COMPARATIVE STUDY OF CONSTRUCTION TECHNOLOGIES FOR UNDERGROUND METRO STATIONS IN INDIA

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Abstract

MRTS (Mass Rapid Transit System) in India is a emerging concept and need of the hour. The construction technology is new to the country and there are many areas regarding construction and planning which needs to be understand. It is inevitable fact that gradually MRTS is going to be the backbone of every metropolitan city of the world with view of its development. Thus, from the infrastructure already constructed under this scheme of development we need to learn and devise the standard features and inputs that can be used for future planning and efficient construction. Metro Rail being the backbone of Delhi transportation system of Delhi's infrastructure, it has many critical factor due to: a) Location of the MRTS route alignment b) Peculiar site, design and construction constraint c) Pressure on the government to commission the transport route lines to smoothen the transport requirement etc. c) To start use of the facility in order to generate revenue and pay back loans taken from international banks etc. Thus, through this paper an attempt has been made to understand the basic concepts regarding the construction methodology and technology primarily used in for "Underground Metro Construction" according to topography and site constraints. Various technological advancements have taken place and gradually new innovative and efficient variations have been introduced in the construction logic for underground metro stations. After establishing a generic understanding of the station peculiarities and construction procedures, information regarding two construction methodology of underground construction i.e. Cut and Cover (Bottom Up and Top Down) and Box Pushing Technique will be analyzed.

Keywords: *Metro, Delhi, Underground Station, Construction Techniques*

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1. INTRODUCTION

1.1 Typical Underground Station Architectural System

Generally, underground metro station consists of concourse at upper basement level and platforms at lower basement. The services like ticketing hall consisting of ticket machines, automatic fare gates, station control are provided in the optimal centrally located portion of the concourse level.

Principal elements of a typical underground station:

a) The platform area
b) The concourse containing ticket issuing machines and access control
c) Offices rooms
d) Equipment room not open to passengers

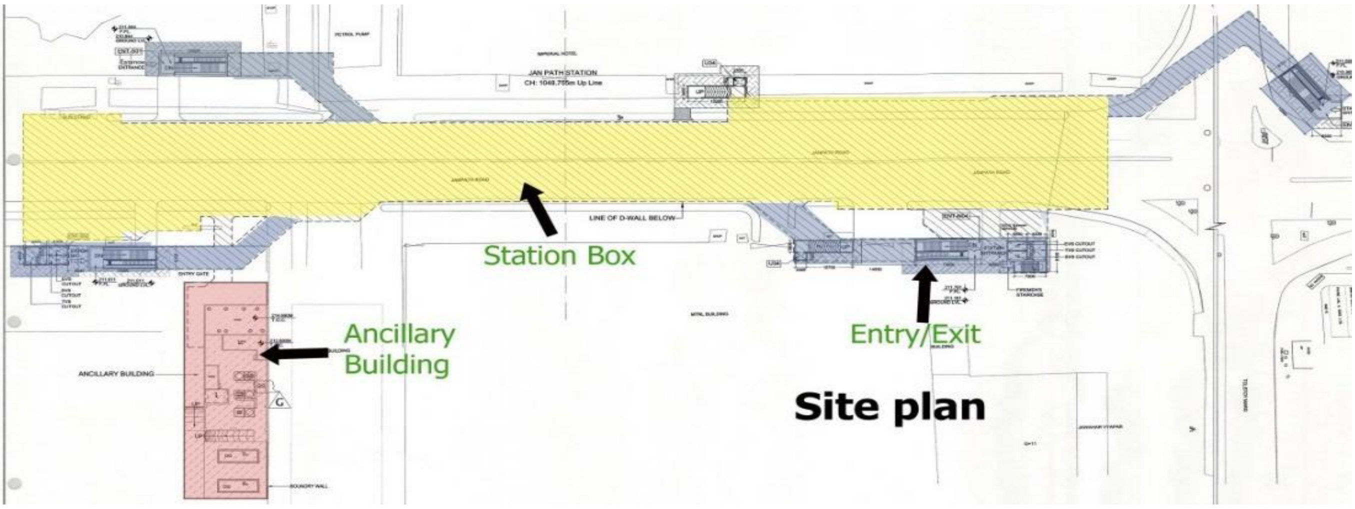


Fig 1: Site Plan of Underground Station (Source: DMRC)

The ticketing halls are designed in such a way to accommodate machine/equipment rooms required for the smooth operations of the station on either sides of concourse. Practically, the length of the platforms are same as of rolling stock of the system and the platform security doors separates it from the tracks. The platforms are designed as large atrium connected with concourse area through stairs, lifts and escalators with a primary function of waiting area and boarding/alighting from trains. Lifts for the elderly and disabled people are provided for easy access For emergency situations requiring quick egress, staircases are also provided at two ends of the concourse level.

These are normally arranged in two levels with the platforms at the lower level and the concourse above. Escalators, stairways and lifts are provided for the use of passengers between the concourse and platforms, and there are also connection between the non-public areas on the upper and lower levels for station staff and maintenance personnel.

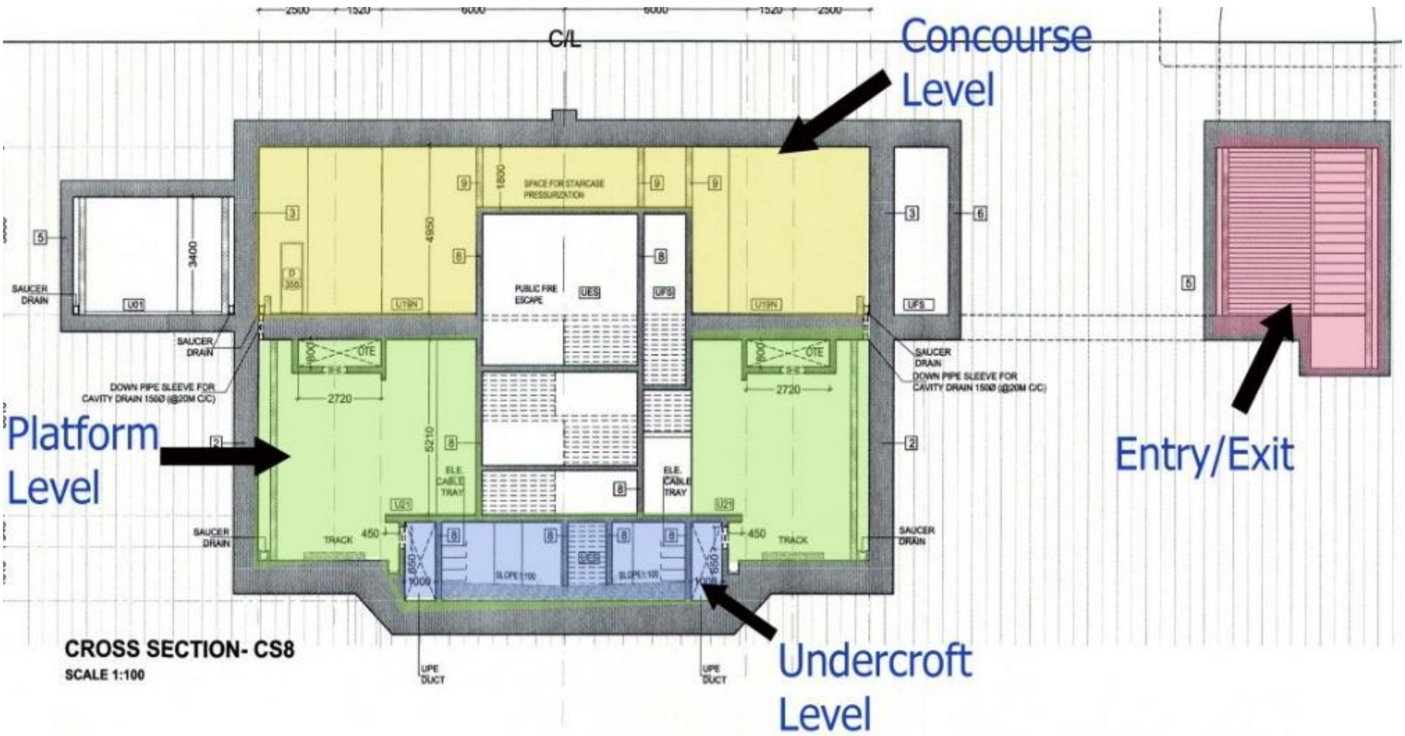


Fig 2: Section of Underground Metro Station:DMRC)

Platform lengths are determined by size of the train and are typically about 140m long for heavy metro, although this can be extend up to 180 m on some systems. An overall length of about 250 m provides space at the end of the platform for electrical switchgear, transformers, emergency generators, signaling equipment and other plant.

The station has different levels for public access and all the utilities and components are divided among these areas, which can be summarized as follows:

Roof level: this part of the station is covered with top soil and is not visible to the public and may be used for landscaping. It is around 1-3m below ground level and forms the top of the station box. In the top down method of construction this is the first phase of construction and excavation of roof slab goes on till the completion of the whole station as the cut outs in the roof slab are left for equipment movement.

Concourse level: this level of the station is for public movement. This is the first level exposed to the public when they enter the station and it serves many purposes such as :

a) Ticketing
b) Equipment are situated here
c) Public interchange movement
d) Other miscellaneous activities

Platform level: this level is for the passengers to board and un-board the train. The platform slab can be cast as an island platform or as a side platform. People have to traverse from platform level to the concourse level to exit the station.

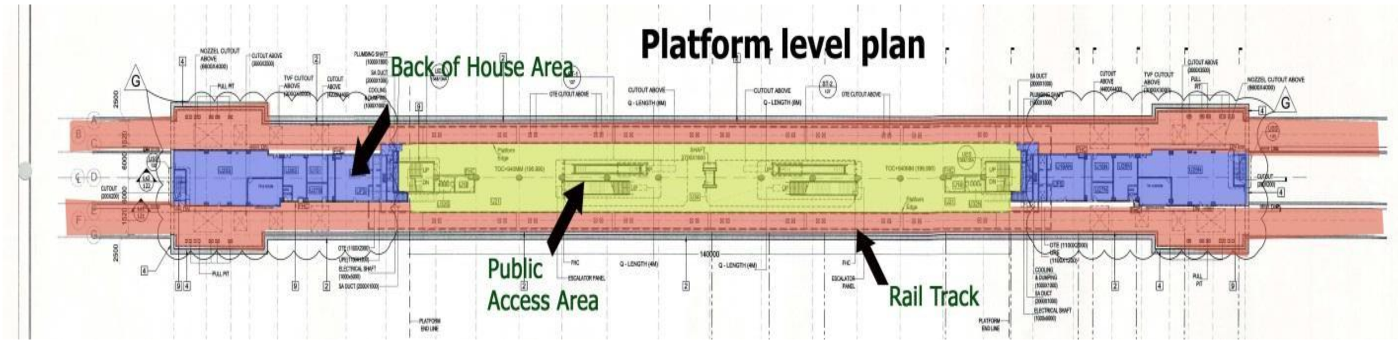


Fig 3: Platform Level Plan(Source: DMRC)

Undercroft level: This is the lowest level of the station and it carries the track for rail movement. Many other cut-outs and exhaust are placed at this level to let go off the heat produced due to train movement.

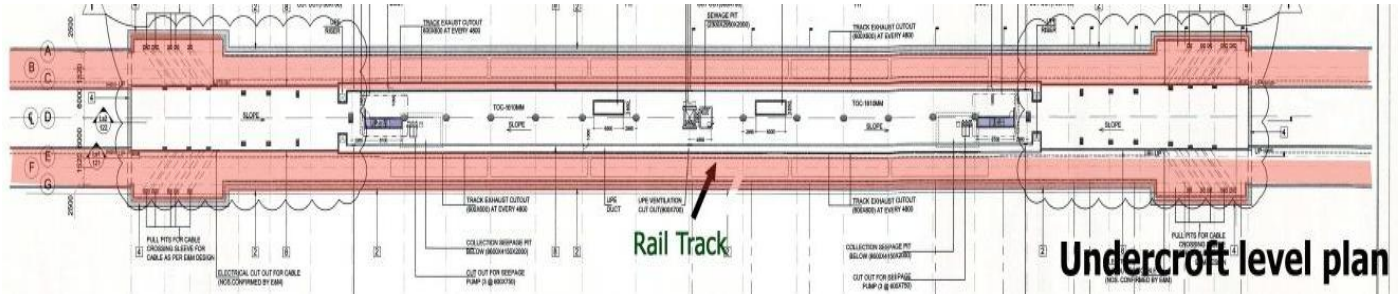


Fig 4 : Undercroft Level Plan(Source: DMRC)

2. FEW UNDERGROUND METRO STATION CONSTRUCTION METHODOLOGIES ADOPTED IN DELHI

2.1 Cut and Cover Method

This method is adopted generally in locations with high density of buildings and population to avoid minimal disturbance to the adjacent structures. In saturated soil conditions, secant pile walls are commonly used to create shafts for stations[1]. A trench is excavated for the construction of a box frame structure which is backfilled subsequently. To reduce traffic disruption, a temporary decking will be provided over the excavated trench immediately after the first layer of excavation is done[1]. Subsequently, the temporary decking will be removed and the original surface will be restored.

Before the excavation starts, shoring i.e. temporary excavation support walls are installed. The shoring is fixed/supported on excavated soil with soil anchors to support the deep excavated sides of the cut to control settlement and soil failure. Slurry walls or cased secant piles are used generally for shoring[2].

Diaphragm foundation walls are created along the perimeter of the excavated trenches filled with bentonite slurry to prevent the excavated sides to collapse from the lateral earth/submerged pressure. The steel reinforcement cages are lowered into the excavated trenches and are filled with concrete to remove the slurry. It acts as the support to both excavated/cut surface and permanent wall of the station[3].

When the desired depth is reached, concrete is pumped to the bottom of trench which pushed out the slurry. The Bentonite is a special clay with high water absorption property which expands in presence of water. Bentonite grout also acts as the necessary waterproofing agent. Various combinations of support system are employed in the construction of large underground projects. Generally, the roof/deck slab is constructed first followed by the construction of piles or caissons in sub-structure. The lower slabs are constructed after the subsequent excavation. Typically, this underground construction method is most suitable for a congested area with a requirement of minimum disruption.

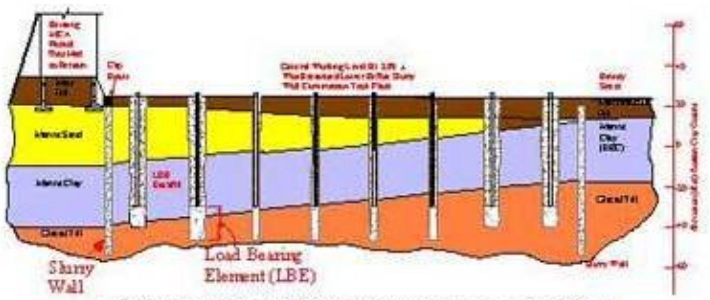
The major demerit of cut and cover method is the requirement of large working area. This method is often required in limited construction space as in the case of congested urban cities. The operational problem associated with this system is conflict between the location and arrangement of its support structure with the excavation and construction of the permanent structure. One solution which can reduce the inconvenience is to use tieback systems which do not conflict with the area to be constructed.

2.1.1 Conventional Bottom-Up Construction

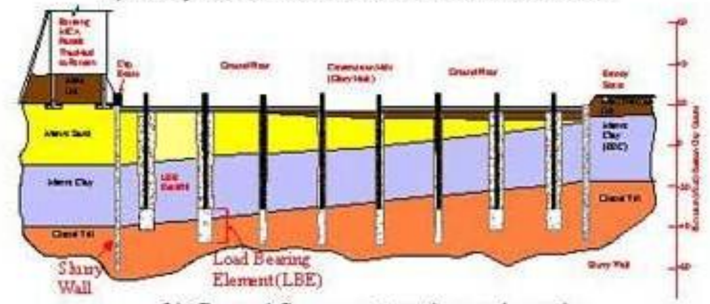
In the conventional Bottom-Up approach, the basement piles and diaphragm walls are casted and constructed before the excavation of the earmarked portion up to the desired depth. The strutting/bracing system are installed to support the retaining walls of the enclosed area up to the desired depth followed with progressive excavation. Corresponding to the depth of excavation, the strutting/bracing systems may require more than one anchorage/supports to resist lateral overturning moments due to earth and/or ground water pressure on the exterior retaining walls.

The process of construction of foundation system generally a MAT/Raft system follows the complete installation of support system and excavation up to the founding level and thereafter upward construction methodology involves the construction of Columns and floor slabs for various levels of basements. Thereafter, construction of superstructure of the underground station follows general practice[4].

The excavated trench is backfilled with soil after the construction of top roof slab is over and the surface is restored as per requirement. Following series of sketches shows the sequence of construction activities in bottom-up construction.

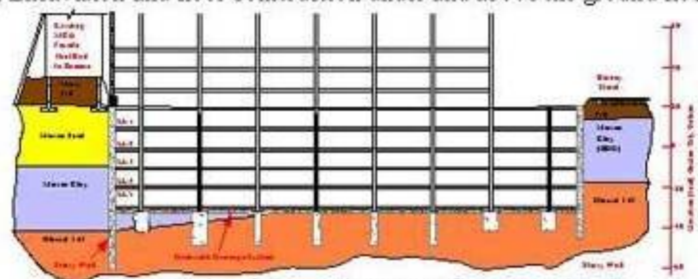


a) Slurry wall and basement column construction



b) Ground floor construction and pouring

c) Excavation and floor construction under and above the ground floor



d) Excavation & lowest basement floor completed

2.1.1.1 Bottom-Up Construction Sequence

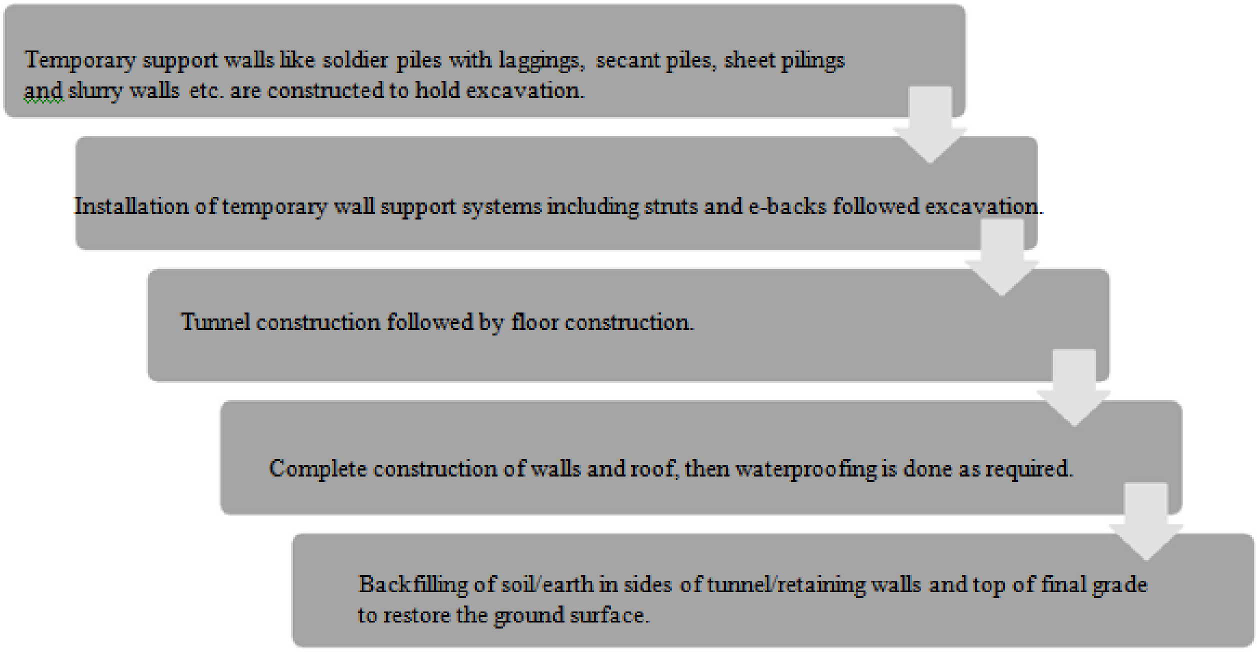


Fig 5: Sequence for Bottom Up Construction Technology

2.1.2 Top Down Construction

Contrary to the Bottom-Up construction method, the principle of Top-Down construction method is to construct moulds first and construct diapharm/floor slabs after each successive excavations. The floor slabs are permanent structures generally made up of reinforced cement concrete, which along with propped cantilever retaining walls replace temporary steel struts used to counteract the earth pressure from the back of the retaining wall. In this manner, the underground station structure is completed after the completion of the excavation. The sequence of construction activities of the underground station structure is from the top to the bottom and is opposite to the conventional foundation eccentric construction methods. For these reasons, this method is therefore called the top-down construction method. The floor slabs constructed in the top-down construction method are designed for heavier soil loads than the steel struts used in conventional methods.

In addition, the superstructure, which is constructed simultaneously during excavation, puts more weight on the column. Thus, the bearing capacity of the column has to be considered. As a result, deep foundations like piles are generally used for the top-down construction method.

The typical construction procedure of the top-down construction method is as follows:

2.1 Construction of the retaining walls → Construction of the piles → Erect steel columns above the casted piles/piles cap → Proceed to first stage of construction → Complete all construction activities till casting of first basement level roof → Construction of the superstructure → Proceed to the second stage of excavation → Complete all construction till casting of second basement level roof → Repeat the same construction procedures till the desired depth → Construction of foundation system → Complete the bottom most level of the structure

Table 1: Construction procedure for top down construction

Contrary to Bottom-Up construction technology, the Top-Down construction method requires less working space. This construction method facilitates in phase construction of superstructure along with substructure which results in fast construction and substantial cost benefits. An important advantage of this method is the ability to minimize the soil and walls lateral/vertical movements, which consequently will minimize the settlements of adjoining structures. As this method allows the construction of intermediate slabs which offers the required lateral stiffness and support to the retaining wall, the requirement of heavy and extensive temporary strutting system is reduced down as is the case with Bottom-up construction.

Another advantage with Top-Down method is the minimization of various construction related issues like slushy ground, continuous dewatering and problems related to bad weather etc. However, few disadvantages are also associated with Top-Down method related to the requirements of skilled work force and higher execution costs. Removal of soil from beneath the floor slabs in cramped conditions may prove tedious and costly compared to the conventional methods[3].

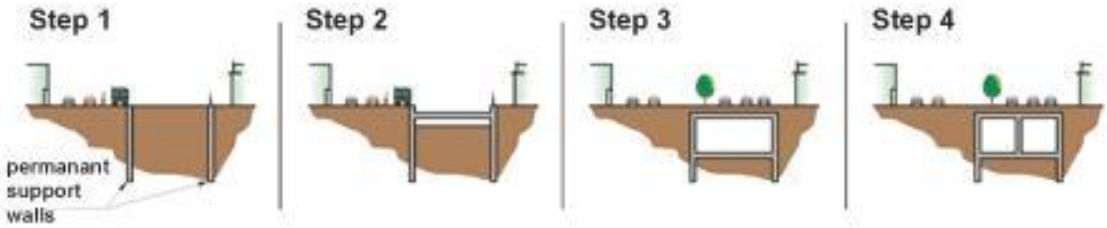


Fig 6: Top down Construction process (Source: www.railsystem.net)

2.2 Top Down Construction Sequence

The construction sequence of Top-Down method for deep basement in detail generally includes the following sequence of operations:

The exterior retaining basement walls are constructed first. The walls either cast-in-situ or precast concrete are constructed by any of the suitable materials/methods like contiguous piles, steel piles or secant piles etc.

The foundations of internal support elements are constructed, before excavation is done. Usually the internal structure comprises steel stanchions on piled foundations. Under-reamed piles and raft foundations too could be used. It is also essential for top-down construction to use only a single pile at each column position and this technique will not permit multi pile-cap arrangements. As the columns will be subjected to loads from the superstructure prior to being restrained by the sub-structure floors, it is necessary to provide temporary lateral restraint to steel stanchions. Pile casing could be back filled with peat shingle. The steel liner above also could be braced to the steel column.

The ground level suspended slab is cast on the ground, connecting it with the diaphragm wall and the pre-casted columns. First, the ground surface is leveled and blinding concrete is poured over. On top, generally ply wood formwork is placed followed by steel reinforcement. Since the slabs act as struts to perimeter wall, slabs should be connected to perimeter wall. The reinforcement in top section of perimeter wall is anchored and lapped with reinforcement of the slab. Opening is left in the slab for the movement of materials and machinery to construct the first basement slab.

(a) diaphragm walls
(b) piles and steel stanchion
(c) upper basement floor
(d) first basement and superstructure
(e) second basement
(f) final basement raft

Then superstructure construction can be done as usual. Basement construction is done simultaneously below. Excavate underneath the ground floor to the first basement level. Level the first ground floor of the basement and prepare the reinforcements. During excavation, dewatering may be necessary, but perimeter wall will act as a cut-off wall or reduce the amount of seepage.

The above procedure is repeated till the lowest basement level. Final basement floor is constructed with desired drainage and water proofing system.

2.3 Box Pushing Trenchless Technique

Box pushing technique is a well-established engineering & construction method for culverts or tunnels under existing constructions, rail embankments, waterways to accommodate road or rail traffic. It is a well proven method to overcome or circumventing geophysical impediments or obstructions in order to build road or rail networks.

Introduction

Box Pushing trenchless technique is a innovative tunneling method for construction of shallow rectangular tunnels beneath critical facilities such as functional railways, major highways and airport runways without disruption of the traffic services or relocating/realignment of them temporarily as in the case of open excavations for cut and cover construction. Originally developed from pipe jacking technology, jacked box pushing tunneling is generally adopted in soft soils at shallow depths and for relatively shorter lengths, whereas Tunnel Boring Machine (TBM) for tunneling would not be economical for shorter lengths[4].

Box Pushing Construction Sequence[5]

The box pushing process starts with the excavation of a launching sink pit where a secure backdrop is constructed to facilitate the hydraulic jacking rams that will push the pre-cast concrete box sections into place. These large concrete boxes are constructed on site to suit the size of the tunnel. The boxes are then hydraulically jacked into position in alignment with proposed tunnel with an excavator cutting out the soil at the interface and removing it for disposal.

As the excavation proceeds the precast concrete sections are pushed slowly into position to form the deck slab, floor and sides of the tunnel.

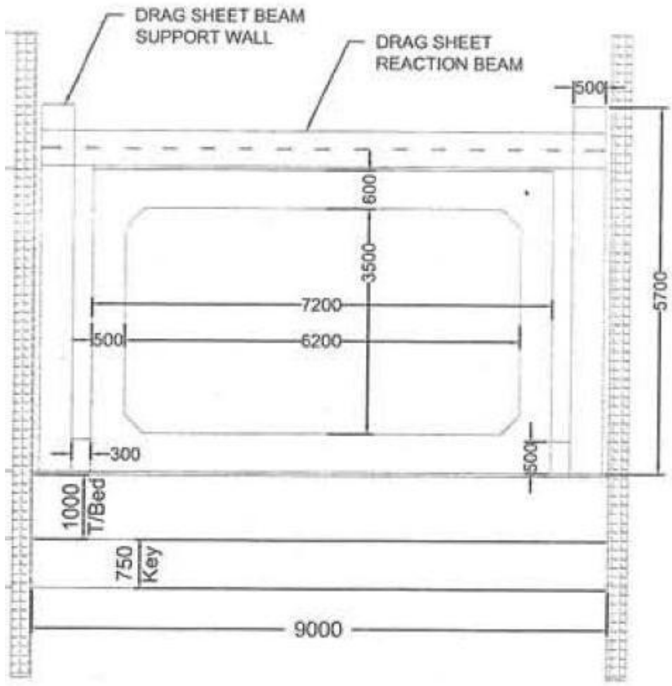


Fig 10: Box dimensions for box pushing method (Source:DMRC)

The typical construction procedure of the Box pushing technique construction method is as follows:

3.1 Excavation for thrust bed and auxiliary bed → Concreting of thrust bed and pin pockets → Casting of box segments → Protection of track and embankments → Arrangement of adequate capacity jacks with power packs → Execution of pushing operation → Construction of wing wall → Construction of toe wall → Construction of return wall → Complete the superstructure

Table 2: Construction procedure for box pushing method

Technology	*Top Down*	*Bottom Up*	*Box Pushing*
Parameters	Construction of underground structure is from top to bottom	Construction of underground structure is from bottom to top	Used for culverts or tunnels under existing constructions, railway embankments and waterways to accommodate underpass road or rail traffic.
Applicability	Used in dense urban areas where lack of space for construction	Used in large open areas where space is available for equipments and construction	Used for shallow rectangular road, tunnels beneath critical facilities
	Erection of moulds and construction of floor slabs right after each excavation	Strutting and sheeting system are used as temporary support for basement retaining wall	Used for short lengths up to 100m.
	Deck slabs are permanent structure which replace temporary steel struts to counteract the earth pressure from the back of retaining wall	The area remains unusable for public utility during period of construction	Used in soft soils at shallow depth and for relatively shorter lengths of tunnel, whereas TBM tunneling would be uneconomical and cut-and-cover method would be disruptive to existing surface activities.
	Does not require very large working space	Tunnel is completed before it is covered up and the surface is reinstated	Traffic disruption is eliminated
	Enables simultaneous construction and of site for public utilities	Larger footprint area is required for construction	Skilled personnel required for Box Pushing
Duration	Takes less time than bottom up because excavation is	Longer time is required as whole of excavation is done and then	Takes very less time as minimum excavation for

	accompanied by slab works and total excavation is not done in one go	substructure RCC works are commenced	working area is required and precast boxes are pushed using hydraulic jacks saving time of RCC works
	Total time taken for completion is 628 days (1 year and 6 months)	Total time taken for completion is 915 days (2 year and 5 months)	Total time taken for completion is 232 days (7 months)
Critical Activities	Site preparation	Roof slab excavation as all further construction is done through the cut outs made in the roof slab	Being a basically step by step iterative process, all activities have Finish to Start relationship.
	Excavation up to the base level	Waterproofing	All preceding activity are pre-requisite for next activity.
	RCC works for each floor slab as staging for upper floors is supported on these concrete bases	Closing of cut-outs	
	Water Proofing	Architectural finishes of station level	
	Back filling		
Relative Cost	Cost saving as heavy temporary strutting is not required	Huge cost incurred in heavy strutting equipments	Huge initial cost of equipment's and machinery
	Higher unit cost due to requirement of skilled supervisory staff and labour	Due to conventional approach, less labour cost	Cost effective from a labor point of view
	Higher safety cost due to difficult excavation process	Due to longer construction period higher cost implications	Cost savings due to minimum diversion of utilities.
	Overall construction duration can be reduced down than that of conventional method thereby saving the cost	May be most cost effective as dust/debris quickly hauled away from the foundation pits before works begins and mistake can be spotted and rectified	
Safety Risks	Trenches Required	Trenches Required	Only Pits required
	Strong layer of RCC slab is required to carry the dead weight and superstructure loads		Higher safety and control during the construction of the structure
Environment Risks	Undesirable in environmentally sensitive areas and in locations with high traffic flow	Excessive dewatering may be required in soils with high water table which may pose risks to the surroundings buildings and structures.	Trenchless technologies can reduce construction related CO_2 emissions by 90% reducing carbon footprint on the environment
Technical Risks	This technique gives the ability to the system to minimize wall and soil movements and consequently minimize or even prevent settlement of adjacent structures.	Structural design may require one or more different layers of struts to offer sufficient lateral resistance against earth and ground water pressure	Only the exact prism of earth that will be filled by the jacked box is excavated.
	Excavation under the slab is difficult	Water proofing can be applied externally on the structure	Difficult to use in depth below water table and dense sands and soil with rock, boulders

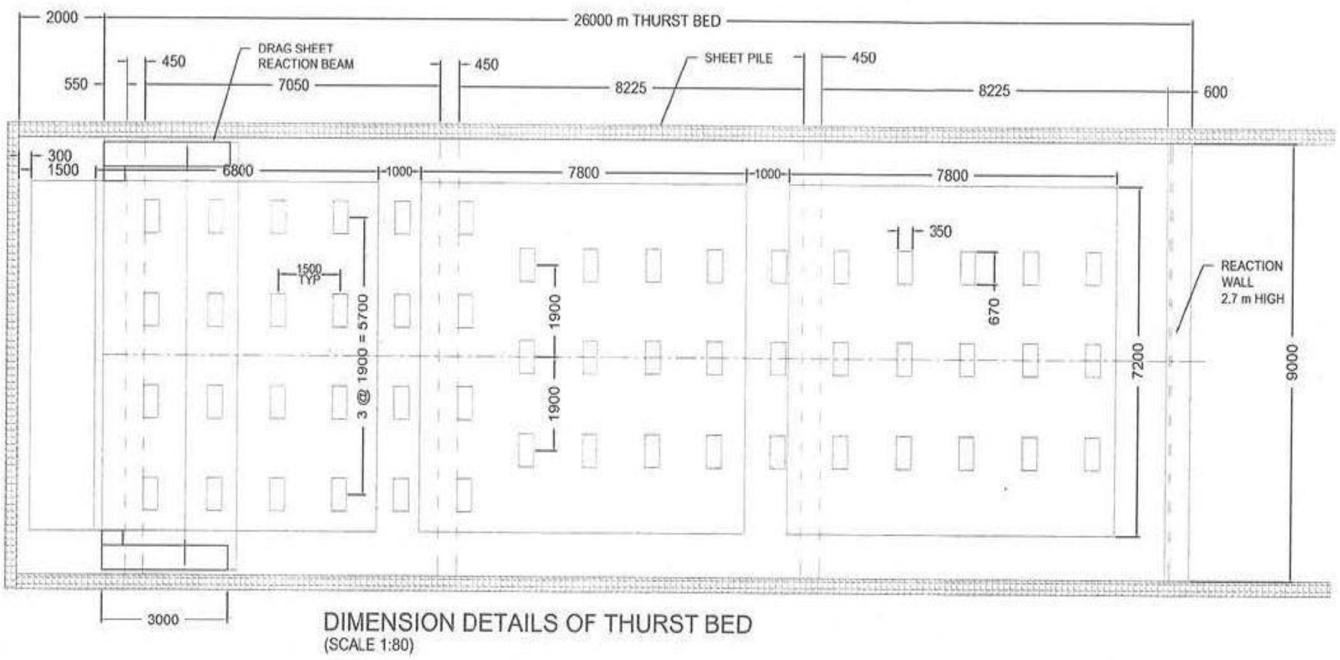


Fig 7: Thrust bed arrangement (Source: DMRC)

3. CONCLUSION AND DISCUSSION

The meticulous designing and planning of the structures specially the underground stations characterize the construction methodology of the Delhi's Mass Rapid Transit System in densely populated and congested areas. The construction schedule requires a speedy and safe construction to be done with least obstruction to existing infrastructure given the severe constraints of both time and available space in Delhi. While standardization in designs and construction technique was attempted to get the maximum benefit and value addition. However, peculiar site constraints compelled for improvisation and modifications in design and construction techniques to suits the requirements at various locations. Aesthetics and durability of the buildings were addressed without compromising the structural, services, functional and safety aspects.

The project has employed state of the art technology in the design and construction of the concrete bridges and the Delhi MRTS would possibly be the precursor to similar systems adopted in other cities with significant urbanization.

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