Full span precast pre-tensioned decks: The future of elevated urban metro viaducts

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Delhi Metro Rail Corporation (DMRC) is constructing the Airport Metro Express Line as a fast, reliable, modern and integrated connection between Connaught Place and Indira Gandhi International Airport. This project aims to provide relief from increased traffic congestion experienced over the last few years. While most of the line is underground, a part of it, from Vande Matram Road to Palam, runs elevated on a railway viaduct. To meet the completion target of 16-months, full span construction method was used in this project. This has resulted in increased speed of casting and erection of the superstructure, compared to the standard precast segmental construction method used nowadays in other viaducts. This paper describes the technical features of the full span deck. Another innovative solution to further improve the speed of construction, namely precast pier cap at top of pier, is also presented.

Keywords: Full span precast pre-tensioned decks, prestressing, precast pier cap.

Brief of the project

The C2-Contract scope is from chainage +6.494 km to +13.533 km. Starting from Vande Mataram Road, crossing the Ring Road and Dhaula Kuan fly-over, crossing the National Highway NH-8 and heading to the Airport, this Airport Line Rail System is a high-speed metro reaching 140 km/h. It is designed to take loads from at leat 4 to 6 coaches of about 25 m long, each having four 17 T axle load. The train itself is designed to run on long-welded rails supported by ballastless track and viaduct structure. Being an express line, the AMEL has very few stations. On this 7 km elevated stretch, only one station is provided at Dhaula Kuan fly-over. Building the C-2 stretch was awarded to IJM. SYSTRA, a project consulting company from France provided the tender design and detailed design of the civil works.

Full span method: Casting and erection

The traditional method of Metro viaducts construction uses single box precast segments (Figure 1). Typically, the spans use 3 m segments. The segments are transported from the casting yard to the site, lifted, assembled, and connected together by

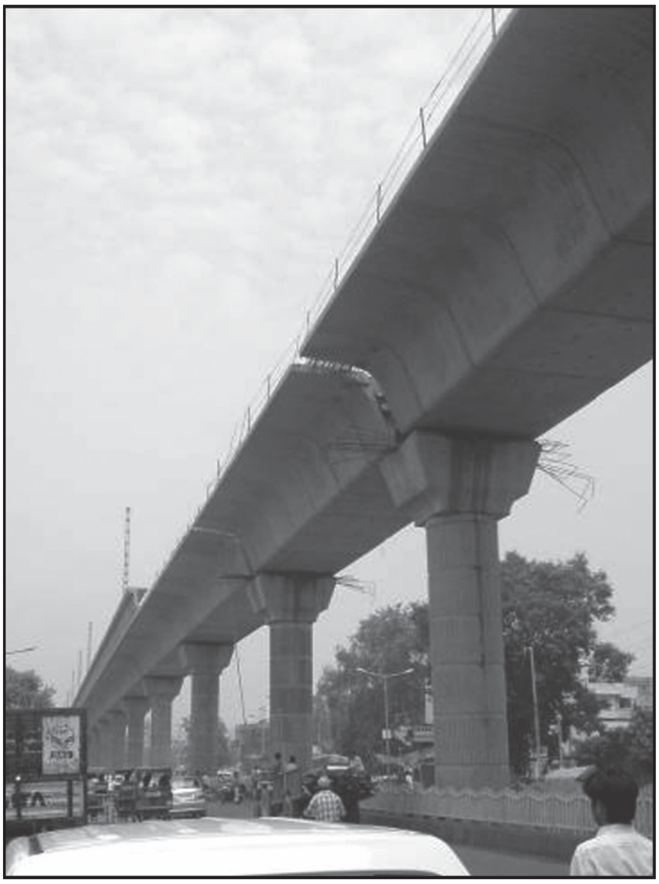

Figure 1. Standard precast segmental viaduct on Delhi Metro

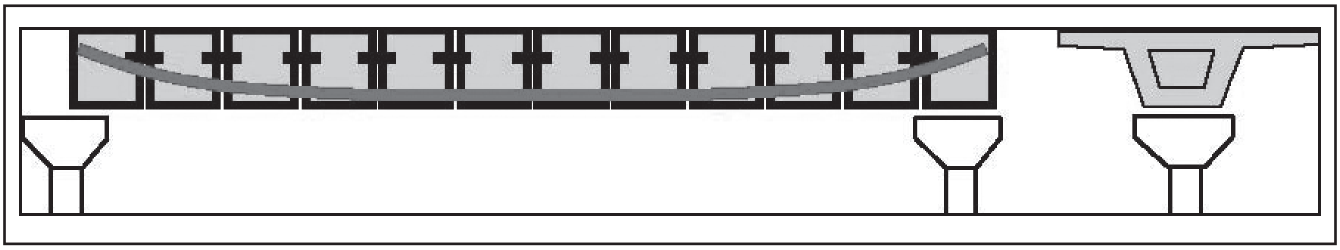

Figure 2. Typical span with precast segments showing temporary prestressing and final prestressing

Figure 3. (left) Temporary prestressing operation (Right) final prestressing

Figure 4. View of the precast U-girder on airport link viaduct

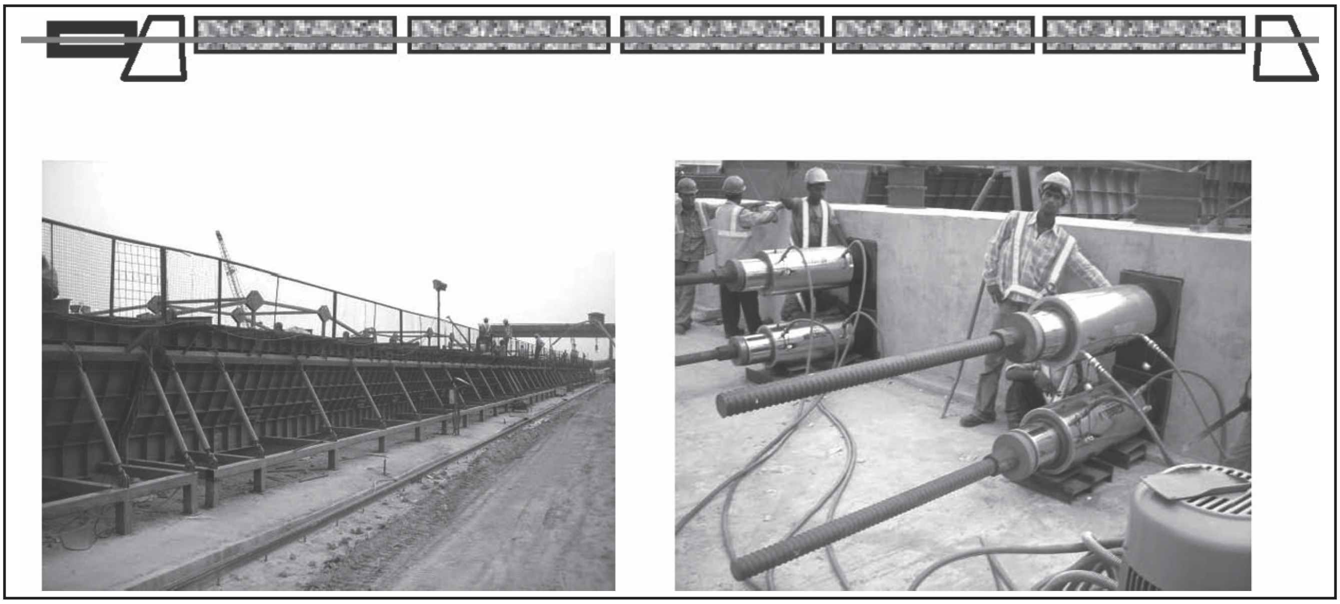

Figure 5. (Left) Long line casting method (Right) Prestressing hardware

prestressing on-site. Although fast and well suitable for urban areas, this method requires some work at site, for exmple:

1. Assembling and gluing segments by temporary prestressing (Figures 2 and 3)

2. Threading prestressing strands

3. Stressing tendons at the ends of the spans, including grouting of ducts

These activities form part of the overall construction cycle of the span and are clearly time-consuming. Because of inherent site work in this method, quality control is not the same as for the work performed at the casting yard.

On the other hand, the full span method consists of precasting the deck units in one single piece at the casting yard, and not in several segments. It is not possible to precast and erect the whole deck supporting the two tracks, because it would be too wide and heavy to transport. Therefore, the deck is split into two independent units.

The superstructure of the Airport link C-2 viaduct consists of 2 precast units with a U-shape section for each track (Figure 4). The main characteristics of the section are:

1. Two top flanges at train coach or platform level

2. Two webs

3. Bottom slab of about supporting the track

4. Uniform cross-section throughout the span

5. Twenty five metre span

The U-girders are cast using the long line method (Figure 5). The fabrication line has 5 casting beds, each about 25 m long, where five full span U-girders are prepared and cast at a time. A stressing equipment at the active end and a reaction beam at the passive end ensure simultaneous stressing of strands for the 5 units.

The formwork consists of the following:

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 for de-shuttering and removing after concreting. They are made of two pieces of 12.5 m length each

4. Bulkheads are 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.

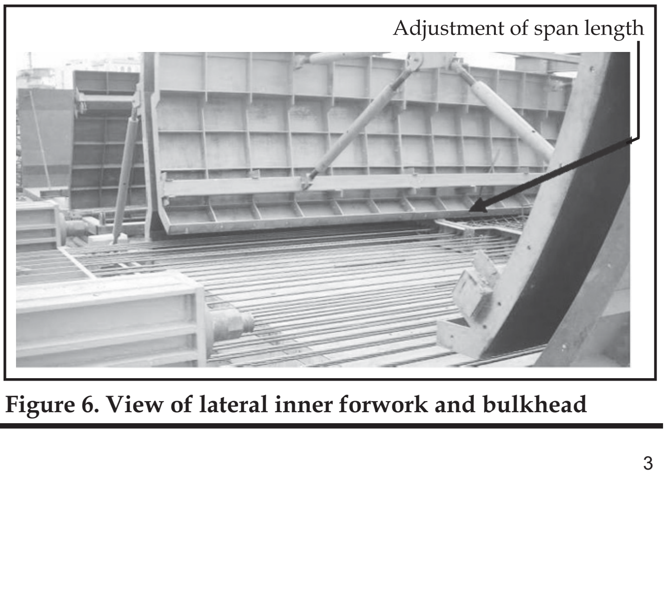

Figure 6. View of lateral inner forwork and bulkhead

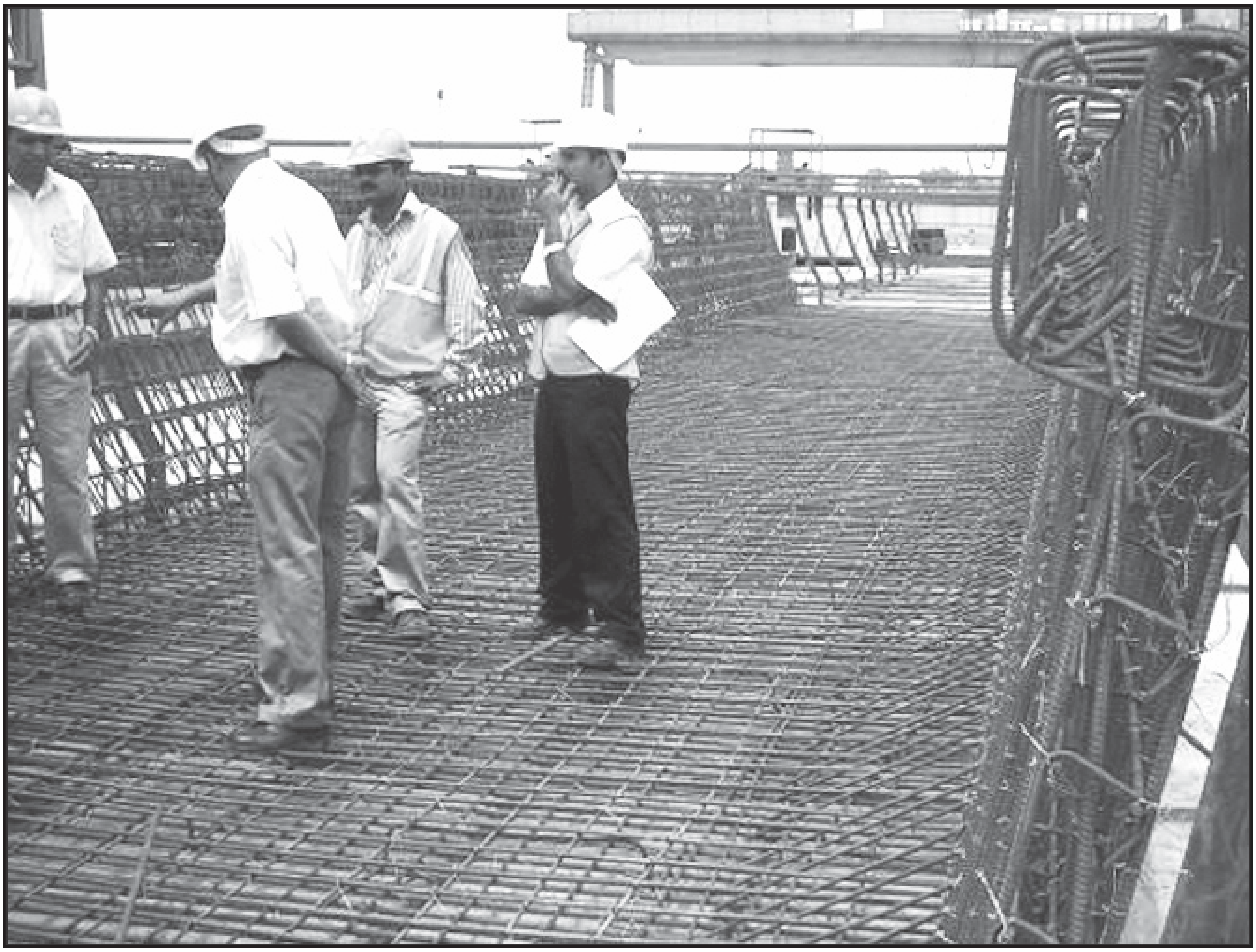

Figure 7. Rebar cage

The long line method offers many advantages:

1. Cost-effectiveness: Five full span units can be stressed at one location using one set of stressing equipment.
2. Time-saving : All operations are done simultaneously for the 5 U-girders.
3. Simple and easy to adjust the spans: There is no thickening at the ends of the full span. So the same outer

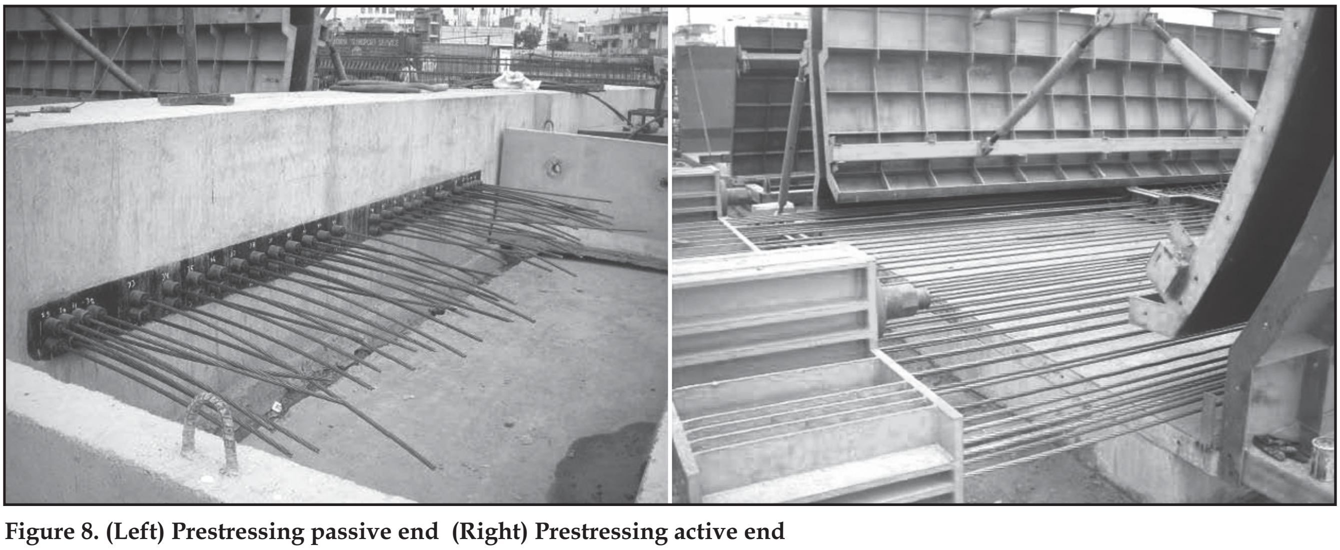

Figure 8. (Left) Prestressing passive end (Right) Prestressing active end

and inner formworks are used. To adjust the length, or provide a skew angle of the end in curved portion, the bulkhead are simply shifted inside outer or inner lateral formworks to the required length and angles (Figure 6).

4. The "U-shape" section, being an open section makes the fabrication of U-girder much easier, faster and convenient for construction. In particular, the following activities are easier to carry out than in the closed section:

   4.1 Fabrication of reinforcement cage on jig

   4.2 Adjustment of reinforcement after installation of rebars in the shuttering (Figure 7)

   4.3 Threading of strands

   4.4 Concreting U-girder

   4.5 Fabrication and handling of inner formworks

All the prestressing strands are straight, horizontal and located in the bottom slab underneath the webs of the U-girder. No deviation is provided on strands at the ends. However, to avoid excessive tensile stresses at the ends of the U-girder during construction, some of the strands are debonded at the first 2 m of the U-girders using HDPE tubes.

Stressing is carried out in 2 stages:

1. stressing at the passive ends is done for each strand using monostrand jacks at about 10% of the required jacking stress. This is done to remove any slackness in the strands which could cause mishap during stressing of the full force.

2. stressing with the remaining jacking force at the active end.

(Figure 8) shows the arrangement. At the active end, the strands are stressed one by one by monostrand jacks but are stretched using a rigid steel beam where all strands are fixed with post-tensioning jaws (Figure 9).

This stressing beam slides longitudinally on stainless steel PTFE surface during stressing operation following the elongation of the strands. The beam itself is pulled using 4 PT bars, stressed by individual jacks.

The casting cycle for one line of five U-girders is described below:

1. Preparation of formworks (cleaning and greasing)

Figure 9. Pulling beam at active end

Figure 10. Lifting of rebar cage

Figure 11. View of inner shutter after installation

Figure 12. View of trailer for transport of full spans

2. Installation of rebar cages in formworks. The full cages are prepared separately and installed in one piece in the formwork (25 m long cage) (Figure 10).

3. Threading of strands within the formworks and through the bulkheads

4. Installat ion and c los ing of the inner formworks (Figure 11).

5. Adjustment of reinforcement and installation of spacer blocks

6. Stressing of strands in two stages:

   6.1 Stressing of strands at the passive ends by using monstrand jacks (for removal of slackness in strands) about 2 t per strand.

   6.2 Stressing with the remaining force in strands using steel beam and pulling jacks

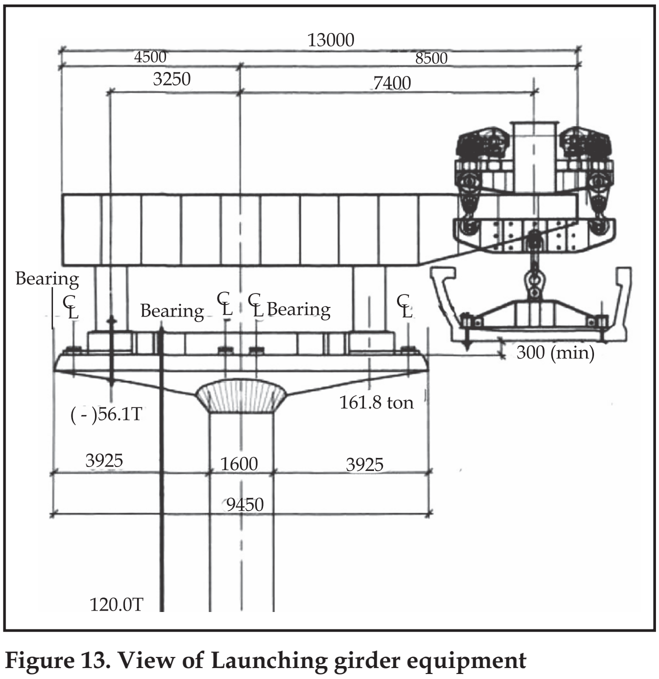

Figure 13. View of Launching girder equipment

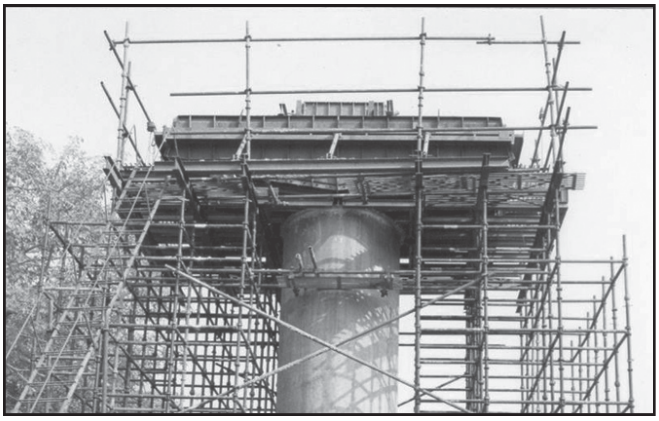

Figure 14. View of traditional pier cap cast-in-place

7. Concrete pouring

8. Curing and setting of concrete – The required concrete strength for prestressing transfer is M35.

9. Release of prestressing force, cutting of strands, removal of inner shutter and lifting of U-girders for stacking

The methodology of casting is simple and does not require elaborate procedure or complicated shuttering, as the shapes of the structure are standardised for the viaduct. Moreover, the U shape of the section is cost-effective, faster and offers simplified procedure for reinforcement fabrication. It also permits easy prestressing, concreting, adjusting of span lengths because of standard sections throughout the span length.

These simplified design and fabrication procedures allow a casting cycle of 6 days per casting line, so 5x2=10 U-girders are cast in 6 days for 2 lines. This represents a pace of 25 spans a month or about 625 meter of viaduct deck per month. This speed cannot be matched by any segmental construction.

Methods of erection

The advantage of the full span method is not only faster casting, but also faster erection cycles compared to segmental construction. In segmental construction, time is consumed for assembling, temporary PT, gluing, prestressing, whereas in full span method only lifting and installation of the precast units are required.

The full span units are transported from the casting yard to the erection site using trailers of two carrier platforms to support rear and front ends of the U-girders (Figure 12). The articulated trailer with hinges between U-girder and platforms, can negotiate sharp radius (about 40 to 50 m).

Different lifting methods can be used for full spans: For instance, lifting by cranes or by a lifting device fixed on top of pier. The Airport Link uses traditional launching girder method (Figure 13), as used in segmental construction.

The launching girder is utilised to lift the 2 precast U girders

Figure 13. View of Launching girder equipment

Figure 15. View of precast pier cap

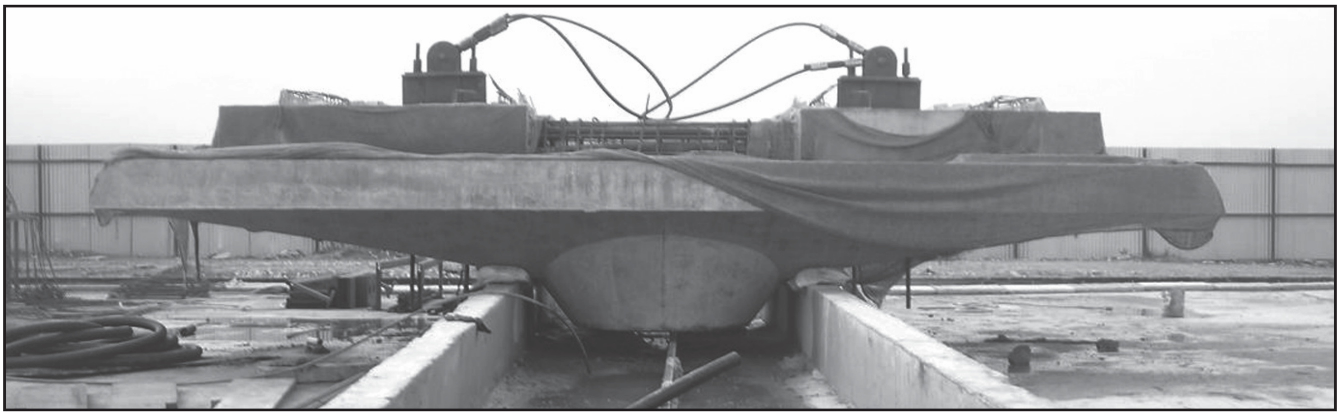

Figure 15. View of precast pier cap

from one side on to the top of pier cap as depicted in Figure 13.

Although this method requires launching of the lifting equipment, it is fast. The erection cycle is 1-day per span compared to 3 days in the case of segmental construction.

Another innovative feature of viaduct design

Further reduction in construction time has been possible on the Airport Link because the use of precast pier cap instead of cast-in-situ construction.

Generally, pier caps are cast-in-place on formworks supported by trestles on ground (Figure 14).

On the Airport Link viaducts, the pier caps are precast in the same casting yard as U-girders. Then these are transported to the site. However, before connecting to the pier top by reinforced concrete connection, geometrical adjustments are made (Figure 15).

The casting cycle of the pier cap at casting yard is about 1 day per casting cell. At site, however, optimal erection cycle is about half day per pier cap.

Conclusion

Constructing full spans and pier caps in casting yards permitted optimisation of the project time and cost of structures. It also introduced more reliability and safety to the project. This was because the construction was performed in a controlled environment.

Although the solutions were innovative, the methods of construction remained simple. In manyways, constructing full span U-girders is simpler than the standard segmental construction.

The solutions developed and implemented on the Airport Link viaduct use precast full spans for the deck. Precasting pier caps is one more step towards industrializing construction of long elevated viaducts for rail or road infrastructure.

Mr. Mangu Singh, a civil engineer, is presently Director (Works), DMRC Ltd. He was involved in the construction of the Kolkata Metro and the underground works of Delhi Metro's Phase-I. He was responsible for the overall planning, design and execution of the High Speed Airport Express Line from New Delhi Railway Station to Indira Gandhi International Airport. Mr. Singh is also responsible for various consultancy works undertaken by DMRC for planning of Metro systems in Mumbai, Chennai, Hyderabad, Kolkata, Kochi, etc. Presently, he is Director (Works), DMRC.

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