Hyderabad Metro Rail Viaducts Precast Segmented Balanced Cantilever Method of Launching of Segments by using LG & OH Gantry at ROB’s

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Abstract

This article presents the pre-cast segmented Balanced Cantilever Method of launching of segments by using LG and OH Gantry at ROB’s for Hyderabad metro rail rapid transit system in red, green and blue lines viaducts on particular locations where constraints obliged to have longer span lengths. Balanced cantilever erection precast segments have been used, combining the advantage of precast segment bridge (speed of construction) with balanced cantilever method advantages (longer spans). Total project length is an elevated viaduct spanning around 72 km of metro line and with 66 stations. Chosen bridge construction technique had to meet several requirements due to numerous constraints, among which speed of construction, geometry adjustability, environment disturbance. These project constraints led to use precast segmented by span ‘Balance Cantilever erection’ method. This construction method is the optimal one in terms of construction speed, quantity optimization, and construction quality and risk management.

Keywords: Metro Rail Bridge, Balance Cantilever Erection Method, Box Shape Precast Segment, Self-Launching Erection Gantry, Post-Tensioning

I. INTRODUCTION

Hyderabad Metro Rail Limited (HMRL) was tasked with the responsibility of developing the Hyderabad Metro Rail (MRTS) Project consisting of 3 elevated lines with interchanges and having a total length of 71.16 kilometers crossing the heart of Hyderabad City.

The Government of Telangana (GOTS) awarded the development of the MRTS Project on a Design, Build, Finance, Operate, and Transfer (DBFOT) mode in Public-Private Partnership (PPP) to Concessionaire, M/s Larsen & Toubro Hyderabad Metro Rail Private Limited on 4 September 2010.

To monitor the project implementation and ensure quality standards of the project, HMRL engaged the services of an Independent Engineer viz M/s Louis Berger Consulting Pvt. Ltd., Gurgaon, Haryana on 8 February 2011 up to the end of the Project on 04-07-17.

The Metro Rail system under construction is a completely elevated system, generally run in the central median of the road. The viaduct structure for the elevated system is a box girder carrying two tracks on a single pier located on the median of the road.

A. Project Features

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Project Features</th>
</tr>
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<tbody>
<tr>
<td>Stations</td>
<td>Segmental Viaduct with some cast in situ spans in few cases including 8 Rail over bridges over the Railway Tracks of the Mainline Railway.</td>
</tr>
<tr>
<td></td>
<td>Total = 66 Elevated station(with 3 Interchange stations &amp; 4 special stations)</td>
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<td>Corridor -1 - Miyapur to L B Nagar - 29.87 kilometres &amp; 27 Stations (All elevated)</td>
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<td></td>
<td>Corridor -2 - JBS to Falaknuma - 14.78 kilometres &amp;16 Stations (All elevated)</td>
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<td></td>
<td>Corridor -3 - Nagole to Shilparamam - 26.51 km &amp; 23 Stations (All elevated)</td>
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<td></td>
<td>Special Stations – 6 nos with three levels (Begumpet , Punjagutta , Jubilee Hills, Hi-Tech City, Ameerpet and MG Bus Stand ,)</td>
</tr>
<tr>
<td>Railway Crossings</td>
<td>8 No’s out of which 2 are Steel bridges with longest span of 84m.</td>
</tr>
<tr>
<td>Rolling stock</td>
<td>Total Train set – 57, with 3 Cars per train set (extendable to 6 cars train set)</td>
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<tr>
<td></td>
<td>Car Body - Light Weight Stainless Steel/Aluminium</td>
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<td></td>
<td>Head Way – 90 secs design but normally 3 minutes during peak and 15 minutes during lean hours.</td>
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<tr>
<td></td>
<td>Couplers - Automatic and Semi Permanent Couplers</td>
</tr>
</tbody>
</table>
Air conditioner - 2 Roof mounted VAC for Saloon and One for Driver Cab
Battery Backup - Battery Backup upto one hour for emergency loads.
Capacity/Train – Approx. 1000 passenger (8 Passenger/Square metre in standing area)

Track work
1435 mm (Standard Gauge), Ballastless (Main Line), UIC -60, HH Rails.
Max. Axle load – 17 tonne.
Curved switches – 1 in 9 switches of radius 300m & 190m (main line),
1 in 7 switches of radius 190m (Depot)

Power Supply, Traction and SCADA System
25 kV, 50Hz AC (Over Head Catenary) and 33KV supply to each station from the Receiving Sub Stations (RSS) for Rail Systems.
(RSS) are located at Uppal, Miyapur, Yosufguda & MGBS for feeding the rail network all the time including during shut down of one RSS.

Signalling System
Communication Based Train Control (CBTC) System- for headway of 90secs - first time in Indian Metros from Operation Control Center (OCC)

Communication

E & M facilities
Fire protection Systems, Electrical supply, UPS, Public Health Systems, Lifts & Escalators, Building Management Systems from OCC.

Fare Collection
Automatic Fare Collection with centralised accounting and control.
Contactless Smart Card (CSC) and Contactless Smart Token (CST)

Depot Three (3) no's
Maintenance Depot @ Miyapur, Uppal (Main) and Falakanuma

Operating Speed
Design Speed – 90Kmph on all 3 corridors
Operating speed – 80Kmph on all corridors

The system is designed to cater 50000 PHPDT for Corridors I & III and 35000 PHPDT for Corridor II.
The construction of the entire 71.16 km has been split into 6 stages with the first stage scheduled to be completed by March 2015 with the entire project scheduled to be completed by July, 2017.
In November 2013, L&T Hyderabad Metro started laying of rails on the metro viaduct between Nagole and Mettuguda, a stretch of 8 km. Hyderabad Metro Rail will provide disabled-friendly system.
The first train of the Hyderabad Metro Rail (HMR) came from Korea during the third week of May 2014. Stringent trial runs will commenced from June 2014 till February 2015, before the service on the first stage of the Nagole-Mettuguda sector is thrown open to the public on 21 March 2015.
The trail runs have started on the Miyapur to Kukatapally stretch in June 2015.
Three interchanges are planned at Mahatma Gandhi Bus Terminus, Parade Grounds and Ameerpet.

![Hyderabad Metro Project – Red & Green line plan view](image-url)
II. ELEVATED STRUCTURE OVERVIEW

L&T Infra has been responsible for elevated viaduct erection using segmental bridge technology, including pre-casting of all segments and their erection based on 3 construction methods:

- Erection by means of launching gantry
- Erection on false work
- Cantilever erection

A. Elevated Viaducts Deck Types

Elevated viaducts deck has been design as box girder beams. Their span length varied from 20m to 48m, with an average of 30m. For few longer spans different design has been chosen:

- Box girders with three continuous spans has been installed, with an average span length of 45m.
- Cantilever method has been used for span length up to 45-85m.

More than 90% of elevated viaducts have been installed using span by span erection method. All segments installed using these methods are box girder shaped.

Fig. 2: Shape of Segments used for Shorter & Longer Span

B. Deck Classification

Spans erected using span-by-span method has been classified upon 3 parameters:

- Length varying from 20 to 44m
- Designation (single track or double track)
- Alignment type (straight, curve, clothoid)
- Radius in plane
  - $R < 300m =>$ none
  - $300 < R < 2000m =>$ curved alignment, all segments are curved
  - $R > 2000m =>$ straight alignment, only on pier segments are curved

Fig. 3: Curved Segments Alignment
C. Pre-casting Yard

Due to the required number of segment, a pre-casting yard dedicated only to this Project has been able to be installed not far from erection site, out of city down town, in QUTUBULLAPUR & UPPAL casting yard. The casting yard laid over a around total area of 100 acres.

Match casting technique has been used on this Project to ensure a severe geometry control.

First, segment reinforcement is preassembled on rebar jig. After a first control, reinforcement cage, including post tensioning ducts, is installed in the casting form by means of tower crane. After mould closing and its geometry setting up, a second geometry control is preceded taking into previous casted segment geometry. Prior to concreting, post-tensioning ducts are filled with a rigid pipe in order to prevent any damage during concreting. After curing, casted segment is shifted nearby the form in order match the next segment to be concreted. Here below Fig. 6 presents the typical casting sequence for segment prefabrication using match casting.

Fig. 4: straight Segment Alignment for Radius >2000m

Fig. 5: General View of Segment Casting Yard

Fig. 6: Segment Prefabrication – Casting Sequence Principal
After casting of the N+1 segment, N segment is transported to the storage area by means of gantry cranes, waiting for transportation the erection site dedicated trailer. Box girders segments have been prefabricated on the pre-casting yard for both span by span erection & cantilever erection spans. The depth and thickness of the web & flange are governed by span by depth rations.

**D. Advantage of Segmental bridge Construction**
- Very economical for long spans
- Prefabricated segments provide more quality control
- The structure can be fully loaded immediately after being pre-stressed
- The pre-stressed cables can be inspected and replaced at all times
- Low weight due to thin bridge sections
- Industrialization of the construction process
- Innovations in construction equipment
- Low maintenance costs
- Speed of construction, time taken less

**E. Disadvantage of Segmental bridge Construction**
- High construction loading or high technology is used
- Need high safety precautions during construction
- Extra cost (due to more pre-stressing required)

## III. PRECAST SEGMENTED BALANCED CANTILEVER METHOD OF LAUNCHING OF SEGMENTS BY USING LG AND OH GANTRY AT ROB’S

### A. Balanced Cantilever Method
- The principle of the method is to erect or cast the pier segment first, then to place typical segments one by one from each side of the pier, or in pairs simultaneously from both sides.
- Each newly placed precast segment is fixed to the previous one with temporary PT bars, until the cantilever tendons are installed and stressed.
- The closure joint between cantilever tips is poured in place and continuity tendons installed and stressed.
- In order to carry out this erection scheme, segments must be lifted and installed at the proper location.
- For bridges are long and the erection schedule short, the best method is the use of launching girders, which then take full advantage of the precast segmental concept for speed of erection.
The gantries can be categorized by their cross section: single truss, with portal-type legs, and two launching trusses with a gantry across. The twin box girders of the bridge in Bharath nagar ROB at Hyderabad Metro Rail Project was built with two parallel, but independent trusses (see Fig 7), with a typical obligatory span of 65.0m, segment weights of 60 tons.

Normally, the balanced cantilever method is used for spans from 60 to 110 m, with a launching girder. One full, typical cycle of erection is placing segments, installing and stressing post-tensioning tendons, and launching the truss to its next position. It takes about 7 to 10 days, but may vary greatly according to the specifics of a project and the sophistication of the launching girder. With proper equipment and planning, erection of 16 segments per day has been achieved.

**Case Study**

![Fig. 9: Plan Showing the Locations of 6 ROB’s at Hyderabad Metro Rail Project](image)
Author has discussed the launching sequences of 3-span bridges with 65 m long main span (39 m + 65 m + 39 m = 143 m) at BHARATH NAGAR – ROB by ‘Balanced Cantilever Method’ of launching of segments by using LG and OH Gantry for the case study.

Fig. 10: Satellite Image & Actual Image of BHARATH NAGAR ROB at Hyderabad Metro Rail Project
IV. MANDATORY REQUIREMENTS

A. Clearances as Per SOD

1) Horizontal Track Clearances
   a) Minimum horizontal from center of track to any structure except a platform – 2360mm
   However minimum of 2800 mm is adopted as per railway requirement.

2) Electrical Clearances: (Electric Traction, 25KV A.C. 50 cycles)
   Minimum vertical distance between any live bare conductor and any earthed structure or other bodies (rolling stock, over bridges, signal gantries) – 250 mm
   However minimum of 500 mm is adopted

3) Vertical Clearances between rail track top to bottom of Superstructure
   Minimum vertical clearance between rail track top to bottom of superstructure – 8650mm as per drawings in principle approved by railway.

B. Bharath Nagar ROB Details – Obligatory Span

- Location: Bharath Nagar
- Chainage (Rly Km): 174/22-24
- Corridor No: I
- Corridor Length: 28.87 Km
- Connecting Places: Miyapur to L.B Nagar
- Obligatory Span Length: 65m
- Sub Structure Type: Open Foundations
- Size of Substructure: Foundation 12.5m x 7.1m
   Pier 2.2m x 2.2m
- Super Structure Type: Precast Pre-stressed

- Size of Segment: 8.80m Top Width
  4.25m Bottom Width
  4.30m Deep
- Segment Width: 3.00m
- No. of Segments
- (Main Span):21
- Max. Wt. of Segment: 58 MT
- Bearing Type& Capacity: POT – PTFE
- Construction Method: Balanced Cantilever Method using Launching girder & Gantry.

Fig. 11: Bharath Nagar ROB Details – Obligatory Span
C. Preliminary Works

1) Stage 1

Works completed before construction of Super Structure over RAILWAY SPANS:
- Completion of Foundations, Substructures
- Segments casting
- Fabrication of LG
- RP4 – RP5 superstructure Construction (cast in-situ)
- Construction of Pier Table at RP4 & RP3
- Completion of Foundations, Sub-structures

![Fig. 12: Preliminary Works](image)

![Fig. 13: Completion of Foundations, Sub-structures](image)

- Super Structure Casting, curing & stacking at pre-cast yard
- Fabrication of LG with required length and capacity

### Launching Girder (LG) Details

1) **Dimensions**
- Length of LG: 117m
- No. of Modules: 13
- Weight of LG: 265 MT
- Width of LG: 2m each
- Depth of LG: 3.0m
- Live Load: 125 MT (Inclusive of Two segment wt.)
- No. of Over Head Gantry’s: 2 no’s
- Capacity of each OH Gantry: 75 MT
- Self-Weight of Gantry: 60 MT

- Construction of Pier Table at RP3 & RP4

![Fig. 14: Pre-cast Yard](image1)

![Fig. 15: LG Fabrication](image2)

![Fig. 16: Launching Girder (LG) Details](image3)
• RP4 – RP5 Superstructure Construction (Cast in-Situ)

Fig. 17: RP4 – RP5 Superstructure Construction (Cast in-Situ)

• Erection of Launching Girder over Rly Span
• Installation of temporary trestles adjacent to Track for LG erection

Fig. 18: Installation of temporary trestles adjacent to Track for LG erection

• Moving and placing of LG over Rly Span

Fig. 19: Plan Showing LG-1 in Final Position
Fig. 20: Plan Showing Both LG in Final Position

Fig. 21:

Fig. 22: Typical Elevation Showing Launching of LG
Hyderabad Metro Rail Viaducts Precast Segmented Balanced Cantilever Method of Launching of Segments by using LG & OH Gantry at ROB’s

Fig. 23: Typical Section Showing Hilman Roller

- Erection of Overhead Gantry over LG

Fig. 24: Erection of Overhead Gantry over LG

- Placing of precast segments over Rly Span by Over Head Gantry
Fig. 25: Joining/Matching of erected Segments

Fig. 26: Stressing of Erected Precast Segments

Fig. 27: Completed Span Segments over Rly Span
Note
Uncertainties and the relatively complex geometry of the bridge - including vertical curvature and variable depth box girders - caused significant challenges during construction. The erection procedures and the launching operations was carefully planned based on detailed calculations to evaluate the uncertainties regarding the support reactions and the patch-loading resistance.

Considering the uncertainties with respect to the patch loading resistance and due to the sensitivity of the support reactions caused by the large torsional stiffness of the box girder, the indirect loads and the construction tolerances, it was decided to monitor the bridge in real-time in order to better control the reaction distribution and to make corrections if necessary. The continuously measured reactions were compared with the predicted values and the level of the supports was adjusted whenever the reactions diverged more than 15 percent from the predicted values. Two adjustments were typically needed for the launching of a 117 m section. These adjustments, which did not cause significant delays, were made placing thin plates under the sliding shoes on the fixed supports on several piers.
With the real-time monitoring of the bridge, the project team was able to correct the support reactions, keep the applied patchloads within the accepted limits, and properly adjust the vertical support positions during launching, allowing the successful completion of the complex erection process.

Table – 2

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Sketch</th>
<th>Pier Nos</th>
<th>ROW &amp; Prem</th>
<th>Type of Pier</th>
<th>Span</th>
<th>ROW Made Available on</th>
<th>Excavation</th>
<th>Rotating Concrete</th>
<th>Viaduct Pier</th>
<th>Viaduct Segments (Lifting, Gluing &amp; Stressing)</th>
<th>Completion of Track Pints Beam</th>
<th>Completion of Track Work</th>
<th>Completion of OHE works</th>
<th>Remarks</th>
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<tr>
<td>1</td>
<td>Bharath Nagar viaduct</td>
<td>BTWN-P-02 / BTWN-P-03</td>
<td>-</td>
<td>SP</td>
<td>13.4</td>
<td>02-08-2012</td>
<td>03-09-2012</td>
<td>10-09-2012</td>
<td>19-09-2012</td>
<td>20-09-2012</td>
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<td>7</td>
<td>Bharath Nagar viaduct</td>
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Total duration to complete 3-span continuous structure for this location was 2 years & 3 months. There was a considerable delay for about one year from the ‘South Central Railway’ for approval of design & giving traffic block during launching and de-launching. Now the stretch is ready for a trial run with almost accomplishment of civil, track OHE & signaling work.

V. CONCLUSION

Precast pre-stressed segmental construction is a versatile technique for construction of present day fast track jobs. Segments can be cast away from actual site, thereby minimizing hindrance to traffic & public in urban environment. In casting yard better control on quality & dimensional tolerances can be achieved. Segment casting can start independently as work on foundations progresses, thereby reducing overall completion time.