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Artikel: Design and detailing for durability: concrete subways and underpasses

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Design and Detailing for Durability – Concrete Subways and Underpasses

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Summary

Durability of structures refer to its ability to endure weathering action, attack by various substances and conditions to which it may be exposed over the serviceable life. Many of the conditions that cause structures to lack durability, are not immediately apparent. Basic causes are attributable to input of harmful materials, aggressive environment or inappropriate design, detailings or construction. This paper discusses design and detailing features for pedestrian and vehicular underpasses, under construction, to improve durability aspect. As such, approach to design and detailing for three cases of subway/underpass projects in India, was to design for durability, faster implementation and simplied construction technique. Projects discussed in this paper are pedestrian subway at Rajagarden, integrated pedestrian & vehicular underpass at Punjabi Bagh in Delhi and underground mass rapid transit system, in Calcutta.

1. INTRODUCTION

Electrically operated intracity Mass Rapid Transit System, whether underground, at grade or elevated is rare in India. Such facilities, to a limited extent, have been built very recently in few cities and some are still in planning/implementation stages. At present transport system in India, primarily cater for motorised vehicles both for mass and individual transport. Most of the major intersections and corridors of the major cities in India are very congested. To ease such congested situations, transport authorities are planning for multilevel grade separators for pedestrian and vehicular movements and also to increase the average speed of movement. Such grade separated movement warrants pedestrian subway, or vehicular underpass. Their planning and design however need to cater for existing underground utilities, narrow roads, lack of space for traffic diversion ground water table etc.

In spite of appropriate and detailed implementation planning and schedules, with cast-in-situ construction, pedestrian subways need at least twelve months for completion, which is too long a period to have restricted traffic movement in an intersection. In order to minimise the traffic hindrance, reduce construction period & on site activities, to improve the quality of construction, etc, the use of prefabricated concrete elements has been introduced for Rajagarden pedestrian subway at Delhi as shown in **Fig. 1**.

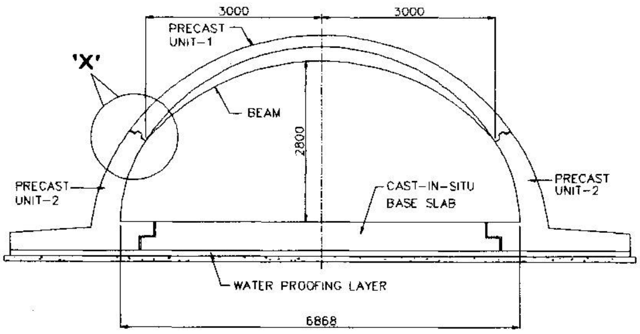


Fig. 1 : Precast Subway showing different Units

For the construction of Punjabi Bagh underpass or for that matter the construction of Calcutta Metro, use of modern systems e.g. TBM or NATM might have been a better choice particularly to maintain normal traffic movement during construction. However, as construction using TBM or NATM is very expensive and need capital intensive equipments, cut and cover technique are more favoured bothfor vehicular underpass or metros.Out of the different forms of temporary/permanent walling, diaphragm wall has been used predominantly.

For underpasses in Delhi or Metro in Calcutta being constructed or constructed, diaphragm walling have been used not only to facilitate other construction activities but also to bear load either in partial or/in total as the case may be i.e. semi-integrated or integrated as shown in **Fig. 2** and **Fig. 3.**

Parameters for design, detailing and construction works method have been carefully selected in these designs and are briefed in the following sections.

2. CONSTRAINTS AND APPROACH

During the planning for design and construction of these structures, number of constraints were taken care of proper implementation as :

- High ground water table
- Existing major underground utilities
- Limited space available for construction in busy traffic corridor

- To keep the intersection traffic moving during construction phase
- Minimise construction time to open the carriageways as soon as possible for the convenience of traffic.

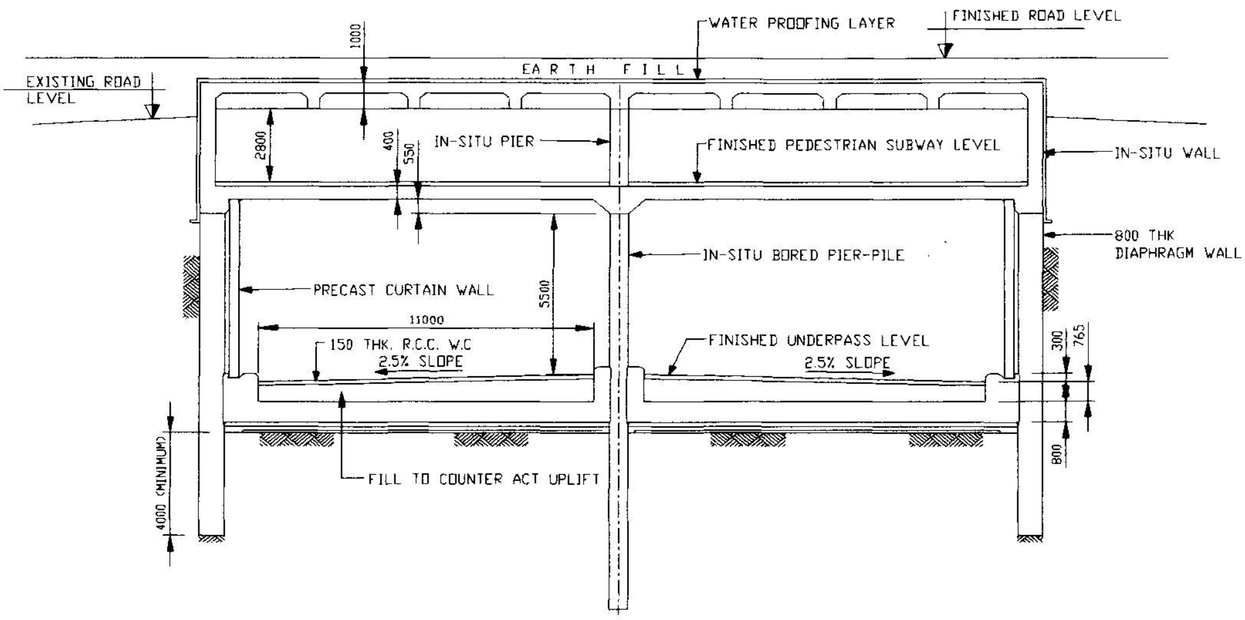


Fig. 2 : Cross Section of Underpass and Pedestrian Subway at Intersection

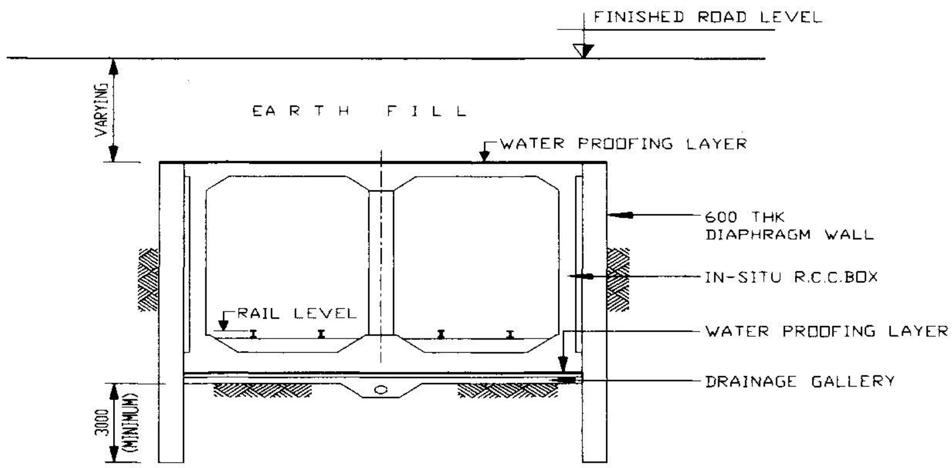


Fig. 3 : Cross Section of Metro : Non-Station Portion (Semi-Integrated Approach)

In addition, as these underground structures, with a high ground water table warrants dry condition inside the underpass or subway, for serviceability and user's comfort, the following aspects were also taken care in the design:

- Water tight joints & adequate water proofing treatment
- System of draining out the seepage and/or rain water from open areas
- Adequate ventilation, forced or natural, particularly for pedestrian subway

Considering the constraints stated above and also the small length of such subways or underpasses, the design and construction methodology adopted, caters for faster implementation without capital cost intensive equipments, minimum possible hindrance to traffic movement during construction and water tight structures to the extent possible including appropriate drainage system.

3. PEDESTRIAN SUBWAY

As discussed earlier, for faster implementation with minimal capital investment on equipment to make the project cost effective and to ensure quality and durability, prefabricated reinforced concrete element has been used for the pedestrian subway and the design considered following important aspects :

- Excavation in stretches to allow traffic movment along the road
- Form to suit for structural stability, drainage, light weight and cost effectiveness
- Element Size to suit transportation and handling
- In-situ concrete base to ensure water tightness
- Proper integration between precast concrete elements and cast in situ elements
- Matching of individual precast element and design of joints both for installation tolerances as well as water tightness
- Appropriate drainage arrangement
- Provision against buoyancy

The pedestrian subway is approximately 40 m long with central opening. Subway form designed as catenary mainly comprising of precast element (**Fig. 1**). The top precast unit (unit 1) was provided with a central diaphragm of varying depth for handling facilities. However for future subways this beam is proposed to be excluded as these ribs create hindrance for installation of lights and electrical cable ducting.

As elaborated in **Fig. 4** the joints have been detailed for easy matching installations with provision for water tightness. **Fig. 5** gives the details of match installation of the precast units in longitudinal directions with provision for water tightness.

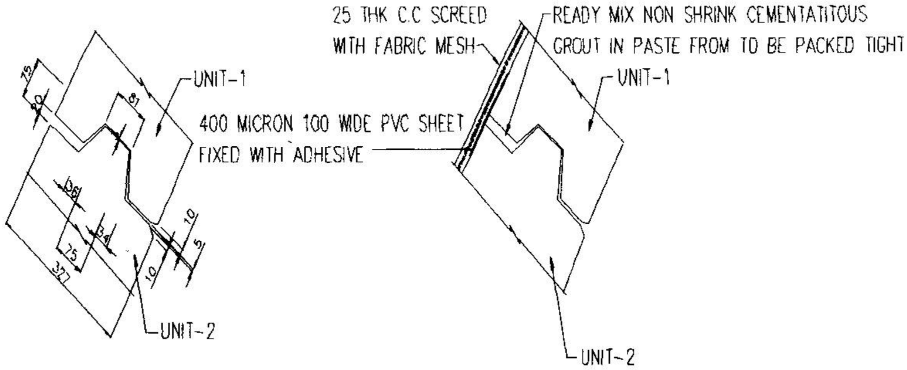


Fig. 4 : Detail `X' (Ref. Fig.1)

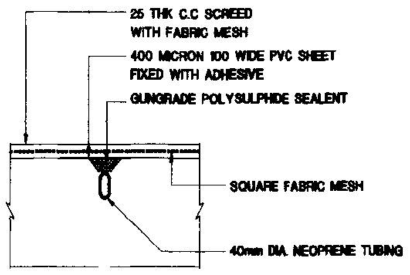


Fig. 5 : Typical Joint between Precast units in Longitudinal Direction

Fig. 6 indicates the methodology of water tight integration of the longitudinal subway at its ends with the approach stairs in the perpendicular direction.

For the integration of the bottom slab with the precast unit (**Fig. 1** and **Fig. 7**), the same has been shaped and detailed such that the connection can be treated as hinge with provision for rotation of the ends of the bottom slab at its ends. The reinforcement detailing has been done to ensure the hinge behaviour.

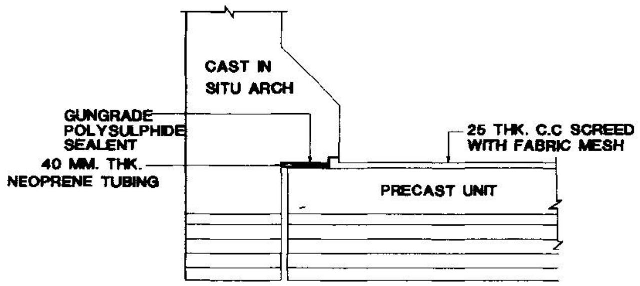


Fig. 6 : Details of Joint between Precast Unit and Cast-in-Situ Arch

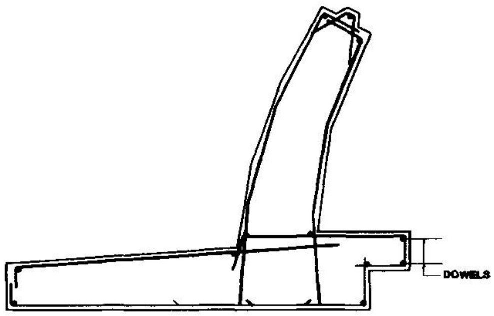


Fig. 7 : R C Details of Unit - 2

Number of prefabricated elements being small, precasting of the elements are done near the site to avoid long/distant travel during transportation. As such elements can be easily transported by a mobile crane and each element can be easily installed in proper place with integration of the other elements. Use of various methods as detailed in sketches ensure water tight subway. However provision for a sump with pumping arrangement has been kept for draining out of the rain water that will pour inside the subway through the open approaches.

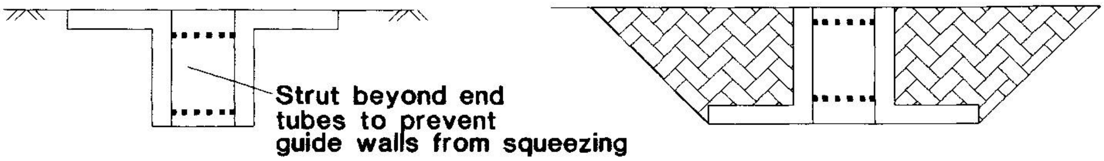
4. UNDERPASS

As mentioned earlier, the cases considered are Calcutta Metro and integrated pedestrian and vehicular underpasses in Punjabi Bagh, New Delhi. As the design approach for both the cases are more or less similar except the changes required for functional performance as semi integrated and fully integrated structural system. The important aspects which are directly related to the serviceability and durability are described in the subsequent sections.

4.1 Guide Walls

The guide walls are not an integral part of the underpass system, yet they are important in excercising control on the construction of the diaphragm walls. The guide walls should be heavy with appropriate depth and contractor should take proper care of the compaction of filling after completion of the guide walls. Accordingly, the design of the guide walls in both the cases are to consider the following aspects :

- Appropriate depths to avoid excessive and cavity formation
- Due consideration to ground water table
- Appropriate head of bentonite slurry with proper viscosity and gel strength
- Avoid movement of the guide walls to ensure verticality of diaphragm wall
- Proper orientation of the guide wall as shown below



Alternative A

Alternative B
(Preferred alternative)

Fig. 8 : Guide Walls

Accordingly, the depth of guide walls in the range of 1.2 to 1.5 m have been adopted.

4.2 Panel Width

Concrete diaphragm walls are generally constructed in panels, wherein each panel acts as an independent unit. While selecting the size of the panel width in both cases the Calcutta Metro with clayey strata and Punjabi Bagh underpass with granular strata, attempt was made to mobilize the strut forces as per the design load.

The panel width has been kept to a size so that one row of horizontal strut only for each panel will be sufficient for the safety of excavation. However the panel width can not be less than the single bite widths of grab. Panel width of approx. 3 m has been found to be cost effective and technically optimum.

In addition, while selecting the size of the panels, the following points had been considered :

- Continuous diaphragm walls need Robust shear connectors which are difficult to provide.
- Concreting have to be completed before the setting or significant stiffening of the panel (Not more than 3 to 3 ½ hours)
- Removal of stop-ends before the concrete is set.
- To reduce the formation of shrinkage crack (Though the curing is under humid conditions the longer panel lengths will be subjected to shrinkage effects)
- Safety of the excavated trench and easy handling of the reinforcement cage.

4.3 Water Tightness

Diaphragm wall are subjected to both soil and water pressures and thereby impermeability of wall panels is of great concern for durable structural system. The various factors affecting the water tightness are :

- Quality of the concrete with regard to maximum aggregate size and water cement ratio (20 m aggregate & w/c ratio 0.6)
- Formation of cracks particularly for longer panels

- Leakage from the joints attributable to differential deflection between the panels
- Semi circular vertical joints at ends of each panel

Sometime shear transfer devices are used to help in reducing the differential deflection between consecutive panels and thereby improves water tightness. But to provide shear connector between two panels is difficult and combersome. Accordingly, in most of the underpasses or metro, water has been allowed to seep through the joints.

The leakage through joint was not critical for Calcutta Metro as the water tightness was ensured through second wall. While in Delhi, cement grout has been proposed at the back of the joint to ensure water tightness to the extent possible as shown in **Fig. 9**. In addition an elaborate arrangement for drainage has been made to keep the underpass dry, serviceable and durable as shown in **Fig. 10a** and **10b**.

4.4 Buoyancy

As the ground water table is very high in both the cases the structure had to be designed to resist the uplift due to buoyancy forces. In Calcutta Metro this was not critical in most of the stretches excepting the station areas, primarily due to overburden on top of the box as shown in the figure.

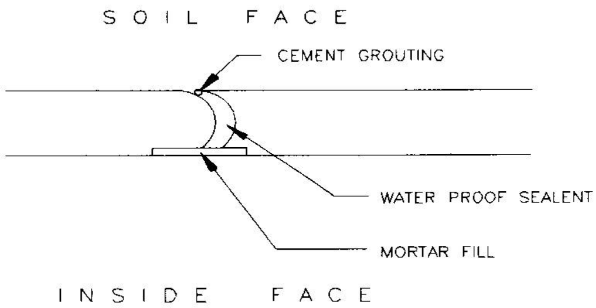


Fig. 9

In case of Punjabi Bagh underpass the uplift becomes highly critical particularly in open to sky approaches due to the absence of adequate over burden. Alternative approaches has been considered to ensure stability

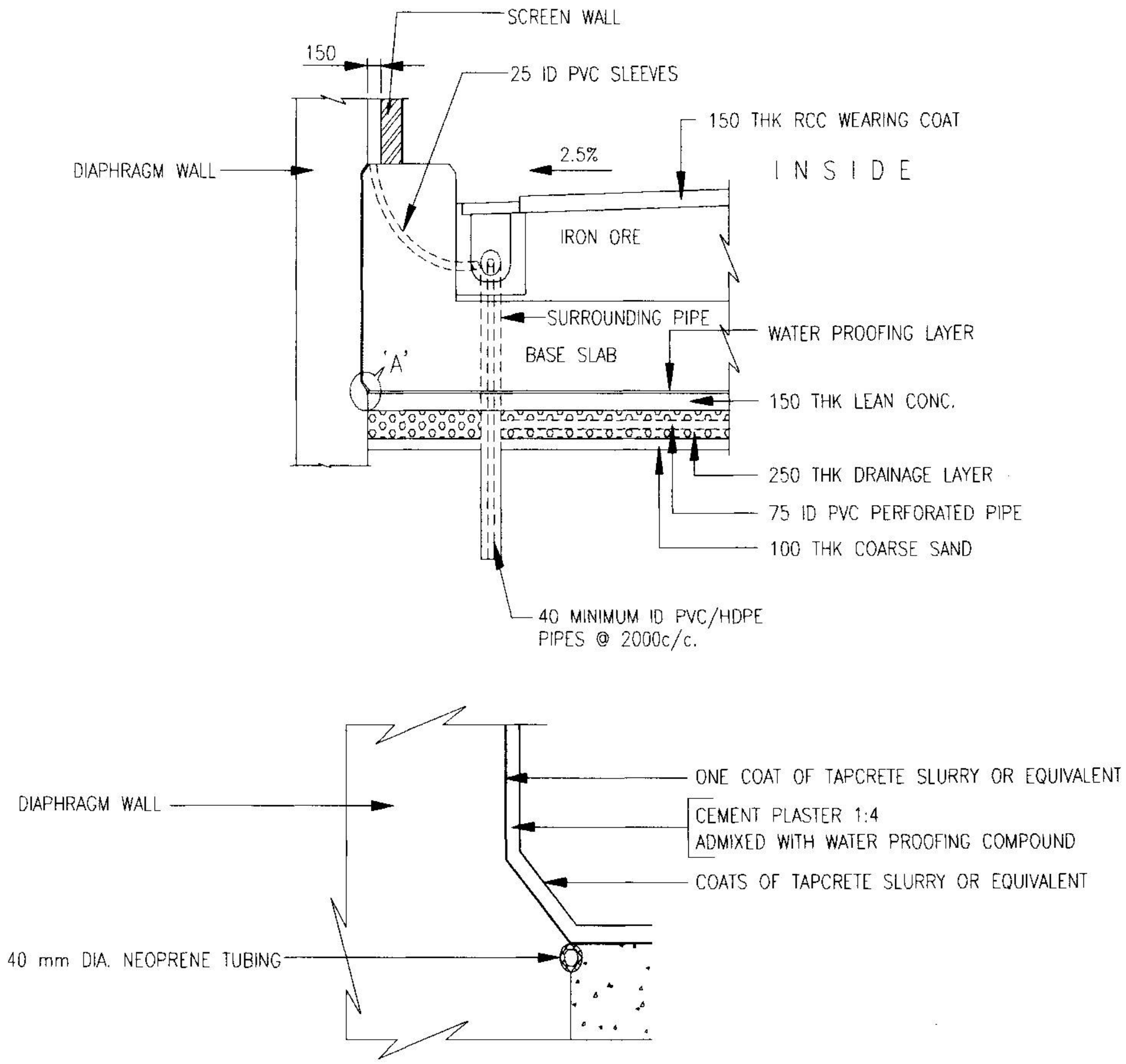
- To put additional weight in the form of iron ore filling
- To provide tension piles to resist the uplift forces.
- To release the water pressure by providing suitable collection of underground water and draining thereof.

Each systems has its own merits and demerits though the authors favour the combination of the last two

4.5 Reinforcement Details

The design and detailing of the reinforcement caging shall take into consideration the following aspects :

- Smooth bar bending with adequate cover
- Bar placement to avoid the trapping of bentonite slurry
- Proper securing of the insert boxes avoiding any protusion
- Appropriate detailing to cater for the handling



DETAIL 'A'
DETAILS OF DRAINAGE SYSTEM FOR UNDERPASS

Fig. 10a and 10b

5. CONCLUSION

Experience shows that improvements in standard of controls has a direct effect on improving the standard of the finished product and thereby its durability. Thus the various aspects concerning the durability, serviceability of the specific project shall be detailed out at the project conception stage prior to design and detailing.