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# Advance Tunnel Construction Technique 'Tunnel Boring Machine'

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**Abstract** - *In this new world of "Technology' the construction technique of structures is also advancing for the betterment and satisfactory output, for this new Advance Construction Techniques, are introduced which helps the part. This Techqniues helps in the construction of buildings, Bridges, Tunnels, Dams, Roads, etc. In this paper, the advanced technique of tunnel construction i.e. 'T.B.M' is described. T.B.M (Tunnel Boring Machine) is a machine used for the construction of tunnels with more efficiency, satisfactory, safety. To grasp the potential of Tunneling by 'Tunnel Boring Machine (TBM)', research has been made to further understand how tunnels are constructed, and how TBM works. The main objective of this paper is to study tunnel construction using TBM, the case study of Delhi metro project, types of TBM, advancement in TBM, and the other factors. The conclusions of this thesis show that how TBM, was a best suitable method for Delhi metro project and how it will improve construction productivity of tunnel operations.*

***Key Words*: *Tunnel Boring Machine (T.B.M), Tunnel, Delhi Metro Project, Advance Construction Techqniues***

## 1. INTRODUCTION

All the machines used for boring tunnels are tunnel boring machines. However, a TBM often refers to a large diameter cylindrical shield, equipped with a rotating cutter-head at the front, a mucking device, and frequently an automatic segment erector. The first successful tunneling shield was developed by Sir Marc Isambard Brunel in 1825 to excavate the Thames Tunnel. The first boring machine reported to have been built was Henri-Joseph Maus's Mountain Slicer. Commissioned by the King of Sardinia in 1845 to dig the Fréjus Rail Tunnel between France and Italy through the Alps, Maus had built it in 1846 in an arms factory near Turin. It consisted of more than 100 percussion drills mounted in the front of a locomotive-sized machine, which was mechanically power-driven from the entrance of the tunnel. During the late 19th and early 20th century, inventors continued to design, build, and test TBMs in response to the need for tunnels for railroads, subways, sewers, water supplies, etc. TBMs employing rotating arrays of the drills or hammers were patented. TBMs that resembled as giant hole saws were proposed. Other TBMs consisted of a rotating drum with the metal tines on its outer surface, or a rotating circular plate covered with teeth, or revolving belts covered with metal teeth. The world's largest up-till TBM is 'Bretha', was designed and manufactured by Hitachi Zosen Sakai Works of Osaka, Japan and which is worlds largest earth pressure balance TBM, with a cutter head of 57.5 feet (17.5 m) across. This machine is 326 feet (99 m) long and weighs 6,700 short tons (6,100 t).

**Fig -1**: View of TBM

### 1.1 Types of TBM

- **Earth Pressure Balance T.B.M**: - A cutterhead consisted of 3 to 8 radial arms with chisels are fitted in the front of the TBM. A bulkhead is provided behind the cutterhead to form a pressure chamber. Spoil is stored in the chamber and is discharged in a controlled rate. The pressure built up in the chamber is then utilized to balance the external pressure. This TBM is used for soft rock or clayey soil.

- **Bentonite Sheild T.B.M**: - A bentonite shield is equipped with the pressure bulkhead and a chamber. The chamber is filled with the bentonite slurry to balance the external pressure. The slurry also liquefies the spoil which can be then transported out by pumping. This type of TBM is used for slurry type soil or mosit soil.

- **Hard Rock T.B.M**: - In rock TBM, the disc cutters are used to cut the rock. The rock failure is actually by the shear that occurs due to the penetration of the cutter tip into the face. The cutters are manufactured with the hardened tool steel and range in size of typically 300 to 500 mm in diameter. The cutters are mounted on the cutterhead in a pattern and number that will provide coverage over the entire face. This type of TBM is used for hard rock Tunneling.

## 2. CASE STUDY

The city of Delhi, capital of India. It has been facing problems such as traffic growth, congestion, pollution, increased accidents since last decade. To ameliorate both the quality and availability of mass transport system with an aim to address the mentioned issues, a non-polluting rail-based mass transit system was sought to be an effective solution given the by Government of India (GoI) and Government of the National Capital Territory of Delhi (GNCTD). To achieve this challenging objective, a tremendous amount of efforts has been directed towards planning, design, and implementation of this metro project. This study attempted to analyze and elucidate the overall Delhi metro rail project implementation through its activities till completion. It explains various infrastructure aspects such as economic, environmental, social those are being/were considered for this project. The Delhi Metro project was divided into four phases for its implementation with a total length of the rail network to be approximately 404km. Presently, Phase I and II have been successfully implemented and are in operation. Phase III and IV are scheduled to be completed till 2016 and 2020 respectively. This project has set many records for its successful implementation such as early completion of phase I, achievement in terms of environment-friendly design and implementation and is being viewed as one of the inspirational models for metro projects planned to be undertaken all over the world.

The increasing level of urban traffic problems such as congestion, rising levels of air and noise pollution, an enhanced threat to road safety, horizontal city expansion leading to higher journey time has made it incumbent to explore a sustainable solution for mass transit for urban mobility. Since the last decade, light/metro rails have been started to be considered as a viable antidote for solving the vicious malaises of urban traffic issues. However, implementation of such a mass transit system in urban areas is a challenging attempt with many potential constraints such as political, social, and environmental. To highlight the difficulties associated with planning to implementation of such infrastructure projects of the mass transit system, this case study aims at elucidating the overall process of infrastructure planning from activities till completion of "Delhi metro rail project".

The initiatives for introducing the metro system in Delhi were taken in the early 1990s. In 1995, the Government of India (GoI) and the Government of the National Capital Territory of Delhi (GNCTD) both formed the Delhi Metro Rail Corporation Ltd (DMRC) under the Companies Act to construct the Delhi Metro. Conceived as a social sector project, a significant portion of the project cost was funded through a soft loan provided by the Japanese government through the Japan Bank International Corporation (JBIC). The rest was contributed by DRMC through equity. E. Sreedharan (Sreedharan) was appointed as managing director (MD) of the DMRC and project manager for Phase I of the project in November 1997. Work on Line 1 of the Phase I started in October 1998. DMRC formed consortiums for advising on the project as well as to provide with the latest technology. DMRC successfully managed to overcome the hurdles in association with ensuring that the project is environmentally safe.

Work on phase II of the Delhi Metro project started towards the completion of phase I in September 2006. Implemented by the Government financed Delhi Metro Rail Corporation to serve 1.5 million passengers per day is being looked up to as an inspirational mass transit project by other large South Asian cities.

### 2.1 Mission

- To cover the whole Delhi and adjoining areas with a metro network by the year2021.
- To serve the customers including 'differently abled' commuters with passion.
- To sustain the image of being number one in the transportation sector in India and to be among the top 3 Metro Rail systems in Asia with regards to:
  - Safety Reliability Punctuality Quality and Responsiveness to the customers.
- To make Delhi metro self-sustainable.

### 2.2 Planning

In the case of major infrastructure projects, lack of funds, political interference, lack of professionalism and accountability, property disputes, corruption, etc. are always considered as factors of hindrances. Therefore, DMRC attempted to put in place effective system for smooth transition of project progress, even before the commencement of the project. To deal with political interference, the DMRC sought autonomy on all major matters and the GoI promised to give it this autonomy.

JBIC was founded in 1961 by the Japanese government as the Overseas Economic Cooperation Fund (OECF). It served as the implementing agency for loan aid given to entities in developing countries. OECF generally gave low-interest (around 2.1%), long-term funds (about 20 years with a five-year grace period). In 1999, OECF was merged with the Export-Import Bank of Japan (JEXIM) to form the JBIC.

The Total length of road network increased from 652km in 1981 to 1122km in 2001 – and is expected to grow to 1340km by 2021. It is estimated that roads occupy 21 percent of the total city area of Delhi.

The history of planning a Metro Project of Delhi provided by Central Road Research Institute (CRRI) for studying traffic and travel charachteristics of delhi in 1969-7. On the basis of that study, Mathematical models were developed to project travel demand. After Post examining several different alternatives, a 'Mass Rapid Transit Network' recommendation was made for Delhi. Metroplitain Transport Team (MTT) sought for some modifications for recommendations of CRRI. The system comprised of 36 Km of underground corridors aligned two axes North-South and East-West Corridors and 96 Km of surface rail corridors. Metropolitan Transport Project (MTP-R, set up by the Ministry of Railways, Government of India) prepared an engineering plan to construct the MTR system.

Town & Country Planning Organization was assigned the work of further projection of transport demand. The concept plan comprised of a network of 58 km underground & 195 km surface corridors.

Delhi Development Authority (DDA) prepared a perspective plan for the Delhi (MPD-2001) in 1984 and recommended for a multi-modal transport system comprising of 200 km of Light Rail Transit System, 10 Km of Tramway, an extension to the surface rail system and extensive road network. The Urban Arts Commission suggested some modifications to the proposal of DDA and recommended for the development of the existing Ring Railway with three radial underground MRT corridors.

### 2.3 Engineering Aspect

Since the start itself, the Delhi Metro portion of the MRTS was an ambitious scheme, consisting of four phases of underground, elevated and surface corridors with a total route length of approximately 415km to be constructed in four phases.

DMRC was given full powers and authority to hire people, decide on tenders and control funds. As a result of DMRC's decision of consulting the Hong Kong MTRC on rapid transit operation and construction.

Techniques construction proceeded smoothly, except for one major obstacle in 2000, where the Ministry of Railways forced to opt for broad gauge over the DMRC's preference for standard gauge. After over 30 years of planning, Phase I of Delhi metro started in 1998. It comprised of 3 corridors of8 sections with a combined length of 65.1km. The Phase I was a first successful milestone achievement of the project which was completed 2.5 years ahead of schedule and delivered under budget at an estimated final cost of US$2.3 billion. The system not only proved to be equally efficient in terms of operation but also, the trains were clean, timely and affordable. Delhi Metro also became one of the only four metros in the world to have operating profits as per the review study carried on by the Indian Institute of Management in Lucknow. Construction commenced on Phase II (123km) of the metro in 2006 with a target completion date of 2010. Phase III (103.05 km, 69 stations) and Phase IV (113.208 km) are planned to be completed by 2016 and 2021 respectively, with the network spanning 404 km by then.

As of September 2015, with the completion of Phase I, Phase II and the beginning of operations in Phase III, the Delhi Metro network comprises of five color-coded lines (Red, Blue, Green, Yellow, Violet), and a sixth line, the Airport Express, also called the Orange Line, serving 150 metro stations (with 6 more stations on the Airport Express line, for a total of 156) and operating on a total route length of 208 kilometers (129 mi). Over hundreds of people, including 93 workers, have died since work on the metro began in 1998.

### 2.4 Planning Extensions

Work on Phase III started in 2011 while the planning for Phase IV has begun. Ex-chief of DMRC forecasted a need for Phase V by the time Phase IV is completed, to cope with rising population and transport needs.

- Phase II: - The deadline for completion of Phase 3 is 2016 with a target of completing 2 new lines and 11 route extensions. Recently, Cabinet approvals have been obtained for 2 new lines and 10 route extensions totaling 103 km, with an estimated cost of ₹350 billion (US$5.3 billion). Construction work is going on currently. In April 2014, the Delhi Lt. Governor gave approval for two further extensions. 28 underground stations are approved to be a part of Phase III covering 41 km with an expected number of More than 20 tunnel boring machines to be simultaneously deployed during its construction. Ridership prediction of 4 million after completion of Phase III is made. With a decision to have communication-based train control (CBTC) for signaling (which will allow trains to run at a short headway of 90 seconds) and accounting for other constraints, DMRC will be building 6 car short stations instead of 9 car long stations for new lines. For the first time, ring lines will be constructed in Phase III which will be different from the traditional approach of constructing long radial lines till Phase II of Delhi metro. In order to the reduction of distance and to relieve radial lines of some congestion, Delhi Metro is aiming to interconnect existing lines by ring lines.

- Phase IV: - Phase IV has a 2021 deadline with a tentative plan of further extensions to Sonia Vihar, Burari, Mukundpur, Reolakhanpur, Palam, Najafgarh, Narela, Ghazipur, Noida sector 62, extensions of Violet line, Green line, Line 8, having a total length of over 113 km.

### 2.5 Methodology of Construction

Mainly the following two methods have been adopted for the construction of station: 1- Cut and Cover method 2- Tunneling using T.B.M.

For the surface station construction cut and cover method was employed while for underground TBM was used for tunneling.

About TBM: - A German laser system was used to guide the TBM along its precise alignment. During the tunneling process, about 42,000 cubic meters of earth was excavated. A total of 1,210 rings, each 1.2 m. in length, were installed simultaneously along with the process of tunneling. Each ring has six segments and these segments and rings are connected by using bolts. A total of 26,600 bolts were used in the 1,450 m long tunnel. To make the tunnel water-tight, hydrophilic gaskets were used between the ring joints. Extensive grouting was done all around the rings to avoid settlement of the ground between the top surface of rings and soil surface.

### 2.6 Background

It consists of a network of 190 kilometers, servicing 141 stations of which 35 stations are underground, 5 are on the ground and remaining are elevated.

The Construction started on October 1st, 1998, and the first section the Red Line was opened in 2002 followed by the Yellow Line in 2004, the Blue Line in 2005, its branch line in 2009, the Green Line and the Violet Lines in 2010, and the Delhi Airport Metro Express in 2011.

Work on Phase III started in 2011 while the planning for Phase IV has the entire network was planned to be constructed in phases spread over approximately 20 years. Phase I (65 km), Phase II (125 km), and Phase III were completed in 2006, 2011, and 2016 respectively, and Phase IV is scheduled for completion in 2021. Work on Phase III started in 2011 while the planning for Phase IV has begun.

Phase III has 28 underground stations covering 41 km. The project was completed before eight months of schedule in December 2004. The next two packages were part of the Airport Express Line which includes C1: a 2.2 km long twin bored tunnel and a 1.3km cut and cover tunnel from New Delhi station to Rajiv Chowk and C6: a 2.6km long NATM tunnel from Talkatora area to Buddha Jayanti Park. The route alignment of this Metro line passed below various heritage structures and buildings of national importance. The tunneling depth below the Rajiv Chowk Metro station at 44m was the deepest ever for the Delhi Metropolitan Region, going below two existing lines.

### 2.7 Economic Aspects

The Phase I and II are operational currently totaling to 190 km of route length inclusive of 22.70 km of Airport Express line and the total cost incurred was around Rs.300 Billion ($6 Billion) considering the rates of the year 2011 and estimated the cost of phase III is Rs. 42 Billion($7.04Billion). Financing for the Delhi Metro was in the partnership of international, national, state and local sources. Japanese Bank of International Cooperation (JBIC) sponsored the majority of financing – 60 percent of funds – in the form of long-term loans. The final 3–5 percent of project costs was decided to be met through revenue from development of adjacent property.

### 2.8 Environmental and Social Aspects

DMRC set a record of being a first railway project to be registered under Clean Development Mechanism of United Nations to earn carbon credits. Through this Metro, the project has given a social lesson of a sense of discipline, cleanliness and enhanced multidimensional development of the place. According to the statistics of 2008 and 2009, DMRC earned Rs. 2.4 crore (USD 0.5 M) from the sale of 82,000 certified emission reductions (CER) under the carbon credits scheme by the Japan Finance Carbon Ltd. The Delhi Metro has been awarded OHSAS 18001(Occupational Health and Safety Assessment sequence 18001) by the Registro Italiano Navale India Pvt. Ltd. The DMRC received the ISO 14001 certificate for establishing an environmental management system making it the First metro in the world to receive this certification at the construction stage.

### 2.9 Result and Analysis

The case of Delhi metro showed the adoption and implementation of more sustainable forms of urban transport. DM achieved its milestone of success by making a feasible and most comfortable mode of public transport leading to a reduction in traffic congestion, reduction in noise and air pollution and ultimately enhanced the overall productivity of citizen of the city and businesses.

## 3. CONCLUSIONS

- It is also no doubt that the new technologies emerging along with the innovations will bring new vitality to the T.B.M as well as a brand-new concept to the construction.
- From the presented data for the T.B.M machines, as well as the data for their application in the tunneling, it can be concluded that these machine types should be used for excavation through most types of strata.

- The tunnel boring machines are machines with very high advancing speed and machines which do not have many limitations with aspect of the working environment. Indeed, it had revolutionized the creation of spaces under our cities allowing metro systems, water and sewage systems, and underground cable networks, all to be built in a safe and sustainable manner.

- T.B.M.s are very varied and their suitability for different soil conditions means that the correct choice of the machine and the level of experience of the operators is critical in their successful use.

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