Construction of elevated viaduct between Trinagar and Rithala on Delhi metro

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The elevated viaduct between Trinagar and Rithala is part of phase I of the Delhi Metro Railway transport system. The paper describes the innovative construction methods employed for achieving fast track construction of the viaduct, especially its foundation and sub structure, with high safety and quality standards.

The work of the phase-I of Delhi Metro Railway transport system (MRTS) is currently in progress. A part of phase-I between Shahdara to Tis Hazari is already commissioned. The stretch between Trinagar to Rithala is presently under construction and the paper deals with the innovative construction methods adopted for achieving fast track construction with high safety and quality standards. Figure 1 shows the key plan of Trinagar-Rithala section of phase-I.

Substructure

The stretch between Trinagar to Rithala with extension of Rithala-Barwala section consists of 269 number of piers supported on bored cast-in-situ piles of 1500-mm diameter and depth varying from 25 m to 37 m.

Pile foundations

The substructures are supported on cast-in-situ bored piles. Generally, 6 piles are provided for standard piers and upto a limit of 16 piles are provided in a group for special spans. The viaduct foundations are aligned along the median of the road to minimise the inconvenience to the road traffic.

Site preparation and survey

Steel barricades were fixed on road for a width of 9 m (4.5 m on either side of the road median) before starting up any works. Necessary traffic diversions were carried out to enable easy flow of traffic. Traffic management plan was prepared in advance and the same got approved from the local authorities. Road signages were provided including blinkers on top of the barricades to discriminate the area of worksite to the road users. On satisfactory results on traffic flow, the existing medians are broken and debris removed from the site. The viaduct alignment was marked and pile layouts were established. Once the pile points were established, the road crest was removed and excavation was carried out upto 1.5 m depth to check for any unchartered utilities. Figure 2 shows the work of site preparation/barricade erection.

Utilities

Based on the preliminary general arrangement drawing, the underground utilities, which were identified through the

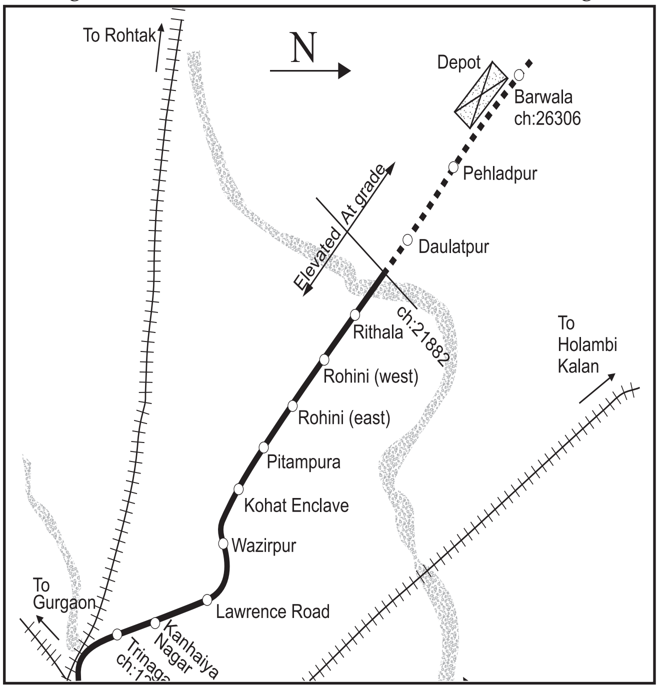

Figure 1. Key plan showing section between Vivekanandpur to Barwala of phase-I of Delhi MRTS

Figure 2. Barricade erected for separating construction activities from the road traffic

records available in various departments, were removed/ diverted in advance so that the foundation works could be taken up. The uncharted utilities as and when encountered during the execution of work, were intimated to concerned agencies and actions taken as per site conditions, that is, change in layout of piles or diversion of utilities whichever was feasible. In many of the cases, the pile layouts were revised.

Piling methodology

Installation of piles was divided in three categories:

1. piling off road locations
2. piling on road locations
3. piling on slope of embankment for railway crossing.

Piling off road locations: Piling work off road locations was planned and executed using rotary type of hydraulic rigs.

Piling on road locations: Piling work on road locations was initially planned using temporary casing upto non-collapsible stratum. Temporary casing were driven and extracted upto a depth of 19 m. Due to sub-soil conditions, piling using temporary casing was not practicable. At these locations drilling mud was used. Utmost care was taken to eliminate bentonite spillage on roads. Portable steel tanks were deployed with closed pile line system including return bentonite and the same were disposed off in tankers and it was ensured that least inconvenience was caused to the road users, Figure 3.

Piling on embankment at railway crossing: Piling work for 14 piers was required to be executed in the sloping embankment where conventional piling rigs were deployed. Sheet piles of 12-m length were required to be driven and soil anchors were used to retain the earth on embankment side and the area was excavated and leveled for work area for placement of piling rigs Figure 4.

Piling methods

Piling using temporary casing: The work involved the following:

1. temporary casings were driven using vibrohammer.
2. rotary rigs were deployed for drilling of bore, pile muck disposed off simultaneously to the designated area (10 to 15 km away from worksites).
3. pre-fabricated rebar cages were lowered using cranes.
4. tremmie pipes were pre-assembled and lowered in bore hole.
5. cleaning of bore carried out with high capacity water pumps.
6. concreting carried out by standard method of under water concreting.
7. temporary casing (upto 19 m long) withdrawn using vibrohammer.

Piling using drilling mud: In this method, rotary rigs were deployed for both driving of pre-tube upto 6 m long and drilling of bores. Other activities were done were done similar to that described as above, except for the activity of withdrawal of temporary casing, which was done using the crane/rig instead of vibrohammer.

Piling using DMC method for embankment: The foundation for the stretch of the viaduct between Lawrence Road and Ring Road at Wazirpur was falling on the slope of an

Figure 3. Piling work in progress

embankment where deployment of heavy equipment was not possible due to underground sewerage channel at the toe of the embankment and the residential buildings were just at 4 m away from the embankment. Tripods were deployed for piling in this stretch. Retention of embankment over which the heavy traffic flow were to be allowed round the clock posed a problem. Sheet piling with ground anchors were required to be adopted before commencement of piling work.

Figure 4. Piling work on slope of embankment

The ground anchors were load tested and on satisfactory test results the same were provided for anchoring the sheet piles against overturning. The embankment is excavated and level ground made to accommodate piling rig. Direct mud circulation method was adopted for piling in embankment stretch.

Structural details of the piles: The structural details of the piles are given below.

Grade of concrete	M 35
Diameter of pile	1500 mm
Depth of pile	25 to 37 m
Total no. of piles	1700
Design load	425 t

Fast track records on piling: The piling work had created a few fast track records which are given below.

1. 169 running metres of pile boring in a single day of 22 hours of working using one R518 type rotary rig
2. Nine piles completed in a day
3. 4700 running metres of piling in a month
4. 33-m long rebar cage lowered in single operation.

Typical time cycle achieved in peak production: Typical time cycles achieved in peak production are given below.

Pile boring	3 hours
Cage lowering	1 hour
Tremme lowering and cleaning	1 hour
Concreting	3 hours

Testing of piles

Before commencement of the installation of working piles, test piles were installed for initial load test at various locations and were tested at 2.5 times the design load. Eight initial load tests were carried out to ascertain the load carrying capacity of piles. The load tests on working piles were done as per codal requirements, Figure 5.

Figure 5. Pile testing being carried out

Due to the space and time constraints, the static load tests were carried out using ground anchors instead of conventional system of loading counterweights. Six ground anchors, having 200 mm diameter, and 35-40 mm depth, were installed. The 12 T 13 system HT strands were used for anchoring of test frame and reaction taken. Four 500-t capacity jacks were deployed to avoid preparation of pile head of larger size to accommodate more jacks. The four jacks could be accommodated within 1.5 m diameter piles. The ground anchors were also tested for load carrying capacity in advance and adopted for load tests. In addition to static load tests, dynamic load tests using .Pile Dynamic Analyser. were also carried. A total of 33 load tests were carried out. The details are given below:

Static load test	:	11
Dynamic load test	:	22

Figure 6. Reinforcement for pile cap laid in position

Besides the vertical load tests, piles were also tested for lateral load tests (both initial and routine). All the piles were tested for integrity of piles by sonic integrity testing initially. On getting consistent results, project authorities have considered reduction in the numbers of pile integrity testing.

Pile caps

On completion of piling work for a few foundations in each stretch, pile cap work was taken up concurrently. Mechanical excavation was carried out, except for the bottom layer, which was manually dressed and levelled. Shoring work for sides of the excavation was carried out simultaneously to avoid any possibility of side collapses due to running traffic on the edge of the excavations. Both steel and timber shoring materials were used depending on soil conditions. At many locations, the water table was very high posing serious problems for stabilisation of sides due to the presence of loose soil. The problem was overcome by deployment of well point system. Six to eight numbers of well points were installed for dewatering depending on the size of the pile caps. Pile heads were cut and removed using cranes. Reinforcement cutting, bending was carried out in a centralised yard and transported to site, Figure 6. Onsite major works were carried out during night time when the traffic was less on roads. Formwork was erected using cranes whenever site condition was favourable; however at many locations formwork was erected manually. Concreting work was carried out by direct pouring method for standard pile caps using a combination of concrete pumps and direct pouring for pile caps of larger size. The pile caps in embankment stretch were cast by pumping due to space constraints for truck mixers movements.

The pile cap sizes varied, depending on the span and size of pier, Table 1.

Table 1. Size of pile caps and the quantity of concrete

Sr. No.	Particulars	Size	Nos.	Quality of concrete, m^3
1	Standard	10.95 x 6.95 x 2.0	230	36650
2	Special spans	15.45 x 15.45 x 2.5	5	2990
		15.45 x 9.75 x 2.5	5	1900
3	Cantilever piers	10.95 x 6.95 x 2.5	5	1000
4	Portal piers	10.95 x 6.45 x 2.0	12	1775
	Total concrete volume, m^3			44315

Table 2. Different types of piers, their location and the total volume of concrete

Sr No	Types of piers	No. of piers	Volume o f concrete, m^3
1	Standard piers	228	10950
2	Special piers for continuous span		
	Circular pier	04	300
	Rectangular pier	10	797
3	Cantilever piers	05	607
4	Portal piers	12	540
5	Crash barrier	206	1800
	Total concrete volume, m^3		14,494

Table 3. Details of equipment used

Equipment	Number
Hydraulic rotary rigs	5
Supporting cranes for piling (20 t capacity)	5
Vibrohammer	2
Loaders and excavators	6
Dumpers	12
Trucks	3
Trailors (20 t capacity)	4
Mobile cranes (5 to 25 t capacity)	6
Crawler cranes (25 to 75 t capacity)	4
Generators (15 kVA to 110 kVA)	12
Air compressors	2
Bentonite pumps (15 HP to 30 HP)	12
Well point system	50
Hydraulic jacks (20 to 500 t capacity)	10
Tripod rigs (DMC)	5
Batching plant (30 m^3 capacity)	3
Transit mixers (6 m^3 capacity)	8
Welding sets	20
Bar-bending and cutting machines	4
Desander	1
Casing oscillator	2

Figure 7. Concrete being pumped in the peer

Figure 8. Prestressed portal beam at road crossing

Speed of piling work

Generally, seven days were required for the construction of a standard pile cap.

The shortest time achieved for a pile cap construction under ideal conditions was as under:

Excavation	6 hours
Shoring, dressing and leveling	12 hours
PCC	3 hours
Pile heads chipping and removal	24 hours
Rebar fixing	42 hours
Formwork	8 hours
Concreting (150 m^3)	5 hours

The maximum single pour of 600 m^3 for the pile cap in special spans was carried out in eight hours.

Post concrete inspections and restoration of roads

The formwork of pile caps was stripped and inspection of the constructed portion was carried out. Normal curing was done for pile caps. Caps curing compounds were used for specific locations where the road was to be restored for traffic immediately. Backfilling for excavated pits was carried out in layers and roads were restored simultaneously.

Piers

Starters were done over the pile cap for varying heights to suit the formwork combination for different heights of piers. Rebar assembly for piers was done on site and that of pier caps at centralised yard and erected at site using cranes. The formwork for piers was erected using cranes. Six different types of pier formwork were fabricated. A total of 10 sets of shuttering were deployed. Pier concrete was done in single pour using mobile concrete pump (placer boom), Figure 7. PVC drain pipes were embedded with outlets in the pier concrete which were later connected with superstructure for rain water drainage. The rain water was discharged in the road median. The heights of piers varied from 6.50 m to 12.75 m. While standard piers were adopted for the foundations falling on road median in general, cantilever and portal piers were essential whenever the alignment of the viaduct is crossing the roads and falling out of the road median/footpaths.

Speed of pier construction

The standard piers were constructed in three days during peak working period. The shortest time cycle achieved for standard pier was as below.

Starter rebar and formwork	8 hours
Starter concrete	1 hour
Rebar for pier	18 hours
Formwork for pier	18 hours
Placing of prefabricated reinforcement cage	2 hours
Concreting of pier	3 hours

Reinforced concrete crash barriers were provided around each pier for an height of 1 m.

Portal beams

Prestressed portal beams were constructed at all road crossings, Figure 8. Temporary structures were designed in such a manner that there was no disturbance to the traffic under the portal during construction of portal beam. The formwork and temporary supporting trestles were preassembled and erected using cranes during late night hours when traffic load was bare minimum. Reinforcement of portal beams was prefabricated including placing of cable ducts and erected in position using cranes. A total of six portal beams were constructed.

Bearing pedestals

Reinforced concrete bearing pedestals were cast for varying height as per the bearing designs and rail level on top. Cut-outs were provided for bearings sleeves during concreting of pedestal. Anchor bolts for launching tackles were also embedded during the concreting of these pedestals.

Equipments deployment

The details of the equipments that were deployed to achieve the required targets of the foundation and substructure are given in Table 3.

Conclusion

The entire work was executed successfully in a short time of 18 months with the following project management techniques.

1. Efficient planning, scheduling, procurement and monitoring of work was done at every level (owner, engineer and contractor). Primavera software was used for project planning.
2. Daily interaction was required with senior managerial persons of the project team for quick decisions.
3. Detailed method statement for each activity wasprepared well in advance and approved for implementation.
4. Weekly and monthly meetings were held by senior executives of the project.
5. Training/orientation programme for the new entrants were given, especially to the engineer, supervisors and operational staff.
6. Safety and environment managers were deployed by the contractor and closely monitored by the engineer and owner.

It was possible to handle the huge volume of work by adopting fast track approach for planning, scheduling, procurement and monitoring of the works at every stage. This is the first time in the entire rail corridor of MRTS Phase . I, that the work of the 8-km long viaduct was handled by a single contractor.

Mr R. Subramanian has been working with Gammon India Limited., for the last 18 years and has experience in execution of works and project management on major road, rail bridges, high raised industrial structures and has also got expertise in handling various complex works on the field of bridge engineering. Presently he is the project manager of Gammon India Limited for Delhi Metro Rail Project elevated structure between Trinagar to Rithala.

Mr Brijesh Kumar Mishra has executed major tunnels in soft and hard strata, high embankment, deep cutting in soil and rock, major viaducts, railway station buildings, residential buildings, road works in Konkan Railway and viaduct and station works, diversion of utilities, land acquisition station with building management system, etc in Delhi Metro Rail comprising 17 years of experience. Presently, he is deputy chief engineer in Delhi Metro Rail Corporation Ltd.

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