40Mpa, whicheverislater. Pre-stressing strands of 15.2mm diameter are used. Slack removal of strands is done by stressing up to 100kg/Sq.M by mono strand jack. After removal of slackness, strands andtubes are thoroughlyexamined toensurecorrectalignment. The strands are then stressed at the stressing force as detailed in the approved drawing. Stressing of strands should be done by single pull jack so that the transferofstressestoconcreteportionwouldbeuniform. The duct is grouted as soon as possible after stressing within 24 hours. After the pre-stressing strands are cut, the surface is coated with epoxy paint and entire recess is filled with non-shrink grout.

Girders are covered with hessian cloths after removal of formwork and these are kept moist at casting bed till distressing is done, after that the girder is shifted to stacking yard & curing for 14 days is done in stacking yard by sprinkling of water.

Precast I-girder is transported using hydraulic axle modular trailer placed on loading area at casting yard. Two guide rope of 20 m each are fixed at both ends of girder to balance in air during lifting. Trailer duly loaded with the Precast I-Girder is positioned as per the marks provided in advance. It is ensured that minimum safe working load capacity of each crane with required boom length, boom angle and radius is maintained as per load chart. Riggers are attached to the lifting arrangement at both end of Girder. Tandem lifting with slow hoist speed is done by two telescopic crane of required capacity. Once the girder is placed in its final position over the bearings, side supporting arrangement are fixed to prevent toppling and tilting of I Girder.

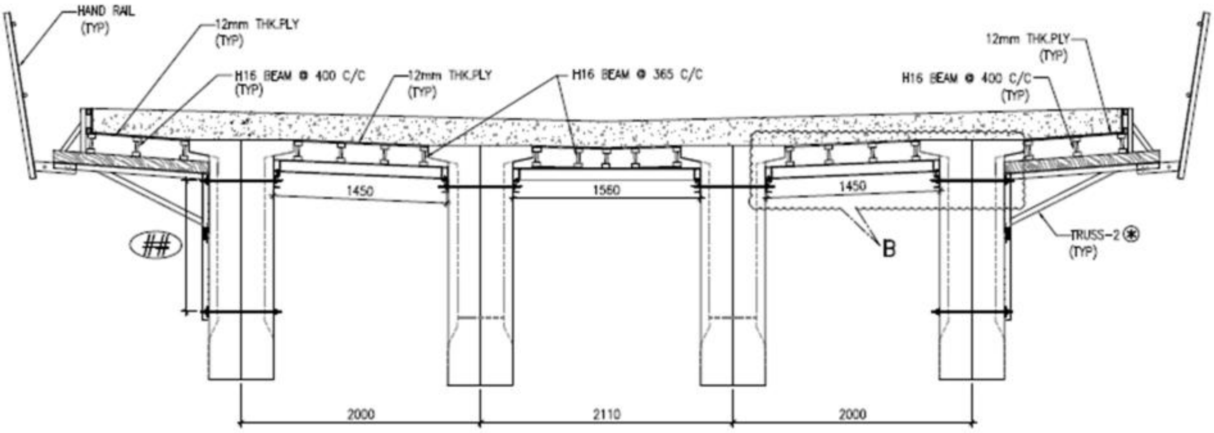

Fig 4: Composite Girder Section

Deck slab casting

Shuttering work is executed at site by using bracket scaffolding system and sacrificial deck sheet formwork. Pre-fabricated steel brackets are fixed on the external face of I girders by using of tie rods. Upon which horizontally H-16 beams are placed and above that 12 mm thickness plywood sheet is fixed. Pre-fabricated deck sheets of 15 mm thickness are nailed between the I-girders on the upper face.

Reinforcement is cut and bent using cutting and bending machines as per approvedBBS at Rebar yard after being treated by anti-corrosion treatment. The rebar are transported to location by 25T capacity flatbed trailer. The rebar are manually fixed onto its position as per GFC drawings. Adequate cover blocks and chairs are provided to maintain proper alignment and level of rebar cage. All these shuttering materials are lifted by using hydra crane of 35T Capacity.

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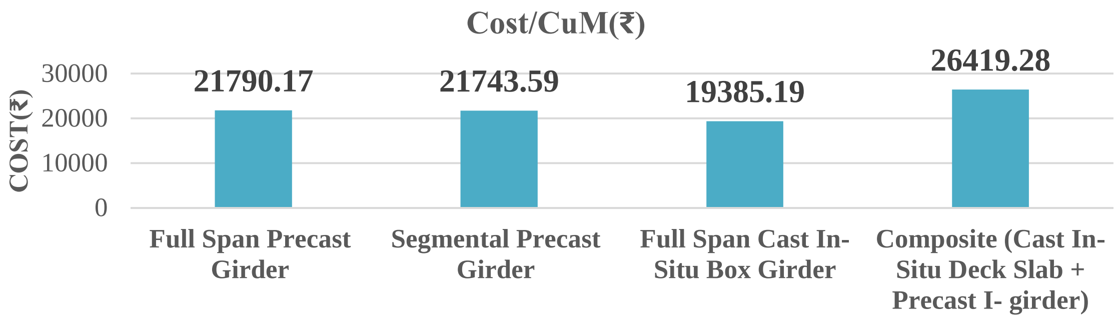
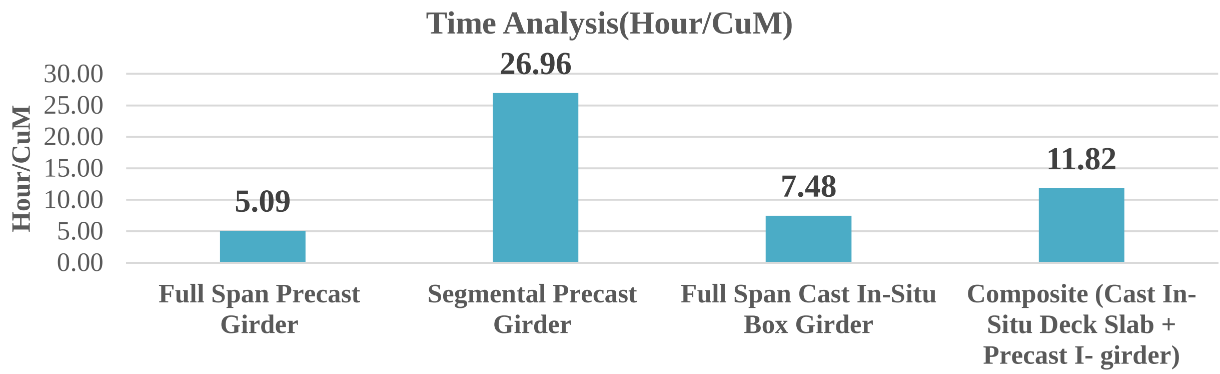
Concrete (Grade M45) is produced at centralized batching plant and transported by transit mixers to site where it is poured through concrete boom placer. Prior to the commencement of pumping of concrete by boom placer, cement slurry is pumped for lubricating the pipelines. Diaphragm wall is casted during/before the time of deck slab casting. The surface of the diaphragm wall which is to be in contact with the deck slab is roughened for making good joints. Viaduct deck slab is placed in 225mm thick concrete. Concrete is to be cured by water ponding method up to 14 days. Outer side diaphragm wall shuttering is to be removed 24 hours. While bottom formwork is sacrificial so it would not be removed. Parapets are cast in casting and transported to site where they are erected using 50T crane.

ANALYSIS

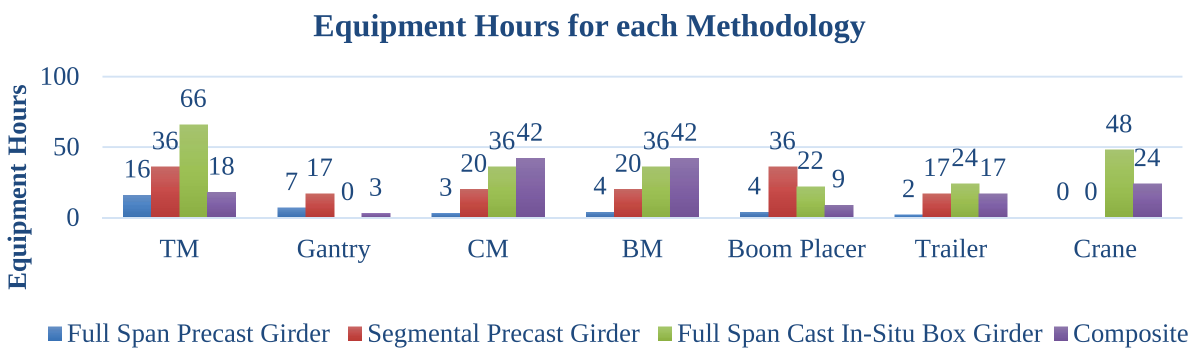
Cost analysis



Time analysis



Level of Mechanization



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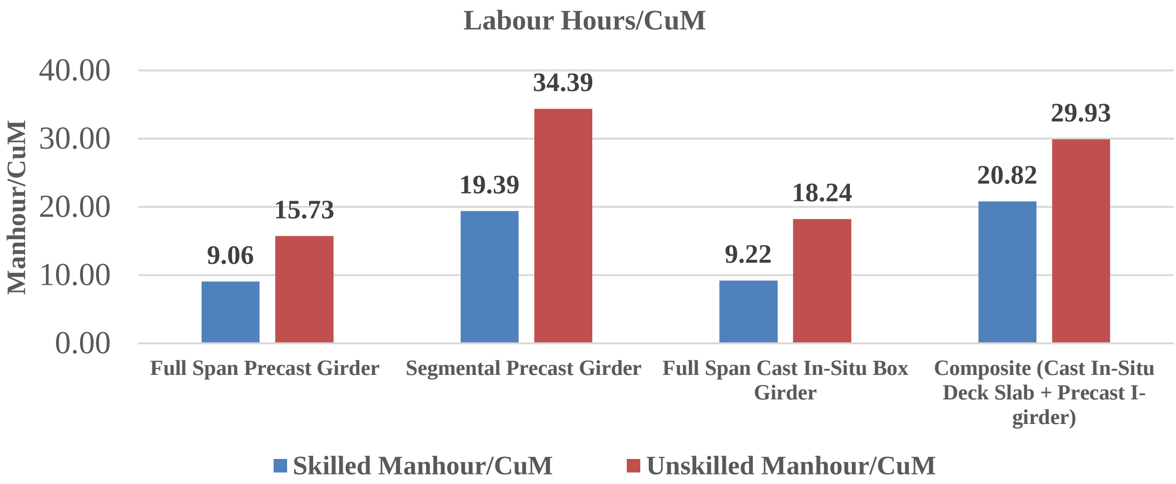
Manpower Analysis



SAFETY ANALYSIS

Table 3. Risk Assessment Sheet

RISK ASSESSMENT ANALYSIS SHEET					
PROBABILITY RATING		**RISK LEVEL (1=Trivial, 2=Tolerable, 3= Moderate, 4=Severe, 5=Intolerable)**			
When it occurs frequently or chances are more than 50%	**H**	**3**	**4**	**5**	
When it occurs occasionally or chances are between 10% to 50%	**M**	**2**	**3**	**4**	
When it has rarely occurred before or the chances are less than 10%	**L**	**1**	**2**	**3**	
		L	**M**	**H**	
		When it can lead to first aid injury or when property loss is less than Rs 10,000	When it can lead to temporary disability or doctor visit is required or when property loss is more than Rs 10,000 but less than Rs 100,000	When it can lead to fatality or permanent disability or when property loss is more than Rs. 100,000	**SEVERITY RATING**
Labels	**Trivial**	**Tolerable**	**Moderate**	**Severe**	**Intolerable**

Table 4. Risk Analysis for Girder Construction

Risk Assessment Sheet							
Case Study-1		**Case Study-2**		**Case Study-3**		**Case Study-4**	
Activity	**Risk level**	**Activity**	**Risk level**	**Activity**	**Risk level**	**Activity**	**Risk level**
Alignment of formwork	2	Lifting &placing of rebar cage	2	Erection of scaffolding	5	Reinforcement works	2
Lifting &placing of rebar cage	2	Shuttering	2	Transportation of reinforcement to site	3	Shuttering	2
						Concreting	2
Shuttering	2	Concreting	2	Reinforcement Binding	2	Stressing	2
Concreting	1	De-shuttering	2	Shuttering	5	Launching	4
De-shuttering	2	Stacking	2	Concreting	4	Shutter fixing	2
Stacking	2	Transportation of segment to site	2	Deshuttering	4	Reinforcement works	2
Launching	4	Erection of segment	3			Concreting	3

CONCLUSION

Ranking of these methodologies is based on the factors like construction time cycle, level of mechanization, manpower requirement, cost, safety, and sustainability. Rank-1 is given to the one which has least time cycle as it will save overall project time, highest level of mechanization, least requirement of manpower, and least cost incurred, high safety, sustainability and constructability, and vice-versa for Rank-4.

Table 5. Ranking of Methodologies for Girder

SR No	Parameter	Rank-I	Rank-II	Rank-III	Rank-IV
1	**Time Cycle**	Full Span Precast Girder	Full Span Cast In-Situ Box Girder	Composite Girder	Segmental Precast Girder
2	**Level of Mechanization**	Full Span Cast In-Situ Box Girder	Composite Girder	Segmental Precast Girder	Full Span Precast Girder
3	**Manpower Required**	Full Span Precast Girder	Full Span Cast In-Situ Box Girder	Composite Girder	Segmental Precast Girder
4	**Cost**	Full Span Cast In-Situ Box Girder	Segmental Precast Girder	Full Span Precast Girder	Composite Girder
5	**Safety**	Full Span Precast Girder	Segmental Precast Girder	Composite Girder	Full Span Cast In-Situ Box Girder
6	**Sustainability**	Full Span Precast Girder	Segmental Precast Girder	Composite Girder	Full Span Cast In-Situ Box Girder

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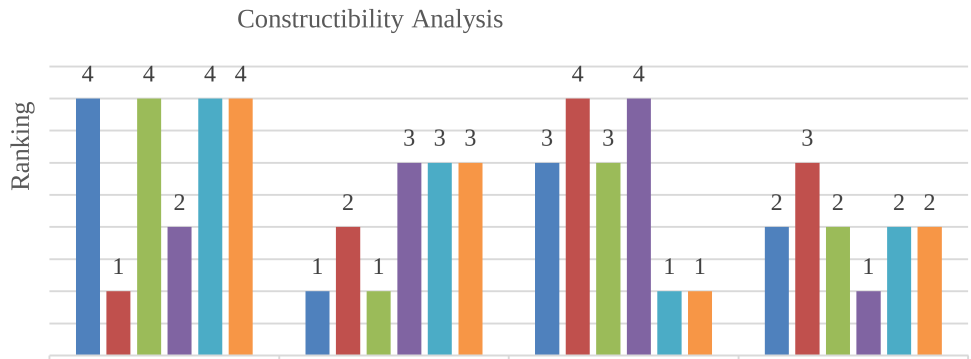
Again for overall constructability analysis, considering all the above six parameters as equally important, the methodology with the highest ranking has been considered most preferable.



	Full Span Precast Girder	Segmental Precast Girder	Full Span Cast In-Situ Box Girder	Composite (Cast In-Situ Deck Slab + Precast I- girder)
Time Cycle	4	1	3	2
Level of Mechanization	1	2	4	3
Manpower Required	4	1	3	2
Cost	2	3	4	1
Safety	4	3	1	2
Sustainability	4	3	1	2

Time Cycle Level of Mechanization Manpower Required Cost Safety Sustainability

Methodology	Full Span Precast	Segmental Precast	Full Span Cast In-Situ Box	Composite
Total	19	13	16	12

Thus, overall considering all the above parameters, **full span precast girder construction** is most preferable out of all the four construction methodology selected for study.

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