CHAPTER 5

CIVIL STRUCTURES & CONSTRUCTION METHODOLOGY

5.0 CHOICE OF SUPERSTRUCTURE

5.1 The choice of superstructure has to be made keeping in view the ease of constructability and the maximum standardization of the form-work for a wide span ranges.

5.2 Following type of superstructures have been considered:

(i) Precast segmental box girder using external unbonded tendons.
(ii) Precast segmental U-Channel superstructure with internal pre-stressing.

The segmental construction has been chosen mainly due to the following advantages:

- Segmental construction is an efficient and economical method for a large range of span lengths and types of structures. Structures with sharp curves and variable superelevation can be easily accommodated.
- Segmental construction permits reduction of construction time as segments may be manufactured while the substructure work proceeds, and assembled rapidly thereafter.
- Segmental construction protects the environment as only space required for foundation and sub-structure is required at site. The superstructure is manufactured at a place away from busy areas and placement of superstructure is done with the system erected from piers at heights.
- Segments are easy to stack in the casting yard/sticking yard in more than one layer, thereby saving in requirement of space.
- It is easier to transport smaller segments by road trailers on city roads.
- It is easy to incorporate last minute changes in span configuration if the site situation so warrants.
- Interference to traffic during construction is significantly reduced.
- Segmental construction contributes towards aesthetically pleasing structures and good finishes.
- The overall labour requirement is less than that for conventional methods.
- Better quality control is possible in the casting yard.
- During construction, this technique shows an exceptionally high record of safety.

5.3 COMPARATIVE ADVANTAGES/DISADVANTAGES OF THE TWO TYPES OF SUPERSTRUCTURES EXAMINED ARE GIVEN BELOW :

5.3.1 Segmental Box Girder

This essentially consists of precast segmental construction with external prestressing and dry joints and is by far the most preferred technique in fast track projects. In such construction the prestressing is placed outside the structural concrete (but inside the box) and protected with high density polyethylene tubes which are grouted with special wax or cement. The match cast joints at the interface of two segments are provided with shear keys as in traditional segmental construction. However, epoxy is dispensed with because water tight seal at the segment joints is not required in association with external tendons. The schematic arrangement is shown at **Fig. 5.1**.

The main advantages of dry-jointed externally prestressed precast segmental construction can be summarized as follows:-

- Simplification of all post-tensioning operations, especially installation of tendons.
- Reduction in structural concrete thickness as no space is occupied by the tendons inside the concrete.
- Good corrosion protection due to tendons in polyethylene ducts; the grout inspection is easier and leaks, if any, can be identified during the grouting process.
- Simplified segment casting. There is no concern about alignment of tendons. Increased speed of construction.
- The elimination of the epoxy from the match-cast joints reduces costs and increases speed of construction further.
- Replacement of tendons in case of distress is possible and can be done in a safe and convenient manner.
- Facility for inspection and monitoring of tendons during the entire service life of the structure.

5.3.2 Segmental 'U' Girder

The single U type of viaduct structure is also a precast segmental construction with internal prestressing and requires gluing and temporary prestressing of segments. The match cast joints at the interface of two segments are also provided with shear keys. The main advantages for this type of structural configuration of superstructure are:-

- Built-in sound barrier.
- Built-in cable support and system function.
- Possibility to lower the longitudinal profile by approximately 1m compared to conventional design.
- Built-in structural elements capable of maintaining the trains on the bridge in case of derailment (a standard barrier design does not allow this)
- Built-in maintenance and evacuation path on either side of the track.

Although, there may be a saving in the construction time for segmental box girder option by almost one day but the 2nd option is recommended for Bangalore Metro considering the advantages as highlighted above, particularly, considering the fact that the 2nd option has inbuilt features such as top flange of 'U' Channel which acts as an evacuation path on either side of the tracks and also possibility to lower the longitudinal profile of the elevated viaduct. The schematic arrangement for this is shown in **Fig. 5.2.**

5.4 GENERAL

5.4.1 Two corridors, i.e. the East – West and the North – South have been proposed for Bangalore Metro. Both these corridors are mainly elevated corridors, located on the median of the roads. However, in the central business district area, these corridors will run underground with switch-over ramps for transitions from elevated to underground length. A small stretch is on the surface for each of the two corridors. The depot on the East – West corridor at Baiyappanahalli is on the surface while the depot at Yeshwantapur on the North – South corridor will be on elevated structures. The break-up of length (in meters) of the two corridors is given below:-

Corridors	Total	Elevated	Ramp	Underground	Surface
East – West	18100	13760	590	3400	350
North - South	14900	10500	800	3300	300

5.5 CONSTRUCTION METHODOLOGY

5.5.1 Surface Section of the Corridors

The surface corridors on the North – South alignment is of very small length and is limited to only Swastik Station and this can be combined with the construction of the station structure. However, the surface sections on the East – West corridor is adjacent to the depot and Baiyyappanhalli terminal station. Construction of these small sections is to be carried out as for any other railway embankment.

5.5.2 Elevated Sections of the Corridor

The elevated stretches are distinctly divided into 4 sections i.e. two on each corridor. Length of the elevated sections on the East – West corridor on west side, it is 6.97 Km & east side is about 7.38 km while on the North – South corridor, it is 6.45 km on the North side and 4.80 km on the South side. Thus the elevated sections can be constructed through 4 different contracts.

5.5.3 Pre-Cast Construction

For the elevated sections It is recommended to have pre-cast segmental construction for super structure for the viaduct. For stations also the superstructure is generally of pre-cast members. The pre-cast construction will have the following advantages:-

- Reduction in construction period due to concurrent working for substructure and superstructure.
- For segmental, pre-cast element (of generally 3.0m length), transportation from construction depot to site is easy and economical.
- Minimum inconvenience is caused to the public utilising the road as the superstructure launching is carried out through launching girder requiring narrow width of the road.
- As the pre-cast elements are cast on production line in a construction depot, very good quality can be ensured.

- The method is environment friendly as no concreting work is carried at site for the superstructure.

5.5.4 Casting of Segments

For viaducts segmental pre-cast construction requires a casting yard. The construction depot will have facilities for casting beds, curing and stacking areas, batching plant with storage facilities for aggregates and cement, site testing laboratories, reinforcement steel yard, fabrication yard, etc. An area of about 2.5 Hect. to 3 Hect is required for each construction depot (one per contract).

For casting of segments both long line and short line method can be adopted. However the long line method is more suitable for spans curved in plan while short line method is good for straight spans. A high degree of accuracy is required for setting out the curves on long line method for which pre calculation of offsets is necessary. Match casting of segments is required in either method. The cast segments are cured on the bed as well as in stacking yard. Ends of the segments are to be made rough through sand blasting so that gluing of segments can be effective.

The cast segment will be transported on trailers and launched in position through launching girders.

5.5.5 Launching Scheme

Launching girder is specially designed for launching of segments. The launching scheme is shown in the **figure No 5.3 to 5.8** Initially, the launching girder is erected on pier head at one end of the work. The segments are lifted in sequence as shown in the **Fig. No.5.3 to 5.8** and dry matched while hanging from the launching girder. After dry matching, the segments are glued with epoxy and pre-stressed from one end. The girder is lowered on the temporary / permanent bearings after pre-stressing. The launching girder then moves over the launched span to next span and the sequences continue.

5.5.6 Sub-structure

Sub-structure for the elevated section will consists of open foundations in rock area and pile foundations where soil is encountered or rock is more than 5 to 6 m below the ground level. It is proposed to provide 4 piles of 1200 mm diameter. A pile cap of thickness of about 2 m will be cast over the piles. It is proposed to keep the pile cap /open foundation top about 500 mm below the road level so as to provide necessary drainage from the viaduct and leave space for crossing of utilities if necessary.
Circular pier of about 1600 mm diameter is proposed to cast in single lift including pier cap to give good finish without any joint in the concrete. For protection of the pier from collision from moving vehicles on the road, a concrete guard is also provided around the pier up to a height of 1 m (GAD of elevated viaduct for standard span of 25m is shown at Fig. 5.1)

5.6 CONSTRUCTION OF THE STATIONS

5.6.1 It is proposed to construct the elevated stations with elevated concourse over the road at most of the locations to minimise land acquistion. To keep the rail level low, it is proposed not to take viaduct through the stations. Thus a separate structural configuration is required (although this may necessitate the break in the launching operations at each station locations)

5.6.2 Sub-structure for the station portion will be similar to that of viaduct and will be constructed in the same manner. However, there will be 3 rows of piers in the station area which will be located on the median and on foot paths on either side.

5.6.3 Super-structure will consist of 3 precast U Girders for supporting the track structure and I Girders / Double T Girders for supporting the platform and concourse areas. A pre-cast or cast-in-situ prestressed cross girder will be required over the middle piers for supporting the platform structure. L-shaped pre-cast cross girders are planned for supporting the concourse girders and escalators at mezzanine level. All the members will be pre-cast in the construction depot and launched at site through cranes.

5.6.4 On the East – West corridor, there are 14 elevated stations and on the North – South corridor, there are 10 elevated stations, it is proposed to have 3 contracts for East West Corridor and 2 Contracts for North - South corridor for the construction of the stations. Thus, a total of five contracts will be required. The required land for construction depots for these five contracts have been identified at the following locations:-

1. Km. 2.800 of EW Corridor 3 vacant plots opposite to BMTC Depot, right side of alignment.
2. Km. 5.699 of EW Corridor, 2 vacant plots, one on left & other on right side of alignment.
3. Km. 8.80 of the E-W corridor, one playground on right side of alignment.
4. Km. 5.864 of the N-S corridor inside the Binny Spinning mill of the Swastik Station.
5. Km 8.554 of the N-S corridor, two school premises on middle of the alignment.
6. Km. 14.194 of the N-S Corridor, open park on left side of alignment.

5.7 GRADE OF CONCRETE

It is proposed to carry out construction work with design mix concrete through computerised automatic batching plants with following grade of concrete for various members as per design requirement/durability considerations.

i)	Piles, Pile cap and open foundation	-	M -30
ii)	Piers	-	M -40
iii)	All precast element for viaduct and station	-	M -45
iv)	Cantilever piers and portals	-	M -45 M -60
v)	Other miscellaneous structure	-	M - 30

For all the main structures, permeability test on concrete sample is recommended to ensure impermeable concrete.

5.8 REINFORCEMENT AND PRESTRESSED STEEL

It is proposed to use HYSD 415 or TMT steel as reinforcement bars.
For pre-stressing work, low relaxation high tensile steel strands with the configuration 12 T 13 and or 19 K 15 is recommended (confirming to IS:14268).

5.9 ROAD WIDTH REQUIRED DURING CONSTRUCTION

As most of the construction is to be carried out on the middle of the road, central two lanes including median will be required for construction activities. During piling and open foundation work, a width of about 8m will be required for construction and the same will be barricaded. It is proposed that two lanes are provided for traffic on either sides during construction by widening of roads, if necessary. In certain cases, one way traffic may be resorted to.

5.10 UNDERGROUND CONSTRUCTION

Detailed geo-technical investigations have revealed that in the areas where underground tunnelling has been proposed, hard rock is not expected to be met except on the stretch from km 8.751 to km 9.018 on the Post Office Road where hard rock is approximately 8 m. below the ground level. The ground water table for underground construction is also expected to be between 3 to 5 m. Earth pressure balanced mechanised shields with an external diameter of 5.95 m. and a finished internal diameter of 5.2 m. can be successfully employed for boring tunnels through this soil strata. The tunnels should have a minimum cover of 6 m. ordinarily and in exceptional areas it can be reduced to even 3.52 m. with special precautions. Cutter wheels of these shields should be capable of cutting through stiff hard soil and not through rock. The shield operations will not cause any ground settlement of more than 8 to 10 mm provided the required pressure in front of the shield is maintained.

DMRC has taken expert opinions from internationally reputed tunnel shield manufacturers like M/s Herrenknecht of Germany and they have opined that there will be no difficulty in designing and supplying the required tunnel shields for this project together with the backup ancillary equipments needed for excavating the tunnels. These manufacturers generally take about nine months time for design and supply of a tunnel shield.

The Herrenknecht shields used in Delhi Metro construction have performed excellently well in soft soil giving a maximum rate of 25 m. of finished tunnel progress a day and an average rate of 9 to 10 m. a day. The tunnel shields will be assembled in the station shaft of City Railway Station and the drive will be continuous right up to the end of Cubbon Park. The shields will go through the station excavations for which it is necessary to ensure that the station excavations are complete (though not the station box) before the shields reach the respective locations. After the up line tunnel is completed the shield has to be dismantled and brought back to the starting shaft and the down tunnel has to be driven.

In regard to the North South line the starting shaft is proposed just after the ramp near the Swastik station and the two tunnels should be driven from this starting shaft. The exit shaft for dismantling and taking out the shields could be the City Market Station itself.

In the location where the rock level is high on the Post Office Road the Central College Station is located which in any case will be done by cut and cover method. This station will cover a length of about 230 m. and possibly the EPBM shield may not have to reach the rock level beyond the station. This can, however, be established only after the detailed bore holes are taken at the critical locations during the detailed design stage.

All the underground stations have been proposed as cut and cover with top-down method. The diaphragm walls for such station constructions would be 80 cm. thick and will function as a permanent side wall of the station. It is, therefore, necessary to construct the diaphragm walls absolutely watertight and with the required concrete strength as has been done in the Delhi Metro station constructions. By resorting to top-down method the surface could be restored quickly and further excavations and construction of the station will not hamper the surface activity. It may be necessary to lower the water table for such cut and cover constructions by suitable de-watering schemes which will also re-charge the water table outside the diaphragm wall periphery so that no settlement of buildings take place. The total length of tunnelling for the two lines including up and down lines would be 13.40 kms. It is possible to complete this length of tunnelling with only two shields, one for the East-West line and the other for the North-South line.

While for constructing of the underground stations suitable land is available, only for the Chikpet Station there is no such open land readily available. The possibility of constructing this underground station by mining method without affecting the structures above were examined in detail. The Project Director of General Consultants, Mr. A.J. Burchell, of Delhi Metro Rail Corporation who has got considerable experience in tunnelling was also consulted and after detailed site inspections and soil data study, he was of the opinion that the station could be done by mining method but opined that considering the condition of the structure above it would be more prudent to construct the station by cut and cover method itself. DMRC, therefore, recommends that the Chikpet Station, even though located in a very crowded market locality where no open space for cut and cover construction is readily available, is constructed by cut and cover method only so as to ensure no serious ground sinkages or collapses. For this purpose we have identified the school land belonging to Central Muslim Association (CMA) Urdu School for being taken over during the construction period. The school and hostel will have to be shifted either temporarily to another building (or permanently to a new building) for the construction period of about 3 years. Alternatively, the school has to be shifted to a permanent new building. The area vacated by the school hostel and the open ground would be enough for carrying out the construction at Chikpet Station by cut and cover method. The school authorities were contacted and they had expressed no serious objection provided the State Government takes up the matter directly with them. It appears they have plans to construct a complex in that area by demolishing the existing structures. Perhaps a solution could be that the structures are demolished and the land taken over during the construction period and after the construction is over the complex can be constructed above the station box incorporating the station and other requirements as well as the requirements of the complex. The whole area will get a big face lift if a very modern complex is planned along with the station construction, in which case there will be no need for permanent acquisition of land for the Metro use as the land can be handed over for the construction of the complex after the station is completed. The complex can be conveniently and safely founded on the station box itself. Since they will be getting the required foundation of the building free of cost it may be possible to bargain favourable terms with the Management of the school for taking temporary occupation of this land for locating the station.

The common station at Majestic will be a four level underground station where the East West line will be accommodated below the North South line. The excavation of this station to the required level well in time to allow the shields to go through is important and according to us, therefore, construction of this station is most critical from the time point of view. Taking advantage of the underground boxes to serve as foundations, a high rise building has been planned on top of these boxes, a part of which will be utilized for the headquarters of the Metro Organization where the Operation Control Centre for both the lines will be located. The podium of the building will have three floors but the central circular tower will have 8 floors. At the ground level only columns will be available keeping the entire area free for pedestrians for circulation and vehicles circulation including KSRTC buses. While the requirements of the Metro Organization can be met in two floors, the remaining floors can be commercially let out thereby ensuring a steady and handsome revenue to the Metro Authority during the operation stage. An Artist's view of the building and the Metro platforms has been indicated in Photo.

At Majestic Station there is a regular inter-change line connecting the North South and East West corridors. This is to enable rakes to be changed from one line to the another during non-operational hours for rake balancing or for taking trains to the Baiyappanahalli Depot for workshop attentions. The rake inter-change line will be a single line to be done by cut and cover method. The curvature of this line will be 150 m. and the length will be 225 m. located on the North East corner of Majestic Station and will be constructed along with the Majestic Station construction itself.

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