Construction of viaduct for metro express line using 25 m long precast U girders – An experience

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The Airport Metro Express Line is the first exclusive line with dedicated check-in counters away from airport at city centre and at city's main railway station. The design speed of this line is 135 kmph with a provision to increase it to 160 kmph. The line starts from New Delhi railway station's Ajmeri Gate to Dwarika sector-21 via Indira Gandhi International Airport. It has six stations namely New Delhi, Shivaji stadium, DhaulaKuan, Delhi Airo city, IGI airport and Dwarika Sector-21 station. This 22.50 km project has 7.185 km elevated corridor and the rest is underground.

Keywords: *U girder, cantilever/L-shaped pier caps, portal pier caps, pre-cast, cast in-situ, post tension, pre-tension, bulk head, solid slab.*

The viaduct uses full-length double precast U girder for the first time in the country. The pier caps are also precast.

In addition sleek long span cast in situ continuous solid slabs feature in this corridor. This was one of the fast-track Metro Projects with completion within 42 months from December 2006.

This gives 20-24 months for civil construction including removal of utilities and acquisition of land. The project costs about Rs. 5000 crore including cost of rolling stock and associated systems.

Fixing of alignment and other urban hurdles

The elevated corridor starts from the Ridge area, passes over the median of Vande Matram Marg, crosses ring railway, Road overbridge (ROB), Grade separator at Dhaula Kansan and through the Reserve forest and Army, Navy and Air force lands runs along the NH-8 towards Airport (Figure 1).

Land acquisition from the owners such as forest department and defence forces for permanent or for temporary use was one of the most time-consuming activities. All construction in ridge area have been banned by the hon'ble Supreme Court, therefore for these projects Court's permission was got through central empowered committee. On receiving court's

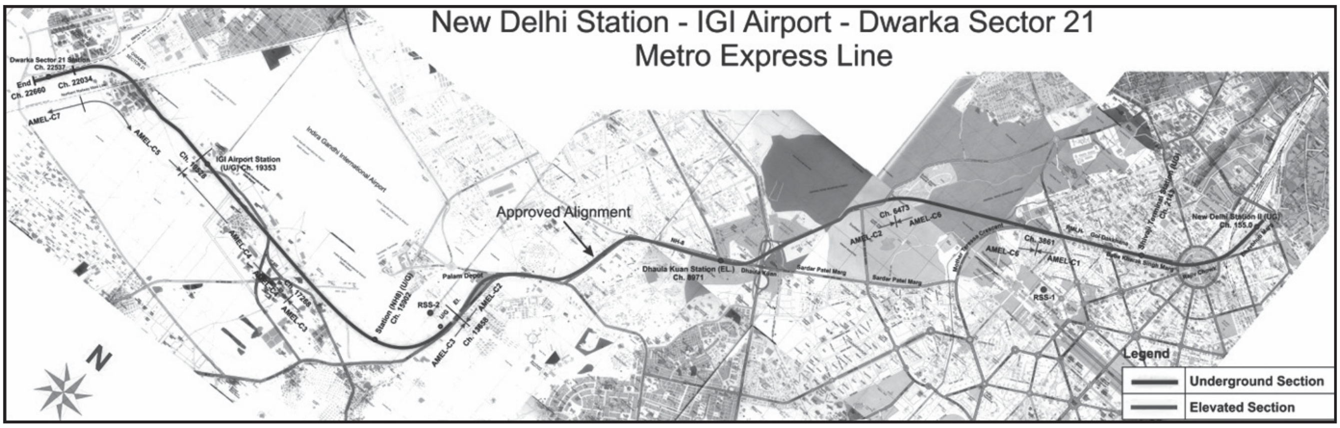

Figure 1. Alignment of the Airport Metro Express Line (AMEL)

Table 1. Safety and health standard during the construction

No.	Parameters	Standards	Achieved
1	Hours worked		2,679,868
2	Lost time injury accidents (including fatal)		7+1
3	Accident frequency rate (AFR)	0.50 (DMRC target)	0.29
4	Performance against DMRC Target (+ better than; - worse than target)	0.50	+0.21
5	Suspended particulate matter (SPM)	500 (μg/ m^3)	409 (μg/ m^3)
6	Noise level (L_{max}) in dBA	75 dBA (day) 65 dBA (night)	71.59 dBA 63.47 dBA

clearance on 7.12.2007 the clearance from Ridge management board and Ministry of Environment and Forest were obtained on 27.11.07 and 07.05.08 respectively. Land clearances from Ministry of Defence were obtained progressively from December 2008 to November 2009. While keeping international health and safety standards during construction (Table 1), the construction was completed in Jan 2010

Many utilities and structures had to be shifted, re-laid or moved. This includes 14 Air Force quarters and an Army mess building. Shifting utilities meant coordinating with more than twelve agencies and departments. Because of wide and sudden variation in geological strata, selection of foundation was a challenge and required sound knowledge of geology and soil characteristics. So, the depth and foundation type was specific for individual structure.

Foundation work

This stretch has 271 piers of which 156 have open foundation and the rest 116 are on pile foundation (Figure 2). Apart from basic load test, load test using dynamic impact was also conducted for piles. The pile integrity was tested regularly to check quality of concreting. Some special piles of 6.0 m were provided at Vandematram Road due to non availability of sufficient road width for open foundation. Otherwise open foundations were provided at all the locations where rock was available up to 6.0 m depth.

Figure 2. Substructure view

Piers

For improving aesthetics, 1.6 m diameter sleek piers were designed for the entire section. However, those piers that were meant for continuous span have 1.8 m diameter. Thick (0.25 m) crash barriers protect close-to–road piers from vehicular impact piers. Cantilever and portal piers are designed in elliptical shape to match the pier cap profile.

The pre-cast pier caps are special features of Airport Line. The pre-cast Pier caps were transported to site and 250 t cranes erected them on top of pier (Figure 3). Two cranes were deployed for erection. After geometrical adjustment on-site, pier caps were connected to the pier top using reinforced concrete. The Pier caps were post tensioned in two stages. (I) before erection of U girder (ii) after erection of U girders. The casting and erection cycle of pier caps were about 24 hrs and 10 hrs respectively.

The pier caps use M45 grade concrete. The pier caps are of three types; standard pier caps, cantilever pier caps (CP) or L-shape and portal piers Figure 6. The cantilever or portal pier caps were used at locations where piers were obstructing the road carriageway. Vertical clearance of 5.5 m was kept everywhere. The CPs were used with minimum eccentricity and with ceiling value of 3.30 m. Normally a cast in situ pier cap construction takes about 45 days, so their use was kept to the minimum. To achieve rapid progress some CPs were precast in three parts and later lifted and fixed monolithically with the pier by post tensioning. However, launching and tensioning precast pieces were not easy (Figure 4).

Originally, portals were also designed as precast beam but this design was not used because of risks associated with lifting

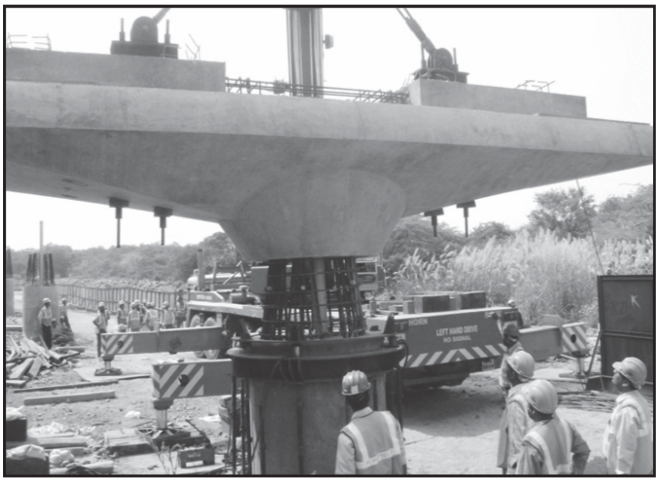

Figure 3. Erection of standard pier cap

and fixing beam weighing about 120 t. Therefore only cast in situ portals have been used.

The clear span of portal piers varies from 12 m to 19 m with maximum height being about 16 m (Figure 5 – Highest Portal Pier No 160).

Precast full span Double U girders were preferred over single U box for the following reasons.

1. Cost-effective as the weight was 10t/m where as segmental box weigh 16t/m
2. Fast erection
3. Aesthetically pleasing
4. No side parapets were needed
5. Overall height is low, because bottom slab supports the track
6. Typical cross-section throughout the span without any thickening at the ends span length 25 m. Figure 7

In particular, the following were simpler in open sections than in closed section:

1. Building of reinforcement cage in jig Figure 8
2. Adjustment of reinforcement after installation of rebars in shuttering.
3. Threading of strands
4. Concreting the U-girder
5. Building and handling of inner formwork.

Casting yard

Establishment

About 45000 m^2 area was needed for two long line beds of 5 girders including space for stacking about 80 girders. However because of non-availability of enough land in Delhi, the yard was started with an area of 20,000 m^2. This space was not enough for best progress. Although it took four months to complete the entire set up, the casting yard was initially set up with two beds of 5 girders each and later the capacity was extended by two more girders on each bed. Two Gantries of

Figure 4. Precast cantilever

Figure 6. View of the highest portal pier, 16 m height

Figure 5. Cast in situ cantilever pier

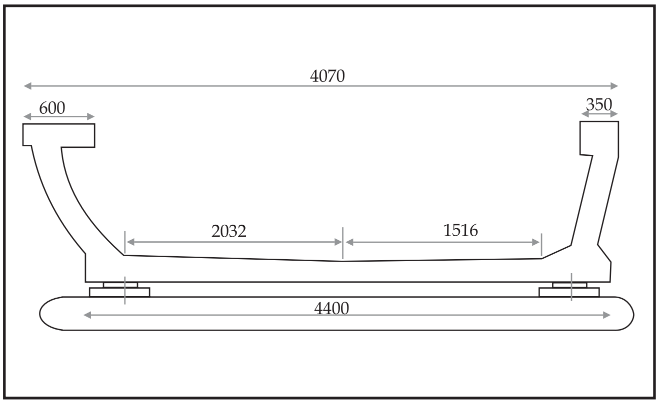

Figure 7. Cross section of the U girder

Figure 8. Placing of U girder re-bar cage

80.0 t were used for girder shifting and placing at loading points. Pier caps casting used four sets of moulds.

The long line method of casting was preferred because of the following advantages:

1. Cost-effectiveness: Seven full span units stressed at one location using one set of stressing equipment
2. Time-saving: all operations were done simultaneously for the 7 U-girders.
3. Simplicity of operation: simple and easy to adjust the spans. There is no thickening at the ends of the full span, so the same outer and inner formworks are used throughout the full span precast unit length. Therefore to adjust the length or provide a skew angle of the end in

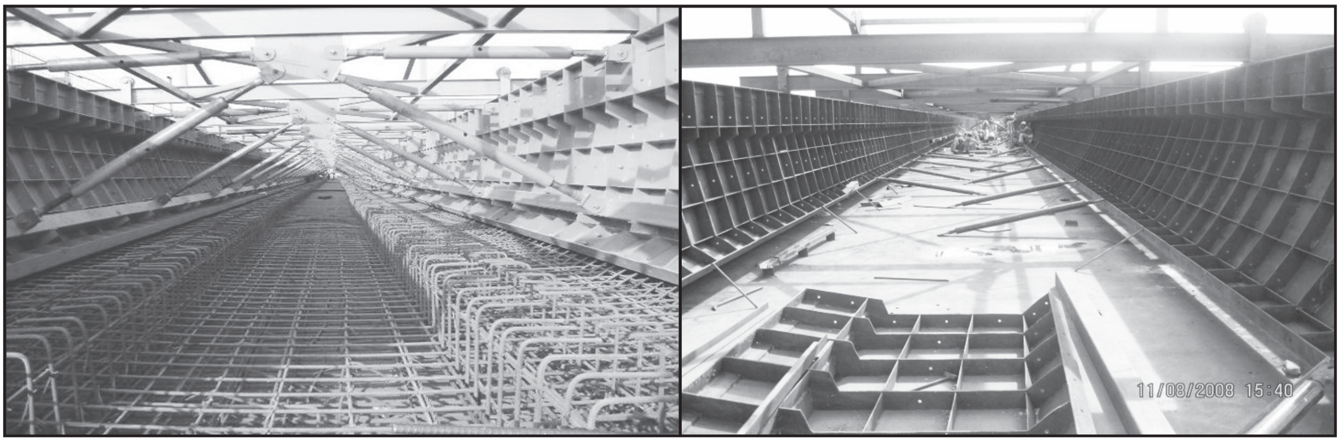

Figure 9. Inner shutter with reinforcements (left) and outer shutter (right)

curved portion, the bulkhead was simply shifted inside outer or inner lateral formworks, which have a fixed length of 25 m, to the needed length and angles.

Formwork

The girders consists of 4 parts:

1. Fixed bottom bed made of steel plates and supported by longitudinal concrete pedestals.

2. Lateral shutters for outer faces of webs and top flanges: these shutters can be moved for final adjustment .

3. Inner formworks for inner face of webs; these formworks are made collapsible using screw-jacks for de-shuttering and removable after concreting. They are made of two 12.5 m pieces Figure 9.

4. Bulkheads provided at each end of U-girders. They include holes for strands.

No shuttering is required for the top surface of the slab because it is finished by levelling.

Casting procedure

The U-girders use M55 concrete and are pre-tensioned with 48 to 56 strands. All operations were carried out following ISO 9001 quality and safety norms. A special arrangement of pulling all the 56 strands at a time was made with a special pulling bulk head (Figure 10) and four jacks of capacity 300 t each. All the strands were stressed from one end called active end. The other end of the long line bed was provided with RCC reaction frame and is called passive end. The pre-stressing force was 1100 t.

During pre-stressing individual strands were kept straight and horizontal and were in the bottom slab, underneath the webs of the U girder.

Strands did not deviate at the ends but to avoid excessive tensile stresses at the ends of the U-girder during construction, around 15 to 20 strands at the both ends (depending up on girder length) were de-bonded on the first 2-3 m of the U-girder using HDPE tubes.

Stressing at the passive ends used mono strand jacks at 10% of the required jacking stress, to remove any slackness in the strands to avoid any possibility of an accident during full force stressing at the active end.

Initially cycle time of girders was about 11 days which improved to 6 days by streamlining and checking critical activities. This is an improvement with a record, as cycle time for similar work in other countries has been 10-12 days. Table 2 details casting yard activities with progressive improvements.

Destructive load test were carried out on precast U girder at yard to validate the design and the results were satisfactory. Minor cracks were visible only when the load exceeded 2.5 times the design load (Figure 11).

Transportation and erection of U-girders

Transportation

Special trailers were made to transport 25 m long U girders. All the wheels of the trailer steer using hydraulic cylinders. Table 3 gives the details of the trailer used in the project. Trailer's Inner and outer circle turning radii were 14639 mm and 20955 mm respectively with a clearance of 11514 mm and 23140 mm for inner circle for outer circles respectively. The trailer has 16 axels. The design capacity was 10 tones per axle including self-weight of the trailer (Figure 12).

Initially, the plan was to launch the girders with the help of launching girders (LG). A special LG was designed to lift U girders of 135t each. Two LGs were to be used from both the ends of viaduct. However delay in fabrication of the LG and the need for completion of continuous stretch from the given end, meant mobilizing two cranes of 250-350 tons to continue the erection.

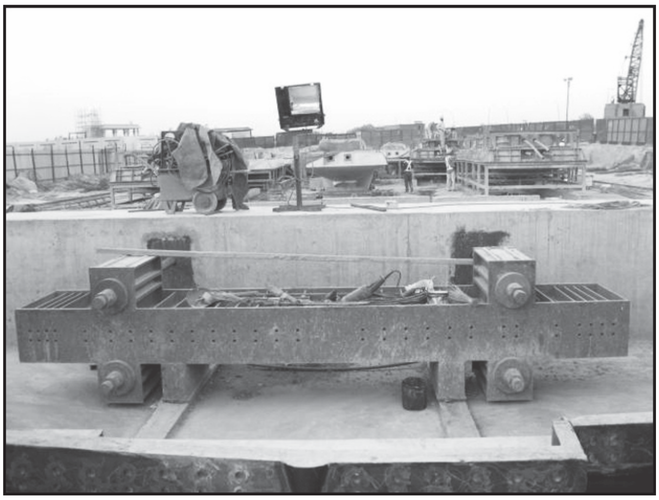

Figure 10. Bulk head

Figure 11. Load testing of the U girder

Table 2. Activity chart of U girder casting

No.	Activity details	Ist casting	VI th casting	XII th casting
1	Preparation of cage for U - girders at bay- 01. This activity involve utting, bending and binding of reinforcement	25 days (Initial setting of form work in casting yard , after arrival from workshop)	6 days	Three and Half days i.e. 94 hrs.(approx.)
2	Preparation of beds for next batch of casting.	-	First casting on Bay - 02.	Done as parallel activity along with lifting of girders from the Bay 01.
3	Placing of rebar cage	10 hrs. @ 2 hrs. per bed	5.30 hrs	6 hrs.
4	Fixing of bulk heads	10 hrs. @ 2 hrs. per bed	6 hrs.	4 hrs.
5	Threading	56 hrs.	22 hrs.	21 hrs.
6	Slack removal	8 hrs	2.30 hrs.	1.30 hrs.
7	Placing, positioning and fixing of inner shutters.	24 hrs	8.00 hrs.	2.30 hrs.
8	Pre-Tensioning of U girders	2 hrs.	1.30 hrs.	1.30 hrs.
9	Concreting of U girders	24 hrs	14 hrs.	16.00 hrs.
10	Removal of inner shutters	8 hrs.	8 hrs.	5 hrs.
10	Curing for de-stressing	96 hrs	84 hrs.	120 hrs.
11	Distressing	1 hr	50 Mints.	45 min.
12	Cutting of strands	12 hrs.	4 hrs.	4 hrs.
13	Removal & stacking of U - girders.	5 hrs.	7 hrs.	7 hrs.
14	Protection of strands by epoxy mortar	-	-	-

Table 3. Specification of trailer used for transportation of U girders

Description	For 25 m. long girder	For 20 m. long girder
Total length of the trailer including puller	40575	35575
Total length of loading area	29400	24500
Total distance between 2 loading points	23200	18200
Total un laden weight of the trailer excluding puller	40300 kg	37300 kg
Loading height of trailer	1200 +/- 300	
Width of the trailer	3000 mm	

Figure 12. Special trailer

Figure 14. Temporary structure for casting continuous span at Dhaula Kuan

This arrangement proved to be successful and was adopted for all the girders. Cranes made possible girders erection even on narrow road such as Vande Matram with a restricted carriageway width of 5-6 m. Most of the launching was done during night by regulating traffic for few hours.

Selection of superstructure

It was a challenge to design and build a viaduct to cross Dhaula Kuan grade separator of eight roads, 3 cloverleaves, a road fly over and a railway line passing through 15 m deep rocky gorge. Various alternatives such as long steel girders and long continuous spans box and solid girders were considered. The design team decided constructing a special sleek solid slab with continuous structure resembling the U girders shape (Figure 13). The solid slab consists of 5 segments of 162 m, 93,114 m, 168 m, and 95 m totalling to 610 m. A solid 1.5 m deep slab that integrates with intermediate piers segment of 168 m and a single span of 50.0 m was designed. The structure was provided on POT-PTFE bearings, with 17000 KN vertical (ULS normal) and 1100 KN lateral loads (ULS, normal). The pre-stressing force was about 7780 KN. Fortunately, special jacks were available with BBR, India. The slabs use 9 to 15 strands (37K15 imported variety).

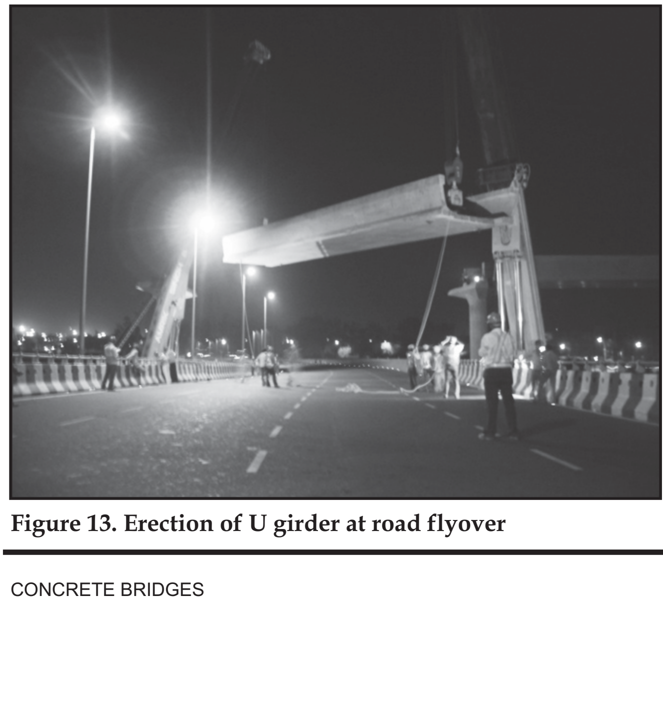

Figure 13. Erection of U girder at road flyover

Construction

Building cast in situ continuous long span viaduct over the busy and congested Dhaula Kuan junction and over the Railway line proved to be a challenge. For temporary structures, a tunnel type section with ISMB was planned at the Road crossing to keep 7.5 m to 8.0 m wide carriageway on either side, with a clear height of 5.5 m for traffic (Figure 14).

Casting continuous span needed 900 to 1600 m^3 concrete in one segment. This was possible only over weekends and at night,

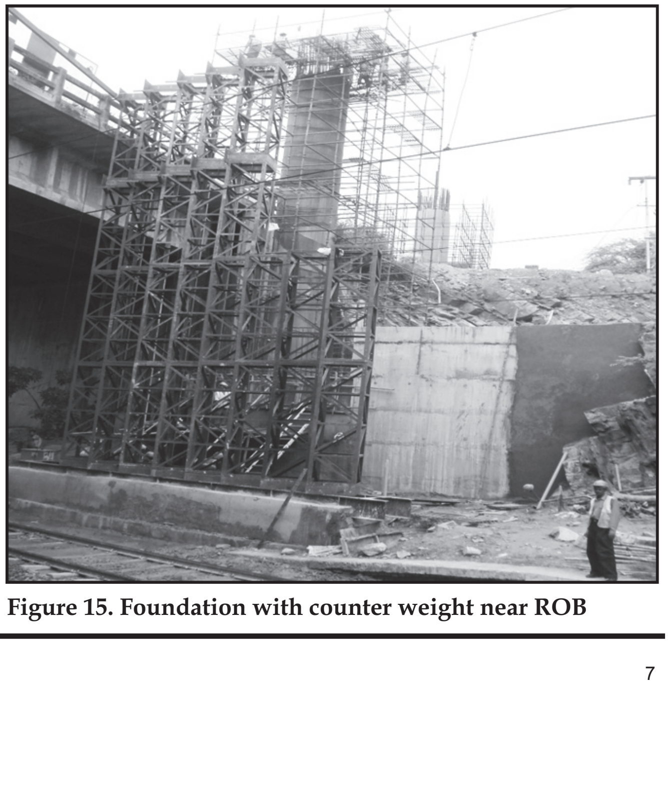

Figure 15. Foundation with counter weight near ROB

Figure 16. Temporary structure over railway line

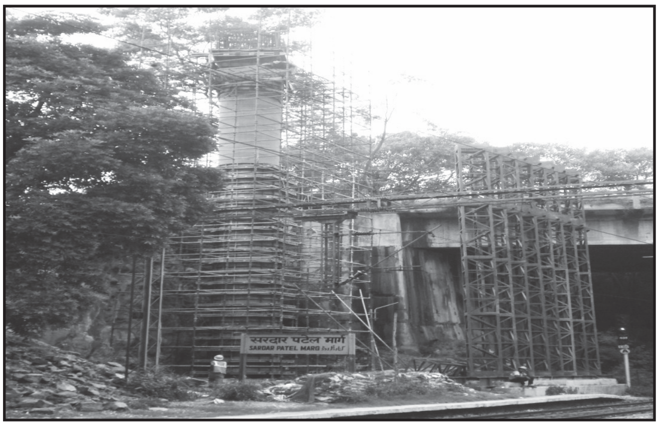

Figure 17. Highest pier, 20 m height

Table 3. Progress of construction

Description	Piling-1000 mm / 1500mm	Open Foundation	Pile Cap	Piles	Cant-in-situ Pier cap	Pier Cap Casting	U-Girder Casting	Pier Cap Erection	U-Girder Erection	Span Alignment
Unit Nos	No's	No's	No's	No's	No's	No's	No's	No's	No's	No's
Total Nos.	489	141	121	262	40	202	504	201	504	252
Feb, 08	-	-	-	-	-	-	-	-	-	-
Mar, 08	-	-	-	-	-	-	-	-	-	-
April,08	-	-	-	-	-	-	-	-	-	-
May,08	-	-	-	-	-	-	-	-	-	-
Jun,08	7	3	-	-	-	-	-	-	-	-
July,08	14	7	1	3	-	-	-	-	-	-
Aug, 08	32	5	1	9	-	-	5	-	-	-
Sep, 08	37	9	8	3	-	10	15	-	-	-
Oct, 08	50	6	7	17	-	15	5	2	-	-
Nov, 09	45	12	14	16	-	6	10	14	-	-
Dec, 08	23	19	9	22	-	13	25	8	18	-
Jan,09	20	22	6	19	-	24	35	21	30	-
Feb,09	45	11	5	28	-	25	42	30	46	-
Mar,09	53	16	14	28	1	25	45	30	50	-
April,09	36	13	7	31	4	26	35	20	44	22
May,09	39 6		8	24	3	17	63	13	40	16
Jun,09	31	4	8	20	4	18	49	21	46	20
July,09	22	1	10	10	5	17	35	17	20	22
Aug,09	5	1	2	6	2	6	35	6	40	24
Sep,09	6	-	6	3	4	-	35	4	40	18
Oct,09	8	1	9	8	4	-	40	2	24	31
Nov,09	8	4	4	13	6	-	31	8	26	34
Dec,09	3	-	-	1	6	-	-	5	32	20

as on other day's high traffic and frequent VVIP movement, stop work for 3 to 5 hours minimum. Accordingly, a vertical construction joint with a 10 mm wire mesh was provided and concreting was done using pumps and boom placers from both the ends. The threading in 162-168 m long continuous span proved to be critical. In general time consuming activities were temporary structure (90-130 days), reinforcement placing (30 days), fixing duct profile (8-12 days), threading (6-10 days), concreting (2-3 days), and stressing (5-10 days).

Figure 18. View of continuous span

Construction over railway crossing

Constructing both substructure and superstructure in 15 m deep gorge with electrified line and about 20 m high piers was a challenge (Figure 17). One of the viaduct piers was so close to the ROB that it was obstructing the foundation of the ROB and sub-base of the Railway track. Constructing foundation and pier was difficult here. So a special foundation with a counterweight of about 300 t was designed (Figure 15).

Cutting rocks mechanically next to the railway line was difficult so it was done manually and took about 4 weeks. Then, a special temporary structure was designed to construct the cast in situ super structure without blocking the traffic (Figure 16).

The entire 610 m long solid slab consisting of 5 segments was completed in a record time of 12 months since award of the tender to M/s Tantia construction Ltd (Figure 18).

The special span has 6 mm thick blue clear polycarbonate solid parapet beautifying the surroundings and blending with the greenery of Dhaula Kuan area.

Epilogue

The cast in situ pier caps and commissioning of casting yard were the most critical activities in this project. Therefore such activities should be especially watched in viaduct constructions. Notwithstanding the challenges faced during construction, completing 7.2 km long structure sets an example in via duct construction. Although Table 3 shows 19 months as construction time, 80% of the construction was completed in just 12 months.

Use of pre-cast pier caps and pre-cast full u girders not only speeded up the construction but also improved the aesthetics of the viaduct because of sleek shape and uniform quality.

It was possible to construct a pier with open foundation in just 6-7 days including launching of pier cap because of pre-cast pier caps. The top of viaduct is now ready for laying of track.

Pre-cast pier caps and pre-cast full span U girders are suitable for constructing long elevated viaducts for rail and road infrastructures.

Mr. O.P. Singh is an engineering graduate from University of Roorkee (now IIT Roorkee) and belongs to Indian Railways Service of Engineers. Presently he is on deputation to DMRC, where as Chief Project Manager, he is responsible for overall execution and supervision of the Airport Line along with land acquisition and other matters. He has 25 years of experience with Indian Railways at various capacities including construction and maintenance of Railway lines. His assignments at DMRC during the last six years include tunnelling under water body and other elevated corridors. He has published papers on tunnelling, cross passages and bridge construction and detection of transverse flaws (kidney formation) in rails.

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