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Full Span Box Girders for the Mumbai-Ahmedabad High-Speed Rail Project: Revolution in Fast Pace Construction

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Abstract: The MAHSR (Mumbai-Ahmedabad High Speed Railway) corridor showcased the country's dream of first HSR (high speed railway) project and will be a major milestone towards country's infrastructure development. Globally, more than 20 countries are already running HSR commercially, Japan has been among the lead players with Shinkansen technology. It has impeccable record of zero accident involving passenger fatalities in last 60 years of its existence long with excellent punctuality records. Shinkansen technology has been chosen for HSR project on account of its technical supremacy. As far as construction of super-structure girders is considered, there are many methods available i.e. SBS (segment by segment girder), FSLM (full span launching method), steel girder, I-girder, U-girder, with FSLM and SBS being the prominent ones. In FSLM Girder, the casting as well as erection is done as a single span of 35/40 m while in case of SBS method, the casting is done in 2/2.5 m segments and erection is done segment by segment. Most of the girder launching work in viaduct construction in HSR projects worldwide has been done using segment by segment launching method. There was a critical need to reduce the higher time taken by this method for launching of span along with quality improvements using technological innovations. Considering this aspect the launching of girder was planned using FSLM as the best solution for the advancement. Presently, only few countries like China, Taiwan utilized this technology for HSR projects in a limited way.

Key words: FSLM, SBS, precast-yard.

1. Project Brief

The MAHSR (Mumbai-Ahmedabad High Speed Railway) Project line connects Mumbai, located in Maharashtra State with Ahmedabad in Gujarat State, passing through one Union Territory, Dadra and Nagar Haveli (Fig. 1). The entire stretch is divided into 8 civil packages from C1 to C8. The overall alignment and station details are presented in Fig. 1.

Salient project details of MAHSR are as under:

(1) Total length = 508 km

(2) Total passenger stations = 12

(3) Total length of corridor = 508.17 km

(4) Total length of corridor as underground section = 21 km

(5) Design speed = 350 km/h

(6) Operating speed = 320 km/h

Presently, construction of 300 km of viaduct has been completed in which 269 km is done with FSLM girder and remaining mostly with SBS (segment by segment girder) girders.

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2. Challenges Involved in FSLM (Full Span Launching Girders) Method

The construction of FSLM girder is very unique & highly challenging. The finally completed viaduct with FSLM girders is shown in Fig. 2.

2.1 Casting of FSLM Girder

The standard size of FSLM girder adopted in this project is having a design span length from 35 to 40 m. Total volume of concrete to cast one girder of 40 m is approximately 400 m^3. This involves challenge for:

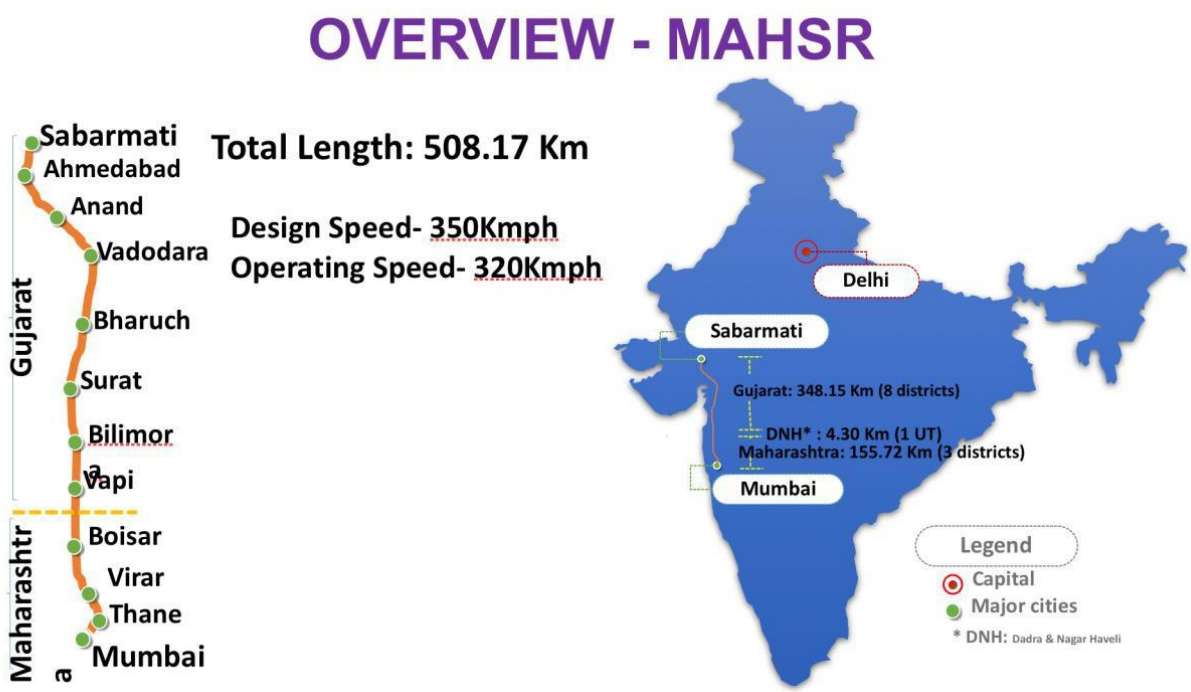


Fig. 1 Overall project summary.

Fig. 2 Successfully launched FSLM girders.

- Fabrication of heavy duty specialised shuttering moulds.
- Concrete pouring arrangements with proper quality assurance.
- Being mass concreting, it is important to control the heat of hydration to avoid the cracks.
- Need of proper concrete mix design and pouring sequence.
- Handling of reinforcement cage of approximate weight of 46 MT.
- Proper sheathing duct arrangements maintaining proper geometry.
- Proper curing arrangements.
- And, proper prestressing arrangements.

2.2 Requirement of Huge Precast Yard

FSLM precast yards are required to have a huge land area accommodating required amount of full span shuttering moulds sets as per girder erection plan. The average monthly requirement for each launching gantry is 50 girders. Considering the productivity of 5 girders per month per shuttering set, there is a requirement of at least 10 shuttering sets which will require large space. In addition to this there would be space requirement for raw material stacking, batching plant, stacking yard, laboratory, administration area, reinforcement area, etc. As per the experience gained during the execution of the project, it can be safely concluded that the precast yard should be of approximately 60 acres for erection limits of 15 km on either side.

2.3 Handling of Girder within Precast Yard

Once casted, the 1,000 MT girder needs to be shifted within precast yard from shuttering mould to stacking yard for second stage prestressing and other finishing works. After finishing, the girder needs to be brought to feeding area. The handling of such a heavy girder within casting yard requires special machineries. In case of SBS segments, simple gantry of 150 MT suffices the requirement of handling the individual segments.

2.4 Handling of Girder from Precast Yard to Launching Location

Again it is challenging to transport the FSLM girder from the feeding location at precast yard to the launching location. Normally, girder needs to be shifted up to 15-20 km from precast yard location to launching location, which requires specialised mechanised arrangements.

2.5 Erection of Girder

Once the FSLM girder reaches site, the erection is a big challenge and requires specialised machinery to ensure the safe erection of girder over pier-caps.

To overcome all these challenges, special provisions were made, which are covered in working methodology.

3. Working Methodology

3.1 Construction of FSLM Girder

FSLM girder construction activity can be divided into five sections: (1) establishment of smart precast yards, (2) fabrication and installation of FSLM moulds, (3) casting of FSLM girder with precautions for temperature control to avoid any cracks, (4) prestressing works, (5) finishing works. In addition, full scale load testing has been done on actual FSLM girder.

3.1.1 Smart Precast-Yard Setup

- Location: The precast yard should be located adjacent to the alignment for dispatch of FSLM girders over viaduct. Also, it is preferable that precast yard should be located near the centre of the erection zone of the precast yard so as to ensure minimum transportation time and efforts.
- The precast yard should have proper facility management plan so that there should be a continuous flow of activities and criss-cross movements as avoided.
- A sample precast yard is attached as Appendix A.

Fig. 3 Outer and inner shuttering formwork.

3.1.2 Fabrication & Installation of FSLM Shuttering Mould Set

Each FSLM shuttering mould consists of two numbers of outer shuttering mould & one inner shuttering mould. Once the concrete pouring in one outer shuttering mould completes, the inner shuttering mould after 3 days is taken out longitudinally and moved into outer mould on the other side to cast another girder. This process continues for subsequent FSLM girder casting. Fig. 3 shows the outer and inner shuttering mould assembly for one set in precast yard.

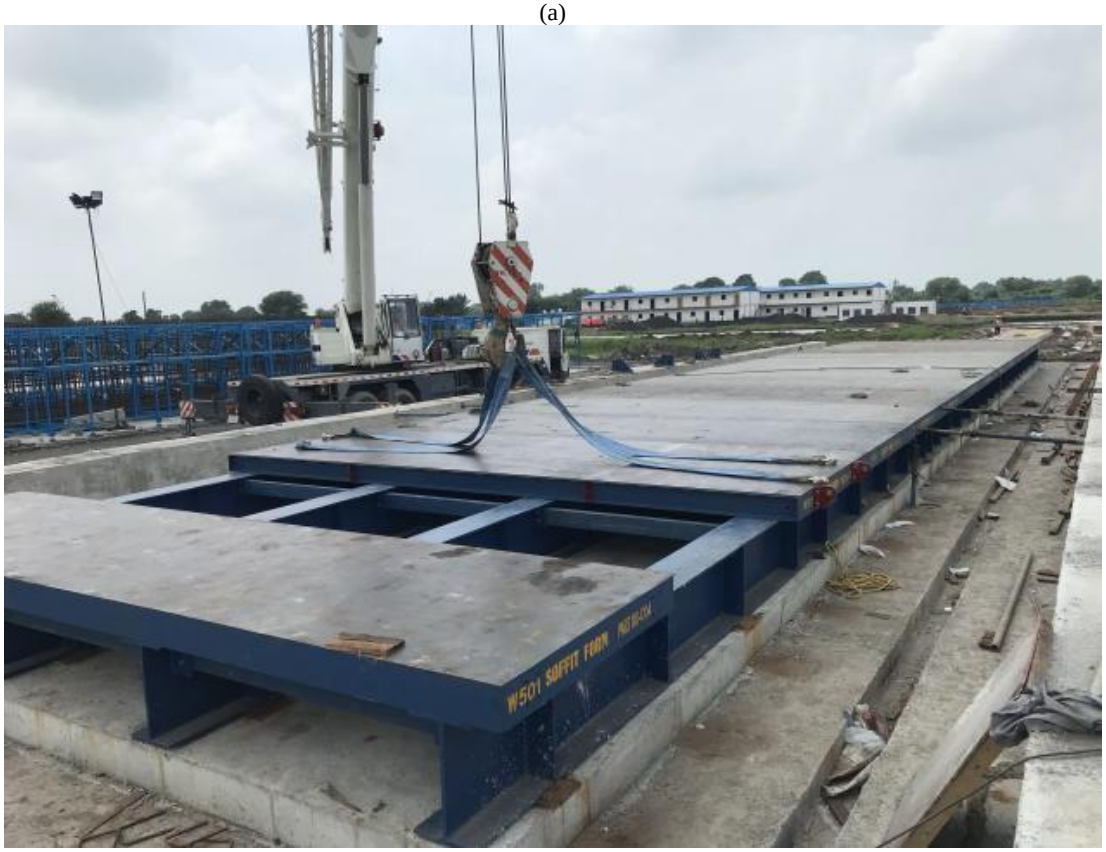
3.1.2.1 Fabrication

- The shuttering mould needs to be very sturdy and long-lasting since hundreds of casting would be done from each shuttering mould. Also, the shuttering moulds should be hydraulically operated so as to ensure maximum productivity.
- Normally, no such precedence was available for fabrication of such type of shuttering mould and it is indeed a matter of pride that most of the shuttering moulds are designed and manufactured indigenously.
- Also, the FSLM girder length in the project is varying between 30-40 m. Hence, few variable length shuttering moulds were designed and manufactured to accommodate the varying lengths.

3.1.2.2 Installation

- The Installation of mould in the precast yard requires highest level of precision and workmanship to ensure the sustained productivity and minimum maintenance. It involves erection of soffit beams (Figs 4a and 4b), main beams, cross beams, soffit plates, outer plate panels, fixing of hydraulic jacks, etc. Also, since there would be movement of inner shuttering mould from one outer to another, it requires special arrangements of linear movement powered by power-pack and opening after insertion in the outer shutter.

(a)



(b)

Fig. 4 (a) Soffit beam of shuttering work; (b) Laying of skin plates of outer shuttering formwork.

- Since these shuttering moulds are required to be shifted in different precast yards, it is important that the moulds are so designed for easy removal and re-installation.

3.1.3 Casting of FSLM Girder

FSLM girder casting involves: (a) placement of reinforcement cage in the outer mould, (b) insertion of inner mould and subsequently opening up, (c) concrete pouring, (d) curing.

Fig. 5 Reinforcement cage fabrication.

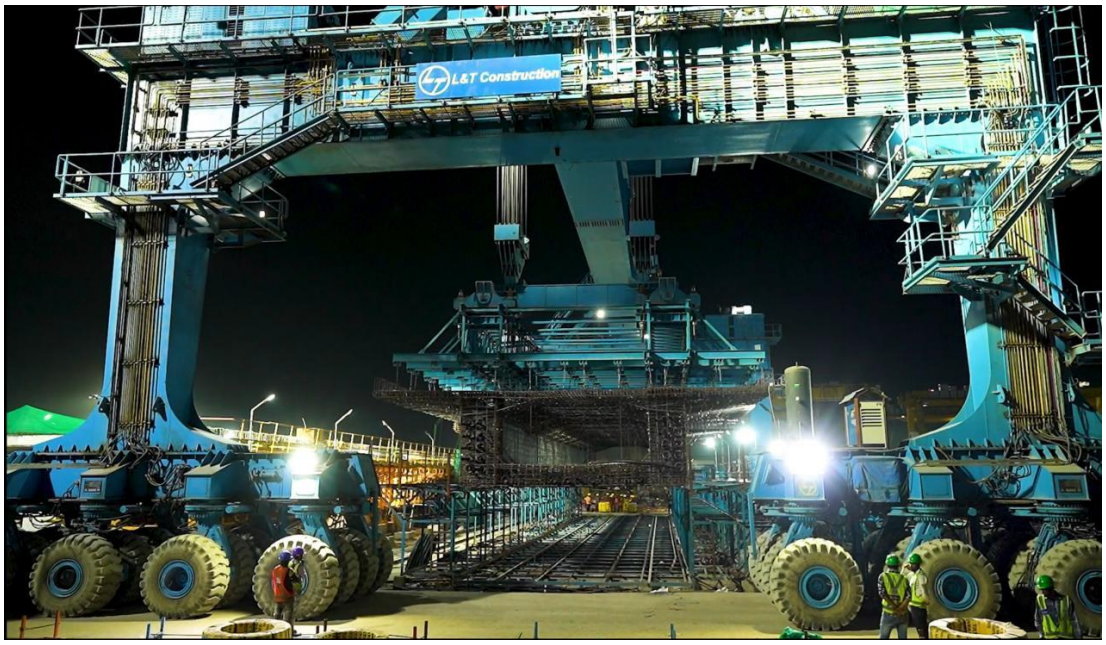


Fig. 6 FSLM girder cage lifting.

3.1.3.1 Fabrication of Reinforcement Cage

The reinforcement cage is being prepared independently in specially designed jigs. Approximate weight of the reinforcement cage is 46 MT for a 40 m span FSLM girder. Representative picture showing fabrication of typical cage is shown in Fig. 5.

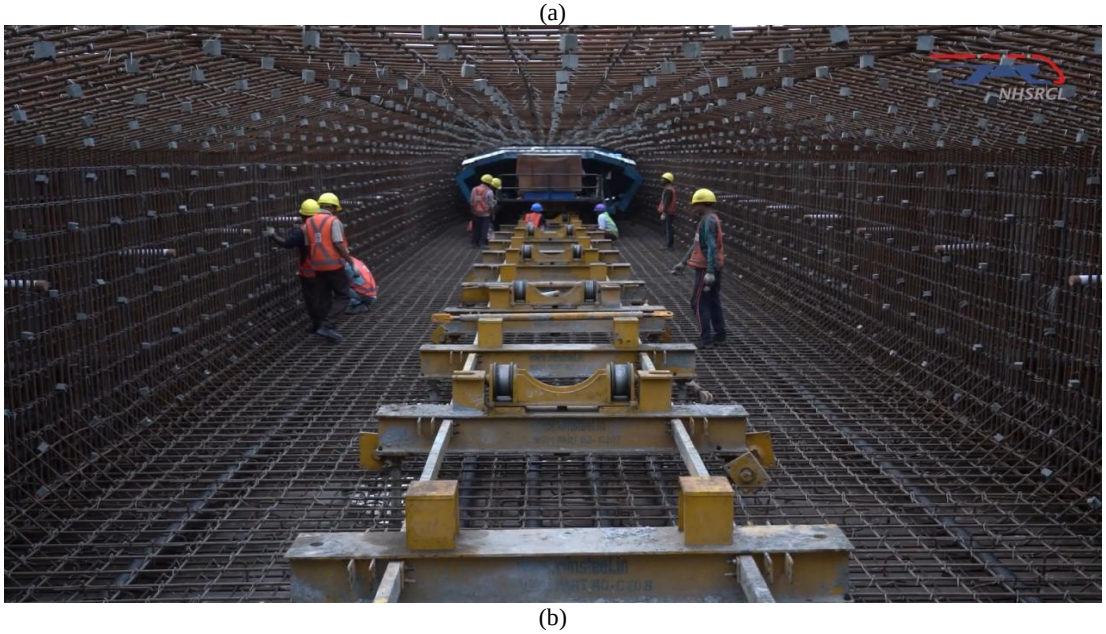
(1) Placement of Reinforcement Cage

The handling of this cage is very important to avoid any distortions and hence it is lifted by straddle carrier using lifting frame (called strong-back), which holds the whole cage from more than 300 points from top and bottom reinforcement layers as shown in Fig. 6.

3.1.3.2 Inner Shuttering Formwork Movement

Once the cage is lowered in the designated outer formwork, inner formwork is moved longitudinally and inserted in the outer formwork in the activated position on the air vent supported rollers as presented in Figs. 7a and 7b. Simultaneously, the outer shuttering is also checked thoroughly before cage lowering as shown in Fig. 8.

(a)



(b)

Fig. 7 (a) Inner insertion in progress; (b) Inner insertion over supporting trolley.

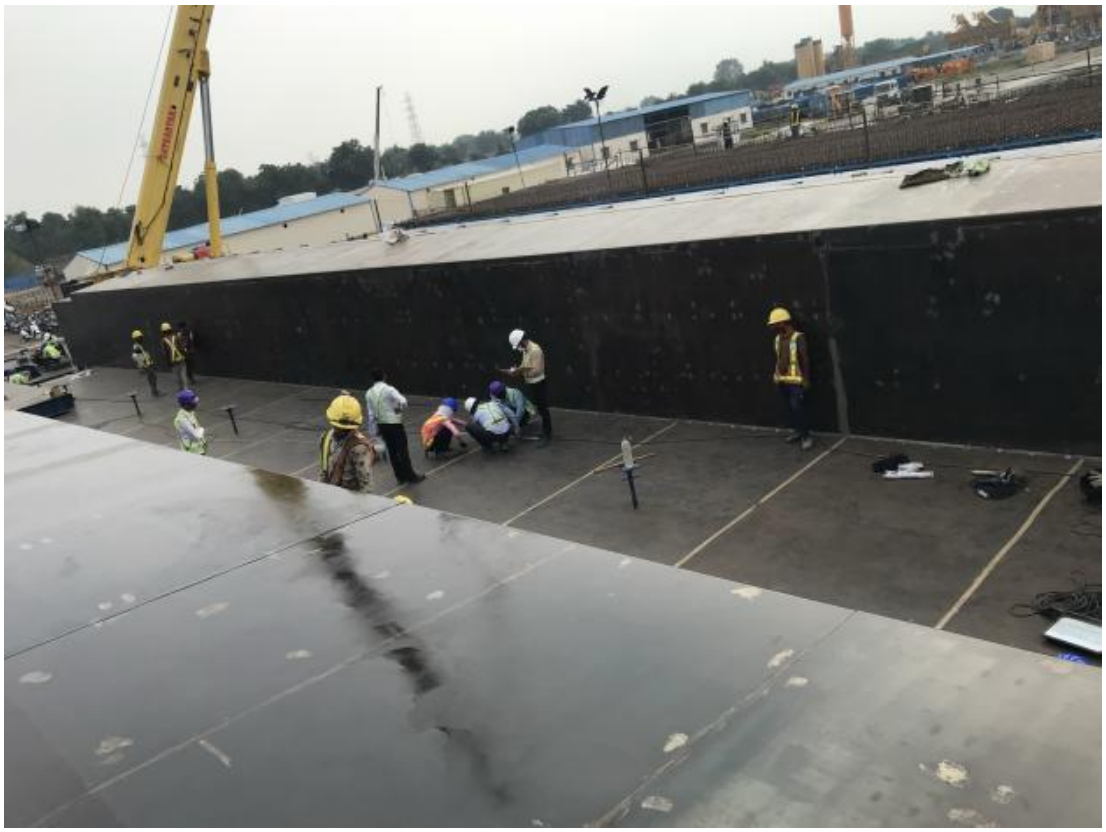


Fig. 8 Outer shuttering survey checks.

3.1.3.3 Concrete Pouring

Concrete quality requirement and its placement had a major role in productivity and quality. To ensure the best quality of concrete, fully automatic batching plants have been installed in the precast yard itself to ensure minimum transit time. The design-mix was finalised after many trials with the primary aims of requisite strength, durability and placability of concrete. The objective has been to produce crack-free concrete and avoidance of cold joints. The design-mix used in one of the precast yards is included as Appendix B.

Pouring sequence plays a major role in achieving good quality of well compacted concrete without cold-joints. Also, the concrete quantity in FSLM girder is huge i.e. almost 400 m^3 which calls for proper pouring sequence. To finalise the sequence, many mock trials were done with different combination and the finalised sequence is attached at Appendix C.

For well compacted concrete, the shuttering moulds are accompanied with 88 hydraulically operated shuttering/form vibrators along with additional needle vibrators at the top.

To ensure the continuous supply of concrete, the pouring is being done using four concrete boom-placer. About 20 transit mixers were utilised for transporting the concrete from batching-plant to casting location. A total time of 4 h is being taken for casting of one FSLM girder.

3.1.3.4 Curing

Curing arrangements has to be impeccable for good quality concrete. For FSLM girder, proper curing scheme through several practical trial and error was established. In the finalised scheme, curing consists of full covering of girder after casting from top in four layers: curing compound, wet hessian cloth, white plastic sheet and then finally tent type green net covering as presented in Fig. 9.

Fig. 9 Final photo during curing period.

Table 1 Workmen requirement.

Item	Workmen required/set
Outer and inner shutter cleaning	10
Reinforcement works	45
Formwork fixing	25
Concreting	55
Curing	3
Total	138

The inner shuttering mould is removed in 3-4 days and on the vertical faces and on the underside of deck slab, membrane curing compound is applied. Once shifting to the stacking yard, the outer surface is also applied with membrane curing compound. The overall workmen requirement is shown in Table 1.

3.1.4 Special Precautions Taken during Casting

3.1.4.1 Temperature Control

Since the casting of FSLM girder involves pouring of 400 m^3 concrete, it is always challenging to control the temperature due to heat of hydration. If not handled properly, it may result in cracks.

It is very important to maintain the concrete temperature at the time of pouring. Measures taken to keep this temperature under 35 ℃ are as under:

• Special Chiller plants were installed near the batching plant to reduce the temperature of mixing water up to 7-8 ℃ along with complete thermo-insulation of supply pipes, to maintain the temperature up to the mixing point.

• Mixing of ice: The ice plants were installed. The ice-chilled water is mixed in the batching plant to further reduce the temperature to 4-5 ℃.

• Aggregate shed, sprinkling of water on aggregate, hessian cloth on TMs (Transit Mixers).

To monitor the rise in the temperature due to heat of hydration caused due to bulk concreting, thermocouple were installed during hot weather to monitor the temperature rise pattern. Based on the interpretation, the curing scheme was decided. The actual location of thermocouple and results are attached as Appendix D.

3.1.4.2 Concreting during Monsoon

The high quality steel and poly material movable and collapsing sheds are designed and fabricated to even cast a girder during rainfall and protection of green concrete during unexpected rains as shown in Fig. 10.

3.1.5 Prestressing Works

The transverse prestressing in the deck slab has been carried out on the achievement of 42 MPa concrete strength (normally achieved in 3 days). To control the cycle time of FSLM girder casting and to make expeditious availability of shuttering mould for

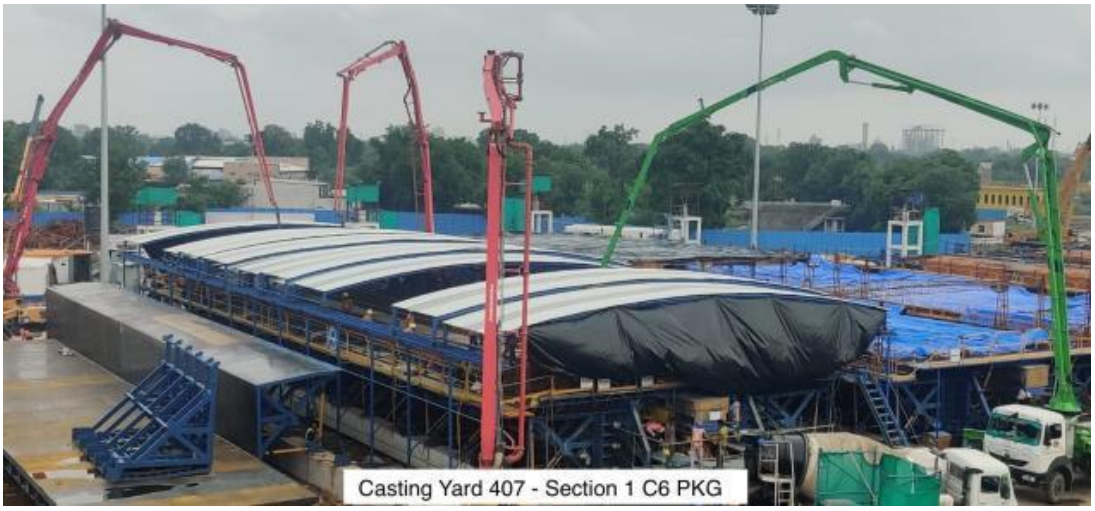


Fig. 10 Casting in progress in rainfall season.

Fig. 11 Straddle carrier lifting and shifting the FSLM girder.

the subsequent casting, the longitudinal prestressing has been modified to two stages. On the achievement of 50 MPa (normally achieved in 4-5 days), first stage prestressing has been carried out which enables the FSLM girder to be shifted from shuttering mould to stacking yard. Second stage prestressing and other finishing works are carried out in stacking yard.

3.1.6 Full Scale Load Testing on FSLM Girder

The full scale girder has been tested for combined construction and operation load of 1,500 MT and results were found satisfactory. The details are attached as Appendix E.

3.2 Movement of Box Girder: Handling of Girder within Casting Yard

3.2.1 Shifting of FSLM Girder from Shuttering Mould to Stacking Yard and Then After Finishing, from 199 Stacking Yard to the Dispatch Location

Fig. 12 Bridge gantry lifting the girder from dispatch area.

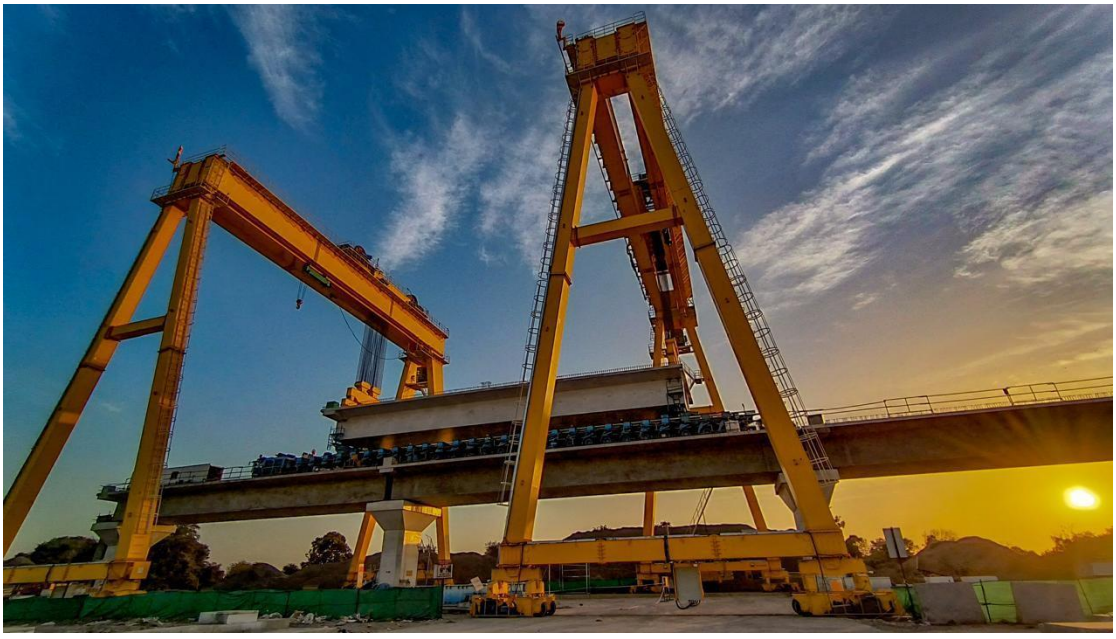


Fig. 13 Bridge gantry loading the FSLM girder over girder transporter.

Fig. 14 Launching gantry getting ready for new FSLM girder erection.

Table 2 Key details for straddle carrier.

Hoisting capacity	1,100 MT
Hoisting height	13 m
Span	30-40 m
Lifting speed (with load)	0.5 m/min
Lifting speed (empty)	1.5 m/min
Travel speed (with load)	15 m/min
Travel speed (empty)	30 m/min

Table 3 Key details for bridge gantry.

Hoisting capacity	550 MT (combined 1,100 MT)
Gantry span	38 m
Lifting speed (with load)	0.5 m/min
Lifting speed (empty)	1 m/min
Trolley speed (with load)	3 m/min
Trolley speed (empty)	6 m/min
Travel speed (with load)	5 m/min
Travel speed (empty)	10 m/min

Table 4 Key details for girder transporter.

Capacity	1,100 MT
Span	30-40 m
Laden speed	5 km/h
Unladen speed	10 km/h
No. of tyres	216
No. of axle	54
No. of trolley	2

Table 5 Key details for launching gantry.

Hoisting capacity	1,100 MT
Span	30-40 m
Hoisting and lowering speed (loaded)	0.05-0.5 m/min
Hoisting and lowering speed (empty)	0.1-1 m/min
Girder hoist height	8.6 m
LG travel speed	0.3-3 m/min
Slope/gradient	1.5% minimum curvature radius 2,000 m

For this purpose, straddle carrier (Fig. 11) is utilised, the salient features, its components and function are shown in Table 2.

3.2.2 Lifting of FSLM Girder from Ground Level to Girder Transporter on Viaduct

For this purpose, bridge gantry is used, details of which are shown in Table 3 and Fig. 12. Both the machines are highly automated, synchronised and operated by the experienced operator and team.

3.3 Handling of Girder from Casting Yard to Launching Location

For carrying FSLM girders from the prefabrication yard to the launching girder area, the girder transporter is used, details of which are presented in Table 4 & Fig. 13.

3.4 Erection of Girder over Pier-Caps

For carrying FSLM girders from the dispatch location to erection location, the launching gantry is used, details of which are presented in Table 5 & Fig. 14.

3.4.1 Methodology for Launching

This section provides a step-by-step sequence of the girder erection process by launching gantry.

3.4.1.1 Auto-launching of Launching Gantry

In a typical procedure, the FSLG first gets ready for next girder erection by auto-launching procedure, in which main body rolls over temporary rails to move in forward direction and consequently hanging front leg to reach at next pier cap position and secured tightly as shown in Fig. 15.

3.4.1.2 Entry of Girder Transporter under Launching Gantry

Next major step is folding up of rear leg and make a way for GT (Girder Transporter) to enter inside between main body of LG with goose neck in the front side as presented in Fig. 16.

Fig. 15 Launching gantry after auto-launching.

Fig. 16 **Launching gantry after GT entry.**

Fig. 17 **Launching gantry during girder lifting.**

Fig. 18 **Launching gantry during FSLM girder lowering.**

Table 6 FSLM vs. SBS comparison.

FSLM	SBS
Monolithic casting if full span (preparation time = 24 h on casting bed)	Segmental casting of span, preparation time = 15 days on casting bed
Total weight to be handled at a time = 1,000 MT	Total weight to be handled at a time << 1,000 MT
Cum. casting time = 6 h	Cum. casting time = 50 h (all segment)
Erection time = 12 h/span	Erection time (av.) = 7 days/span
Complete prestressing work carried out at precast yard	Major prestressing work carried out at launching site
Design of span length range = 30-40 m	Design of span length range = 30-45 m (60 m continuous river span)
Minimum radius R = 2,000 m (ours is 6,000 m)	Minimum radius R = 1,000 m

This requires very careful monitoring of load, line and speed of GT and checking of LG readiness with correct positioning of winch trolley and securing and fixity of LG legs.

3.4.1.3 Lifting of FSLM Girder from Front End and Sliding the FSLM Girder Up to 37.5 m

Once the GT reaches its configured position, the GT jacks on all the 4 sides got activated with a girder to be fixed from front end by LG winch trolley and sliding from another end on GT rollers. In some LG model (like in MMH: Material & Metals Handling) there is an auxiliary leg which rests on GT during girder launching operations. Process is shown typically in progress in Fig. 17.

3.4.1.4 Lifting of the Rear End of the FSLM Girder with Back Side Winch Trolley after Traversing 37.5 m

After further movement of girder handing over front winch trolley, the second winch trolley is connected with girder lifting location and girder is consequently lifted from the rear end too.

3.4.1.5 Bringing the FSLM Girder in Position and Lowering

Finally, the girder gets lowered carefully over rechecked pier cap, pedestal and pre-installed seismic stoppers and survey checking and fine tuning for alignment is done through control points as shown in Fig. 18.

The complete FSLM girder casting and erection, photographical process is reproduced in Appendix F.

4. The "Make in Bharat" Initiative

Alignment of the High-Speed Rail project is truly conceptualised with the "Make in India" initiative, with amalgamation of Indian construction industry. All the major machineries are made in India, for example, FSLG, GT, straddle carrier, etc. are all made in factory of MMH L&T Division. These giants are developed with a certain capability to handle 1,000 MT girder weight all together. This will help in future enterprises development and local manufacturing units to produce more startups and new industries for high speed rail division.

5. Conclusions

To conclude,

(1) Speedy construction of works—the erection of viaduct using FSLM methodology. The comparison details of the time taken for various activities between FSLM and SBS method, are presented in Table 6.

(2) Quality of works: In the case of FSLM girder all the activities like casting, prestressing, finishing are being carried out in controlled atmosphere of casting yard while in SBS lots of activities like gluing, prestressing are done after erection at elevated location. Hence, the quality of FSLM girder is definitely better than SBS girder.

(3) Safety: In the case of FSLM girder all the movements are done over viaduct while in the case of SBS all the segments are to be transported over public roads. Further, In the case of launching in SBS, the segments are being hanged for about 7 days before prestressing which may lead to safety hazard. In the case of critical crossing, it is easier to cross by FSLM girder due to reduced time.

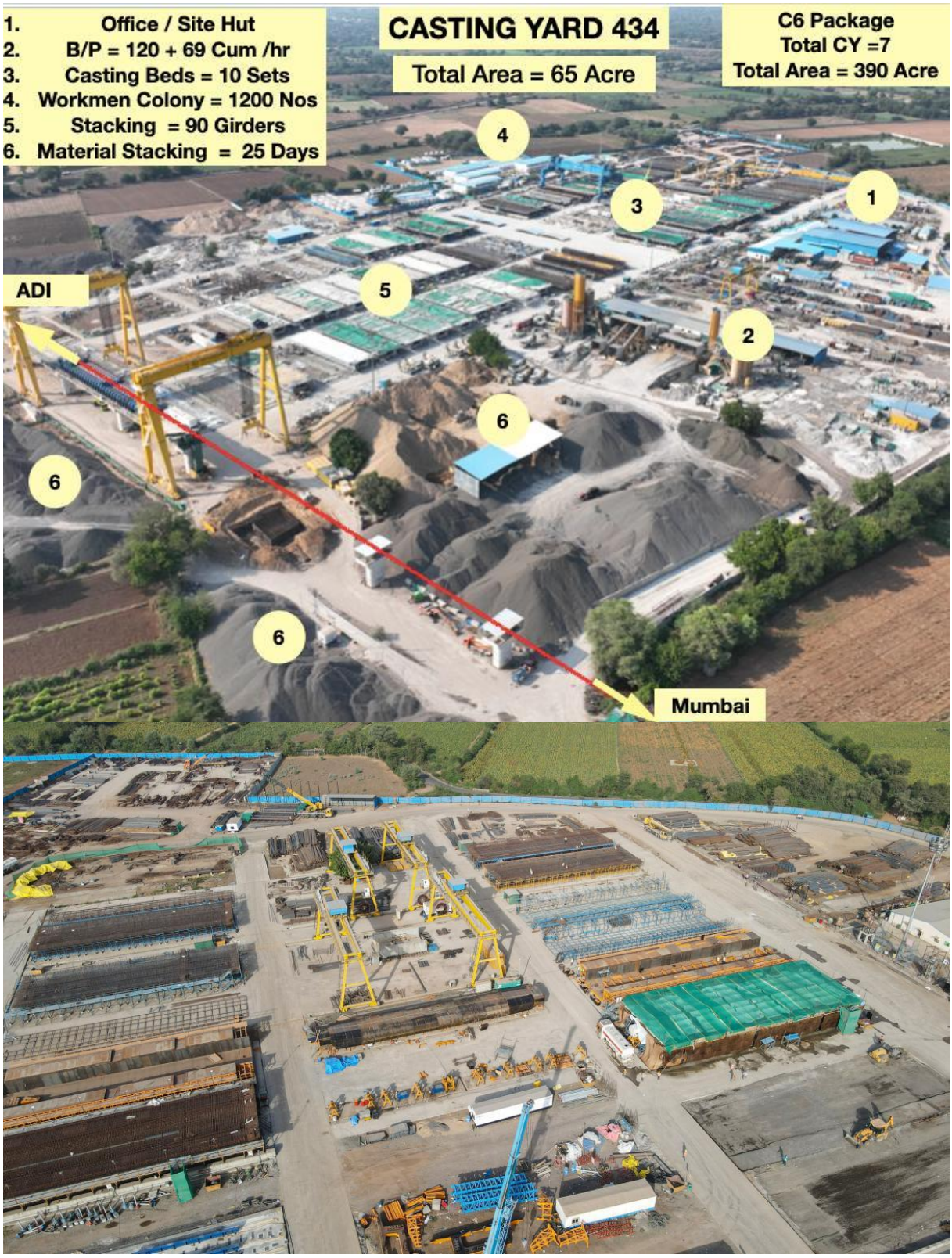
Data Availability Statement

All the data reproduced in this work are based upon practical experience gained by the authors after construction of hundreds of girder in their various Precast yard facilities. The detailed data that support the findings of the author are available with the author and can be made available upon reasonable request.

References

The experience gained by the authors at construction site during the course of execution of the project is the primary reference to write this paper.

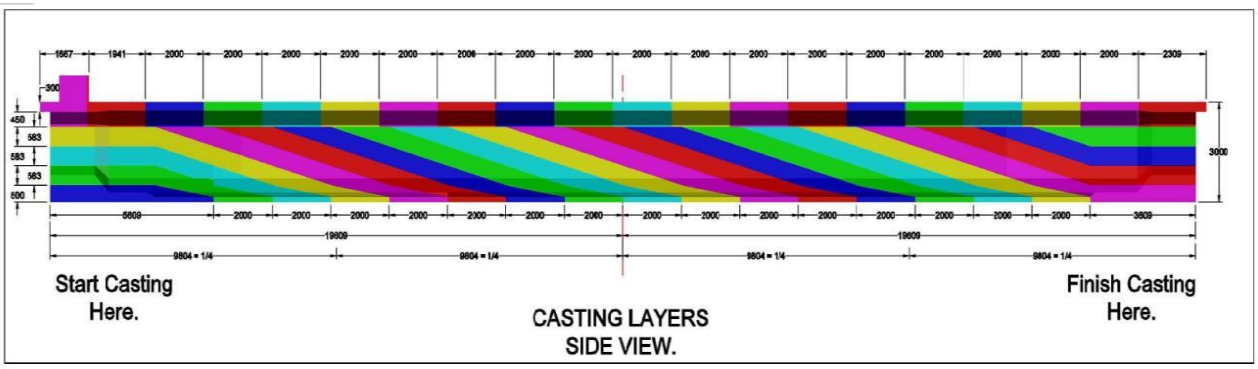
Appendix A: Full functional casting yard layout and facility management details.



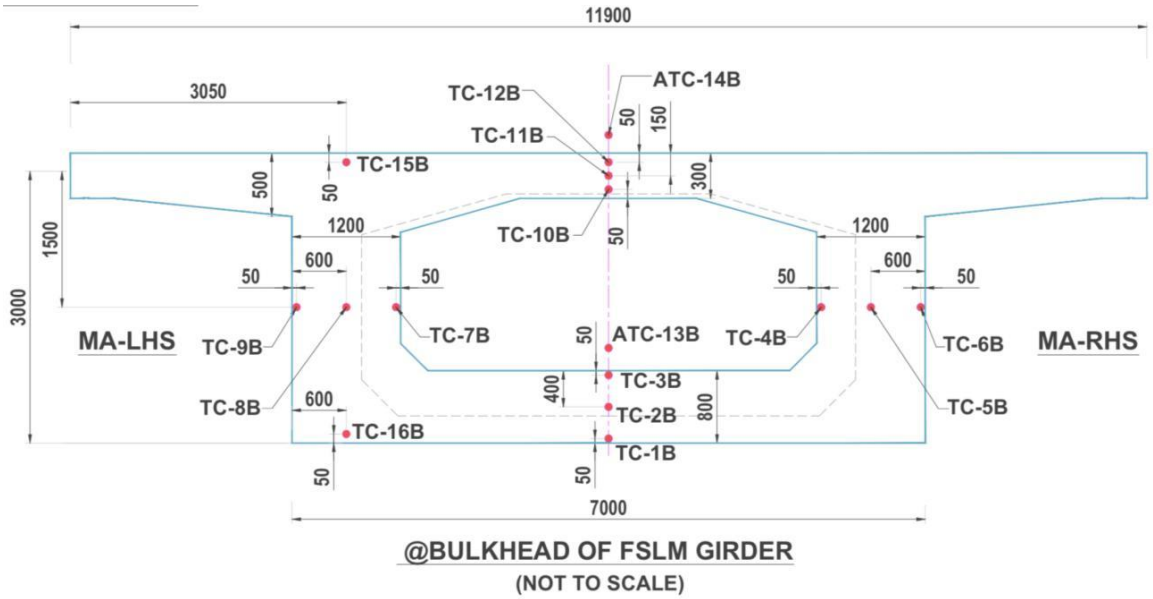
Appendix B: Actual design mix of concrete used in the project.

For M50 grade concrete (target mean strength = 62 MPa)				
Serial No.	Ingredients	Design Mix 1	Design Mix 2	Design Mix 3
1	Cement	450	450	430
2	GGBS	0	0	0
3	Microfines	20	20	30
4	Water	155	150	147
5	CA (20 mm)	559	553	557
6	CA (10 mm)	559	553	557
7	FA (natural sand)	380	785	790
8	FA (cursched Sand)	398	0	0
9	Admixture	0.9%	1%	1%
10	*w*/*c* ratio	0.33	0.32	0.32
11	Slump	170 mm (after 120 min)	170 (after 120 min)	160 (after 120 min)
12	3D cube strength	48 MPa	47 MPa	48 MPa
13	7D strength	55 MPa	54 MPa	57 MPa
14	ACT (avg.)	69 MPa	67 MPa	70 MPa

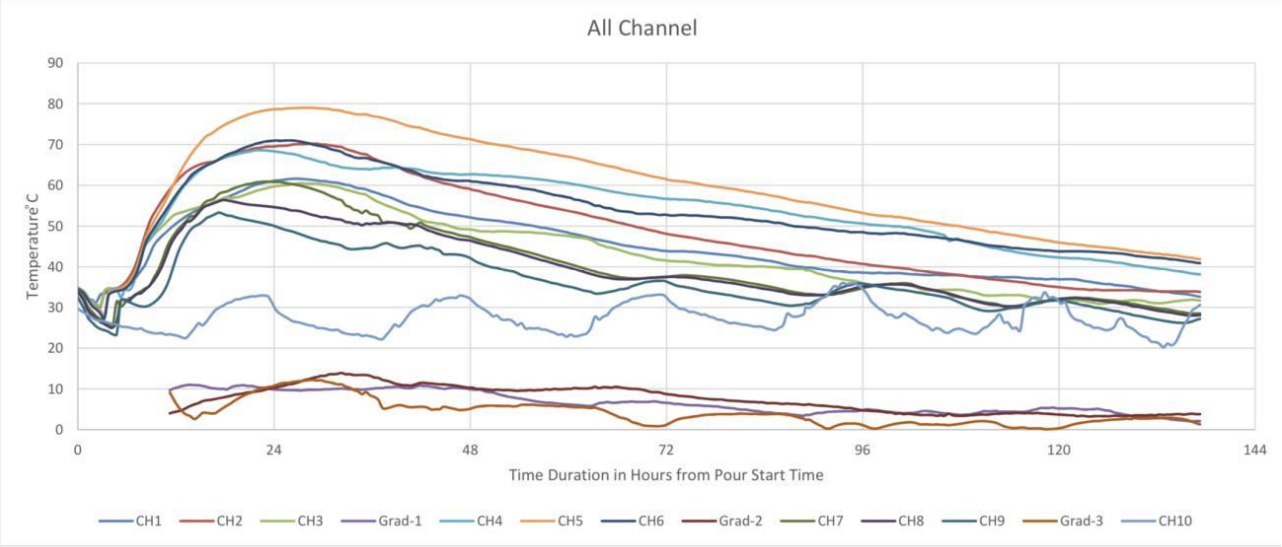
Appendix C: Typical pouring sequence scheme showing the concrete flow in different colours.



Appendix D: Thermocouple location shown which is embedded in girders during summers, also showing the final graph generated by thermal data on hourly basis.

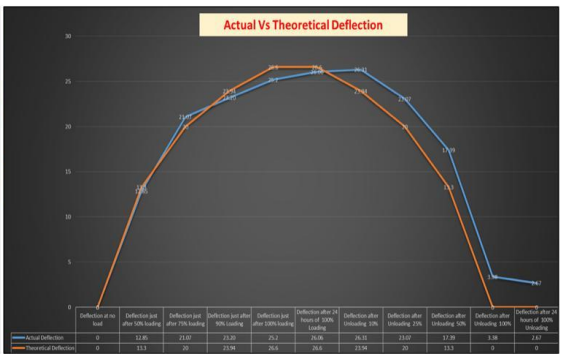


Graph for Channel Wise Temperature V/S Time Duration, PCY -3 at CH.434, Structure No - 441, P09 - P10



Appendix E: Load Testing Salient Details as Carried out in MHASR Project

- For the first time in India, Full Span Box Girder (970 MT wt.) casted as a single unit.
- India is the 4th country after China, Taiwan & Indonesia to use Full Span Box Girder
- Full Span Girder Launching is 10 times faster to Segmental Girder Launching method
- 1500 MT Load applied – Based on Construction Stage Load (Girder Transporter + 40m FSLM) > Service Load
- Theoretical/ Actual Deflection- 26.6mm / 26.31mm



Appendix F: Full scheme of casting and launching activity shown through major activity photo in sequence.


FSLM - ERECTION
1
Girder Shifting - Straddle Carrier to Bridge Gantry
2
2 X 550MT = 1100 MT
Girder Lifting - Bridge Gantry to Girder Transporter
3
Girder Transportation
4
1100 MT Capacity
P10
P9
P8
P7
Launching of Girder