Aesthetics and technologies for urban bridges

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It is highly essential that a bridge needs to be aesthetically pleasing, blending well with the surroundings. Particularly, in the case of bridges in urban areas, construction needs to take place without disrupting traffic. In this paper, the author highlights both the aesthetics and technological aspects in the design and construction of a few urban bridges in Delhi.*

During the past, mere construction of facility was given importance; its impact in surrounding was considered insignificant. Time has now come to think in a different fashion while constructing in cities. The form, size and shape of the structure are of great significance. The construction need to be carried out without slowing or shutting down any activity. As a matter of fact, the structural conception and the selection of construction technology must primarily be driven from these aspects.

The paper demonstrates how these important considerations were implemented in some of the noteworthy urban bridges.

*Selected for reader interest. The paper was presented at the 3rd international conference on "New dimension in bridges, flyovers, overpasses and elevated structures", Singapore and is republished with minor editorial changes, with prior permission from CI-Premier Pte Ltd, Singapore.

Planning

In the planning of most bridges in urban environment, physical constraints above and below ground are the main challenges. The geometry, length and width of the structure as well as location and shape of sub-structure and configuration of foundations may not be ideal from the functional or structural point of view, but is dictated by existing or planned facilities or buildings.

While the above ground physical constraints can be visualised in advance and hence taken into account in the planning stages, the location and identification of underground services criss-crossing below pose serious problems.

A number of utility agencies are involved in the establishment and running of the city's underground services and the records, if available with them, are usually incomplete. Efforts on the detection of underground utilities can best be met with limited success. Since "uncharted" utilities can be encountered without warning, the design should be flexible enough to cater to such eventualities.

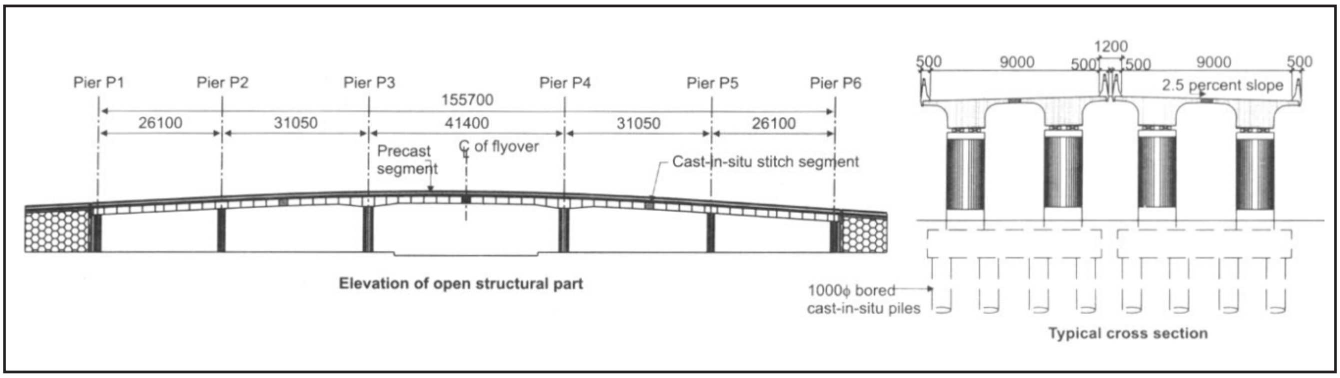


Figure 1. The concept GAD used for flyovers in Delhi

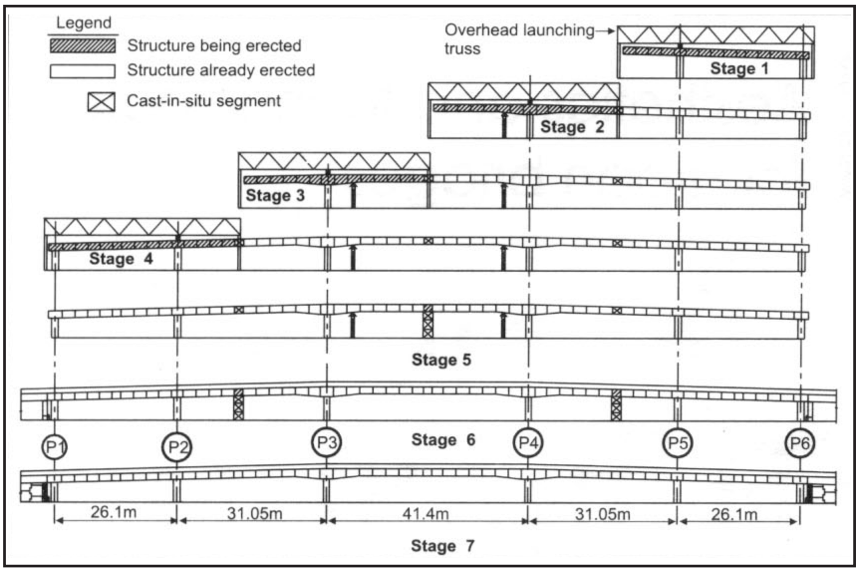


Figure 2. Erection sequence for a typical sub-bridge

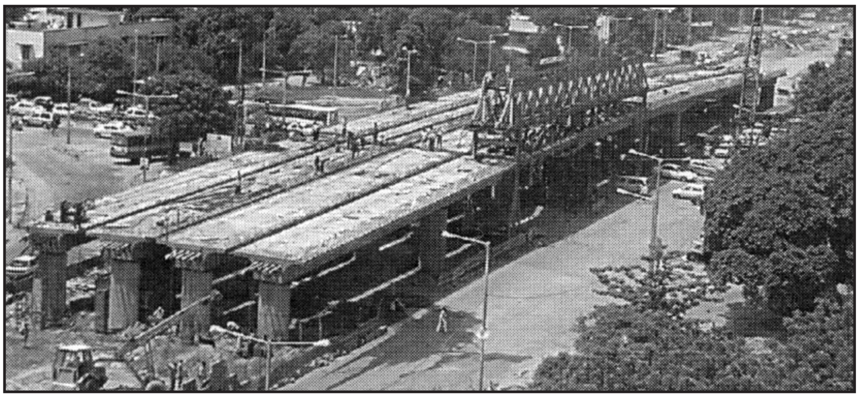


Figure 3. Precast segmental flyovers in Delhi: Erection of four independent sub-bridges in progress

Environmental impact

Due to its sheer size and importance in sociological terms, a large structure looms prominently in the public consciousness. Implanting a large and permanent structure within the existing environs has significant repercussions, often with considerable detrimental effects. A bridge must necessarily perform two functions : a utilitarian one permitting traffic to cross over obstacles and, an aesthetic one which enhances the quality of the environment. No hard and fast rules can be laid down on concepts of beauty and aesthetics as they come in the realm, not so much of logic and rationality, as in the sphere of perception and feeling. However, human beings do have a deep sensibility to their surroundings, which affect their mental and physical well-being.

The form, size, shape and texture of the elements of the bridge are of paramount importance as the structure is likely to be viewed from various angles, from varying distances, and at different times of day and night. Fast construction with minimum disturbance to existing traffic is the key to reduce environmental impact during construction and must form the most important element in the selection of design concepts and construction technology for urban bridges.

Precast segmental flyovers for Delhi

Precast segmental technique was used for the flyovers constructed for Delhi Government. Aesthetically-elegant solid rectangular girder shaped elements were employed for the six lane flyovers. The elements weighed only 30 t and required trusses weighing as little as 50 t for their erection. The recently opened flyovers won in open competition and include:

1. two important crossings on Ring road
2. two important crossings on Outer Ring road

Two more similar projects have been taken up for implementation on the Ring road.

Four spine beams constitute the superstructure, Figure 1. The open length of the flyovers is a five-span continuous structure having spans of (26.1+31.05+41.4+31.05+26.1)m with expansion joints located at the two end abutments. Each spine beam is first completed as an independent unit named as "sub-bridge" as shown in Figure 2. The effective erection cycle per sub-bridge is about four weeks. In the next step two sub-bridges on either side of the centre-line of the flyover are joined together, Figure 3, with 600 mm wide cast-insitu longitudinal

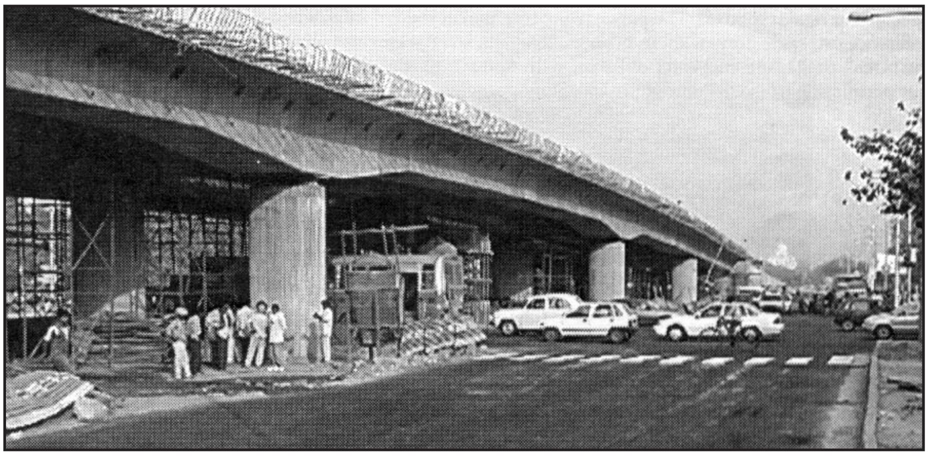


Figure 4. Precast segmental flyovers in Delhi: Traffic below the flyover was not interrupted during construction

Figure 5. Clover Leaves at ITO Delhi: The sharply curved clover leaves connect the central artery (Vikas Marg) to the existing IP estate flyover

stitch followed by transverse prestressing at the deck slab level thus forming a "restricted" three-lane 9-m wide carriageways for both up and down traffic. For the erection of precast segments at site, a two-span assembly girder, Figure 2, is used which has two parallel triangular trusses provided with hangers to hold the segments during assembling. The segments are joined with epoxy glue while temporary prestress is applied across each joint. The permanent prestress consisted of a maximum of 12 cables of type 1906 (19 strands of 15.2 mm) per sub-bridge. Special architectural engineering features include a slim superstructure (span/depth ratio of 27.6) and elliptical piers with textured surface of vertical fluting. It is noteworthy that traffic below the flyovers could be maintained uninterrupted during construction as shown in Figure 4.

Interchanges at chronically congested traffic intersections

The ITO, Dhaula Kuan and AIIMS-Safdarjung crossings in Delhi are notorious for their congested, polluted and accident-prone characteristics. These intersections are being re-modelled with new constructions, which include complex bridges where architectural engineering has been given high priority.

The Clover Leaves project at ITO

This structure located at ITO, Dhaula Kuan, is an unusual concrete structure, which has met challenges of design, construction, performance and quality by utilising advanced techniques of design and construction. The project comprises of two independent loops of 11.9 m width each, Figure 5, catering to three-lane one way traffic. They connect the existing IP Estate flyover at their high points and to the central artery (Vikas Marg) at their low points. The total length of the elevated clover leaves is 513 m. A sleek low profile continuous 4-span structure (4 x 25 = 100 m) with a prestressed voided slab section for each structure was selected after a critical analysis of the several possible alternatives. Through innovative concepts it. was possible to incorporate the following unusual features:

1. sharply curved geometrics (radius 48 m) to suit site constraints which generated a tilted deck with crossslopes of up to 7 percent.

2. low height of piers, which precluded the use of pier cap from aesthetic considerations, Figure 6.

3. reductions in superstructure depth so as to achieve a span/depth ratio of 20 to create a slim deck.

4. connection of clover leaves with the existing flyover by separate structural element which integrated the two structures architecturally.

The Dhaula Kuan Interchange

This interchange, located on the main artery leading from the airport to the city is one with intricate highway geometry with

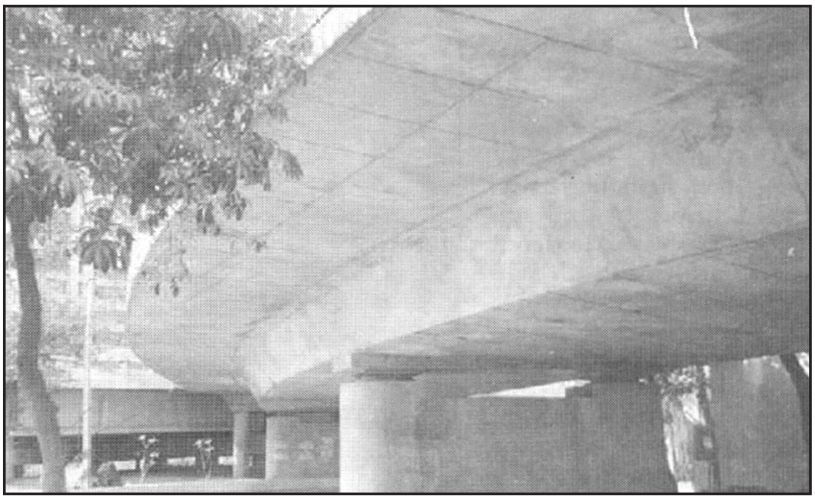


Figure 6. Clover Leaves at ITO in Delhi: Voided slabs prestressed deck on capsule shaped piers

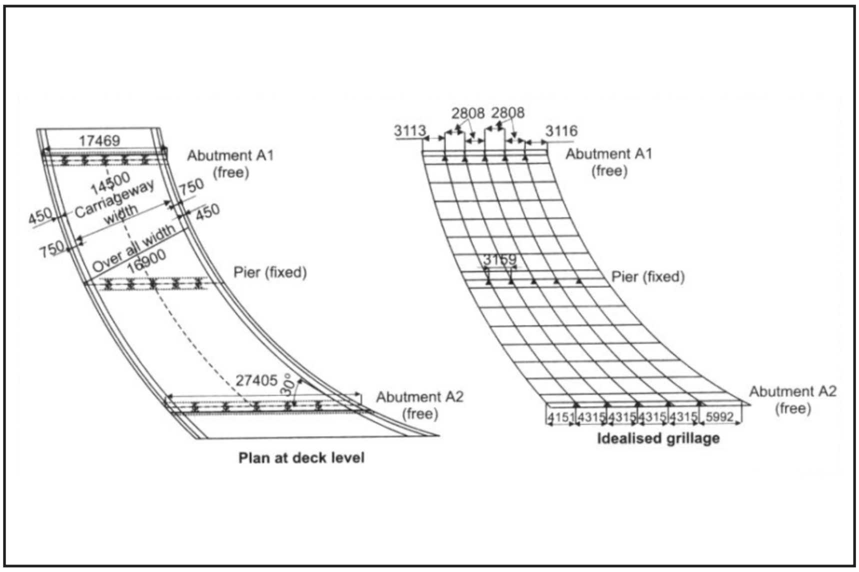


Figure 7. Dhaula Kuan interchange at Delhi: Curved-cum-skew bridges (cast-insitu solid slab)

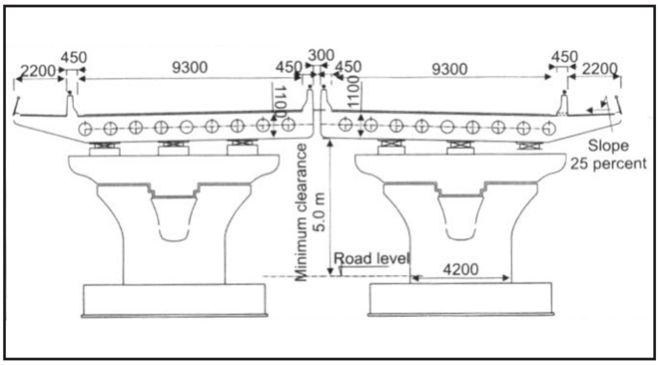


Figure 8. Dhaula Kuan interchange in Delhi: Straight bridge (cast-in-situ voided slab)

five roads meeting at the junction. It consists of one straight bridge and two curved-cum-skew bridges. The two span curved-cum-skew bridges have complex geometries in plan and consist of solid prismatic concrete section, Figure 7, which also depicts the structural idealisation adopted. The straight bridge, on the other hand, is of variable depth, cast-in-situ voided slab construction shaped much like the wings of aircraft, Figure 8.

The main structures of the Safdarjung interchange comprise of a five-span curved bridge (central span 28.3 m) and a 4-span skew bridge, both straddling across a main artery (Aurobindo Marg). The variable depth cast-in-situ solid slab continuous superstructures are constructed with careful planning of traffic diversions during construction. Specially designed blisters prevent dislodgement of the superstructure during a severe earthquake. The final appearance of the curved bridge is depicted in Figure 9.

Structures of Delhi Metro

Fast track elevated MRTS construction includes 14-km long viaduct snaking through the most crowded part of the city. It includes precast segmental viaduct, incrementally launched bridge over river Yamuna, integral bridge with a 70° skew and large span crossings at important roads. The world famous state-of-the-art 200-km long Delhi Metro, planned to be completed in phases upto 2020, will alleviate the many woes of the citizens and improve the quality of their lives.

The two-track precast segmental viaduct consists of simply supported standard spans in the range 21.1 m to 29.1 m. The construction technique enabled transportation of the typical small 2.5-m long match cast segments weighing 40 t to 50 t without difficulty through crowded streets and their eventual erection using overhead and underslung launching trusses. The segments were epoxy-bonded at interfaces and prestressed using 19K15 tendons. Figure 10 shows the finished structure where the MRTS alignment moves from the side of the road to the central verge; portals and inverted L-shaped piers were required at such locations. Striking appearance of the streamlined box section and pleasant form of the sub-

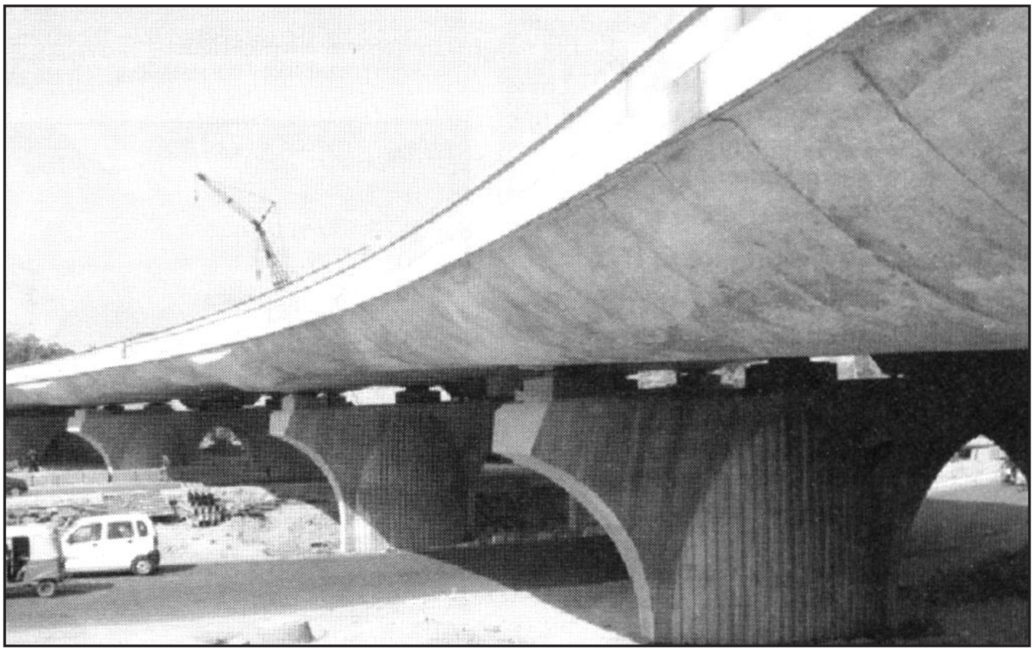


Figure 9. AIIMS-Safdarjung crossing; note the streamlined shape of deck and architecturally shaped piers

Figure 10. Precast segmental viaduct for Delhi Metro; note that the portals and different pier shapes were required as alignment traverses from side of road to its centre

structures, Figure 11, were special features of the viaduct. The 650 m long Yamuna bridge is founded on wells (caissons) that are sunk about 40 m from the bed level down to firm strata, Figure 12. The box girder superstructure supporting the two tracks of the MRTS was incrementally launched from the East Bank over 12 x 46.2 m = 554.4 m length, employing a temporary steel nosing in front, Figure 13. Typical segments were cast in 23.1 m lengths and "pulled" by the same amount by using two synchronised jacks of 500 t capacity each. Special architectural engineering studies were conducted to arrive at the correct proportioning and shape of the visible elements, that is, the deck and the piers.

It is accepted now that the best arrangement for bearings and expansion joints of moderately long concrete bridges is that in which these elements are absent. This statement is not only true from the point of view of aesthetics but also from purely engineering considerations. Improved durability, maintenance-free character and enhanced seismic resistance are the main advantages that can accrue to the project by what are called "integral bridges". A rather difficult bridge from the point of view of its geometrics was conceived for curved flyover located about 2 km east of the Yamuna bridge on the MRTS. The flyover is an "integral" bridge, that is,

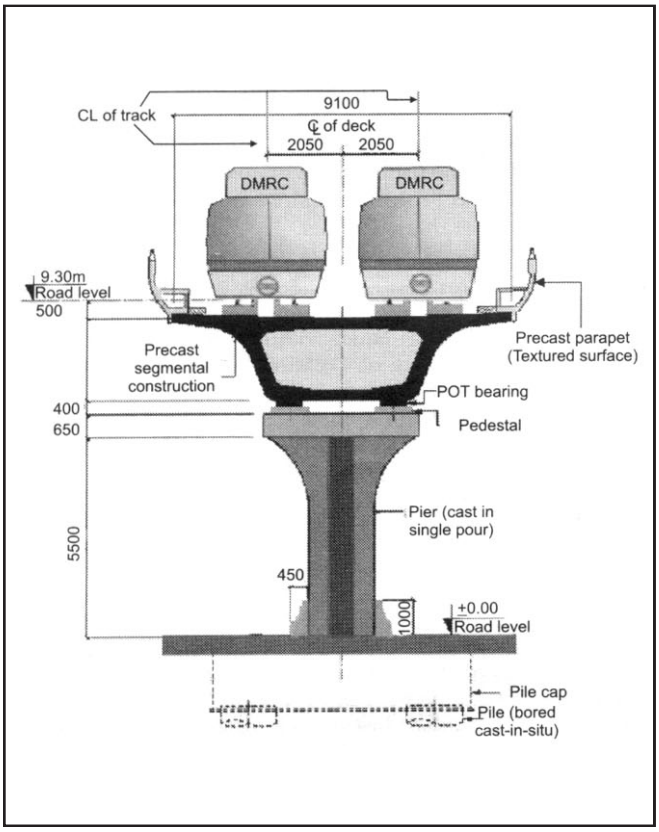


Figure 11. Delhi Metro viaduct: Structural engineer's impression

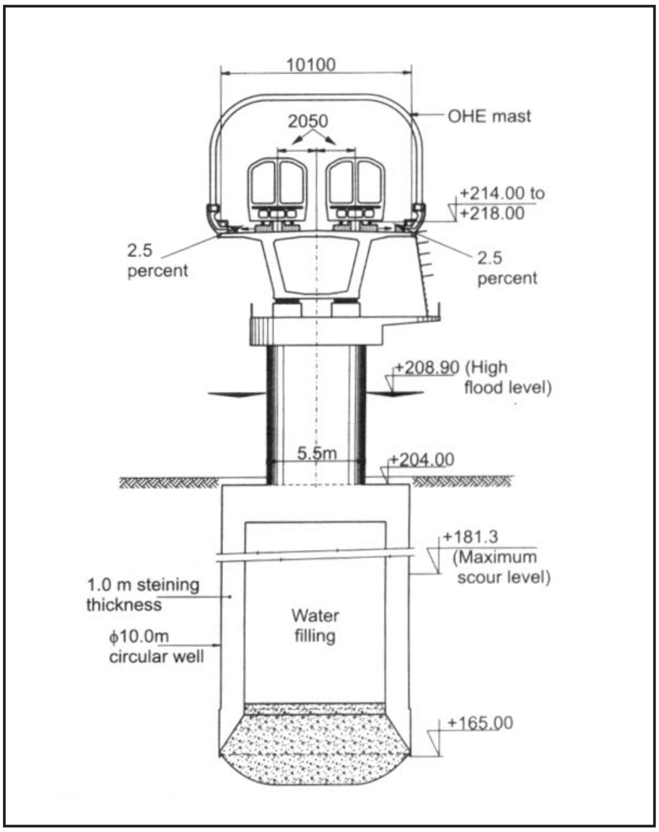


Figure 12. Yamuna bridge for Delhi Metro: Typical cross section

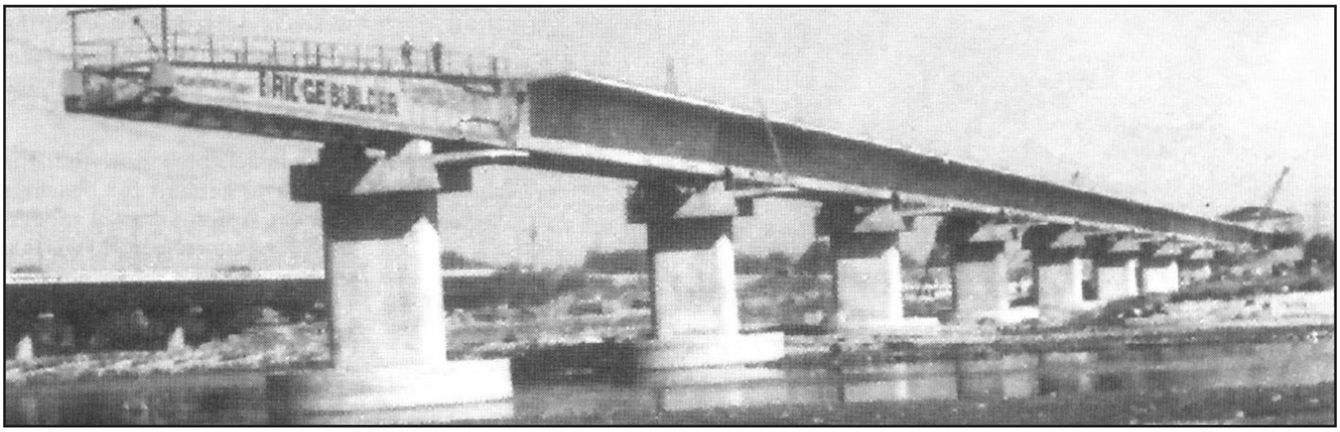


Figure 13. Yamuna Bridge for Delhi Metro: Superstructure (554.4-m long) being incrementally launched

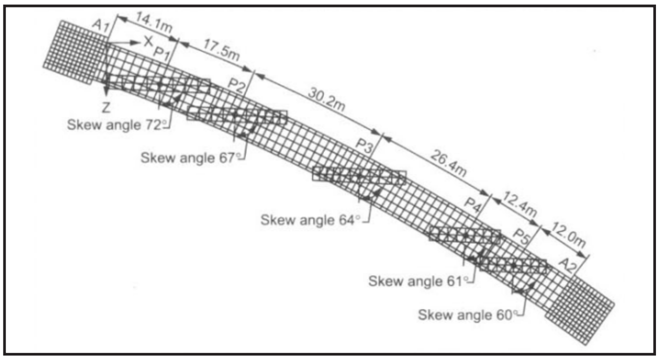


Figure 14. Flyover using "integral bridge" concept for Delhi Metro: Structural idealisation in plan

the piers and abutments are monolithic with the deck thereby eliminating the bearings as well as the expansion joints. The six-span curved bridge of 117 m length has a very large skew (varying from 72 degrees at one abutment to 60 degrees at the other).

Figure 14 shows the structural modelling of the deck and that of the full structure, while Fig 15 shows the construction nearing completion. Of particular interest is the fact that the structure is not assumed as fixed at the foot of the piers and abutments but that the pile cap and piles are included in the idealisation.

The soil resistance is idealised by springs of appropriate stiffness. This type of structural modelling ensures that the creep, shrinkage and temperature rise/fall, all of which are of considerable significance in an "integral" bridge can be taken into account in a realistic manner. Seismic forces in longitudinal direction and earth pressures on abutments can thus be transmitted to all elements of the "integral" bridge structure with a good simulation of the actual situation.

The highly indeterminate structure would result in improved seismic performance as compared to conventional bridges with bearings and expansion joints. The textured surface of the abutment and return walls combined with the circular free standing piers were specially conceived to improve the visual impact of the bridge.

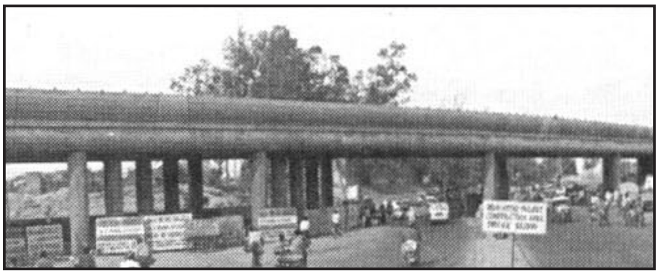
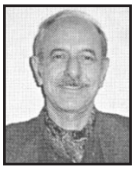


Figure 15. Flyover using "Integral bridge" concept for Delhi Metro; the curved flyover has 70° skew and has no bearings or expansion joints on piers/abutments as depicted in the picture

Conclusion

An urban bridge should always be an aesthetically-pleasing structure and not an ugly structure sticking out like a sore thumb. It must be elegant, graceful, beautiful - a poem in concrete — that merges so smoothly in its milieu as to enhance the environment instead of detracting from it. A well-designed, well-constructed aesthetic bridge not only brings joy to its users, but activates their civic pride and motivates them to protect it against any wanton vandalism of its more vulnerable elements.



Prof Mahesh Tandon is the Managing Director of Tandon Consultants Pvt Ltd and a distinguished visiting professor of Indian Institute of Technology (IIT) at Kanpur and Roorkee. He is a Fellow of the Indian National Academy of Engineering , and is a member of its Governing Council. He is the Chairman of the National Information Centre for Earthquake Engineering at Indian Institute of Technology, Kanpur. The design of Delhi Metro's important structures like incrementally launched bridge over river Yamuna, precast segmental viaduct and integral bridges at GT Road are credited to Tandon Consultants Pvt Ltd. Noteworthy building projects presently include the Indira Gandhi National Centre for Arts in New Delhi, the Khalsa Heritage Memorial Complex at Anandpur Sahib, Punjab and Station Buildings of Delhi Metro. Amongst the awards received by Prof Tandon are those given by Institution of Engineers (India), Indian Roads Congress, Indian Institute of Bridge Engineers, Indian Concrete Journal, Association of Consulting Civil Engineers, Alumni Association of College of Engineering Pune, etc.

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