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Planning of Tunnel Structures for Mass Rapid Transport System, Dehli

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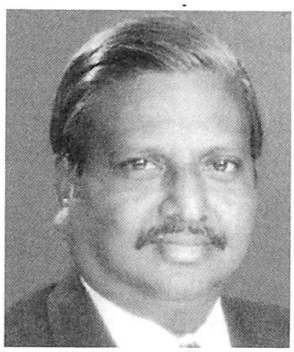

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Summary

Delhi, the national capital of India with a population of about 11 million is, perhaps, the only city of its size in the world, which depends almost entirely on buses as its sole mode of mass transport.The proposed Integrated Multi-Modal Mass Rapid Transport System for Delhi envisages construction of a network, having a combination of underground, elevated and surface sections totaling 198.5 km. The Modified First Phase, expected to cost around US$ 1.39 billion, shall have a 11 km Underground Metro Corridor passing through diverse types of soil and rock and hence calls for various types of construction methods; 7.53 km is proposed to be constructed by "Cut and Cover", 1.97km by "Bored Tunneling", and 1.53 km by "Rock Tunneling". The paper describes the project and details the philosophy of planning and designing the proposed "Tunnel" structures. It also analyses the economic considerations and reports the proposed financing plan.

1. Introduction

In Dehli, the bus services are inadequate and because heavily over-crowded. This has led to proliferation of personalized vehicles (around 2.7 million), and nearly 70% of these vehicles are two-wheelers. The result is extreme congestion on the roads, slow speed, increasing accident rate, fuel wastage and environmental pollution. With a view to reduce the problems of Delhi commuters, Government of India (GOI) and Government of National Capital Territory of Delhi (GNCTD) have launched the Integrated Multi- Modal Mass Rapid Transport System (MRTS) for Delhi at an estimated cost of Rs 48.60 billion (1.39 billion US$) at April 1996 price level, which includes a discounted Interest during construction of US$ 38.9 million. Like that of Singapore Mass Transit Project, which had a gestation of some 14 years, Delhi MRTS project also had a gestation of more than 20 years from 1974, when the first planning started. This was mainly due to the initial high priority of the developing country on public housing, schools, drainage, water supply and many other basic requirements than projects of this nature requiring heavy investments. Delhi Mass Rapid Transport System project will be implemented through Delhi Metro Rail Corporation Ltd., a para-statal joint venture company, set up on 50:50 partnership basis by GOI and GNCTD. The Delhi MRTS is essentially a "social" sector project, whose benefits will pervade wide sections of the economy. The economic IRR of the project has

been worked out as 21.4%, and the financial IRR is less than 3%. The full system (**Figure 1**) will have a network of 198.5 km. The Modified First Phase (**Figure 2**) shall cover a network of 55.3 km consisting of 11 km underground **Metro Corridor** (**Figure 3**) and 44.3 km of elevated/surface **Rail Corridors** (**Figure 4**). The Modified First Phase is estimated to carry 3.18 million passengers per day in the year 2005, when all the sections (55.3 km) of the Modified First Phase is planned to be commissioned. The passenger-km carried per day would be of the order of 23 million and the mean trip length would be 7.12 km [1].

2. Planning Objectives and Basic Parameters

The planning of Delhi Mass Rapid Transport System had 4 main planning objectives: (a) should meet the demand for the year 2001 and beyond, (b) should reduce the journey time, (c) should provide relief to the road system, and (d) should involve least investment. Naturally the system had to be a proven one instead of being experimented for the first time. This lead to a few other secondary objectives/ decisions: (a) should be such that the overall capital and operating costs are minimized, (b) should not only be efficient but the foreign exchange requirement should be minimum, (c) should be possible to easily manufacture the coaches in India; if imported, technology transfer should be feasible, (d) should exploit the airspace development (property development) over the stations and depots, (e)multi modal transport integration should be given importance to attract the commuters, (f) alignment shall be such that the requirement of urban land and disturbance to existing properties are minimized, (g) should link the existing Railway system, and adopt Indian Railway Standards as far as possible.

As per the Government policy of Unigauge, the "Broad Gauge"and a corresponding tunnel size of 5.4m has been adopted for Delhi MRTS. Several techno-economic studies were undertaken to optimize coach design, the guiding criteria being passenger comfort, reduced journey time and energy efficiency. Whereas the coaches proposed for Rail Corridors is 25kv Electric Multiple Unit (EMU) coaches, for the Metro Corridor three-phase AC induction motor drive with Variable Voltage Variable Frequency (VVVF) control and light weight coaches (3.2m wide) have been planned. Initially, coaches for Metro Corridor will require to be imported along with transfer of technology. Subsequently, the coaches will be manufactured indigenously. Considering the economy in the requirement of power during operation and the low initial investment, 1500 v dc with fixed overhead conductors have been proposed for Metro corridor. On economic considerations, only air cooling has been proposed in the underground Metro stations. Coaches also are not planned to be air conditioned. The requirement of the property development and multi-modal integration aspects have greatly influenced the planning and design of stations and the tunnel structures in the stations. Property development has been planned over the stations and depots and about 198 hectares of area is planned to be built.

3. Planning and Designing of Tunnels

The 11 km underground Metro Corridor between the proposed Vishwa Vidyalaya station and Central Secretariat station passes under some of the busiest areas of the city. The alignment passes through diverse types of soil and rock and hence calls for various types of construction methods. The work also involves working under the water table which is generally at 7 m below the ground level. The alignment has been kept shallow and the platform level is, generally, about 13 m below ground level. Rock comprisisng of quartzite and interbeded micaceous material is encountered between Delhi Main and New Delhi Stations, for a length of

about 1.6 km. Near Chawri Bazar station, the rock is at about 10 m depth from ground level. The rock is jointed with low RQD (Rock Quality Designation) with uniaxial compressive strength of 750 kg/sqcm to 1250 kg/sqcm. The balance portion of the alignment has non plastic to low plastic silty sand (alluvial) facilitating long lengths of bored tunneling. Plasticity Index of of soil varies from 2 to 8 and field permeability varies from 10^{-3} to 10^{-5} cm/sec. The section beyond ISBT upto Vishwa Vidyalaya has mixed type soil conditions of silty-sandy soil alternating with rocky ridge and, hence "Cut and Cover" construction method has been proposed, in this section. Thus, 7.53 km of the underground Metro Corridor is proposed to be constructed by "Cut and Cover" method, 1.97 km by "Bored Tunneling" method in soil with Tunnel Boring Machines (TBM) and 1.53 km by "Rock Tunneling" method. Presense of silty sand and high water table has necessitated adoption of diaphragm wall for retaining the soil in "Cut and Cover" section.

Cross sections of "Cut and Cover" box section and circular tunnel are shown in **Figure 5** and **Figure 6**. The tunnels are circular in shape considering the methodology of the execution of the tunnels and usage of tunnel boring machines. Whereas the diameter of tunnel adopted in Hong Kong, Calcutta and Singpore metros is 5.2m, Delhi shall have a tunnel diameter of 5.4m. In-situ lining in concrete in "Rock Tunneling" section and precast concrete lining segments in the "Bored Tunneling" are proposed. However, in the "Cut and Cover" section twin boxes are preferred considering easy method of construction. In most of the projects in India the desirable option is only concrete. Obviously, for the tunnels for the MRTS, the natural choice was concrete.It is proposed to construct the tunnels through design and construct contracts so that contractor can adopt their construction method and equipment. It is estimated that the construction of Metro Corriodor (11km) shall involve 3 million cum of earthwork, 0.68 million cum of concreting and also shall require 0.12 million tonne of steel.

Measures for controlling subsidence and settlement during tunneling have been proposed, which include provision of adequate soil cover over the tunnel, adoption of appropriate tunneling technology, use of segmental lining, use of tunneling shield, efficient and immediate grouting and soil stabilization over the tunnel and proper dewatering techniques. During construction, ground movement will be monitored regularly.

4. Stations

Stations in Underground Metro Corridor have been located on considerations of accessibility, integration with other modes, availability of space for parking, ease of passenger dispersal, etc. The Modified First Phase envisages construction of 10 underground stations; 9 stations by "Cut & Cover" method, in order to minimize the cost of construction and one station (Chawri Bazar), being located in a thickly populated area shall be constructed by "Rock Tunneling". The facilities provided in the stations shall be comparable to that provided in any other Metro in the World.

5. Estimated Costs and Financing Plan

The total estimated cost of the Modified First Phase at April 1996 price level works out to Rupees 48.6 billion (1.39 billion US$). The Civil Engineering construction cost of the tunnels of 5.4 m finished diameter by "Bored Tunneling" works out to approximately as US$ 22 million per route km at April 96 price level. The cost of construction of tunnel in rock works out to approximately US$ 19 million per route km. Cost of construction by "Cut and Cover" tunnels

works out to approximately US$ 29 million per route km. Whereas the total capital costs including that of rolling stock, land etc., incurred/ estimated (updated to April 1996 price level) for the Metros in the World works out to 61-201 million US$ per route km [3], the estimated cost of the proposed MRTS for Delhi is 60.9 million US$ (based on the exange rate of Rs. 35 per 1 US$). It could be seen that the system planned for Delhi is economical, in addition to being easier to construct by national contractors. The project shall be financed by the Overseas Economic Cooperation Fund (OECF) loan of Japan to the extent of 56% of the estimated capital cost; 30% of the capital cost shall be contributed equally by GOI and GNCTD and 8% shall be subordinate debt towards the cost of land. It is estimated that property development may generate the balance requirement of about 6% of capital cost, during construction stage.

6. Conclusions

Efforts are on to optimize the size of structural members and to improve the aesthetics further. Utility of space in underground tunnels and stations has also been planned to be optimized by adopting economic layout techniques. The Project will throw up a number of challenges to the Design Engineers and Construction Engineers, in view of a wide variety of constraints that are required to be taken care of during construction.

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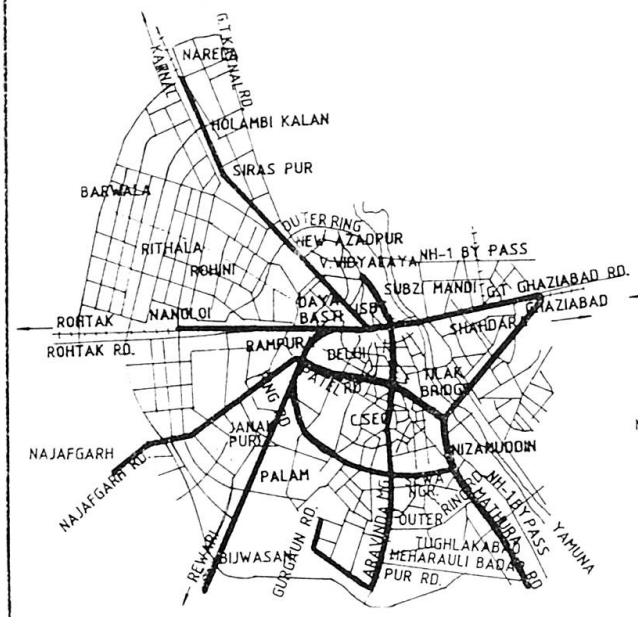


Fig. 1 Full System of Delhi MRTS

Fig. 2 Modified First Phase of Delhi MRTS

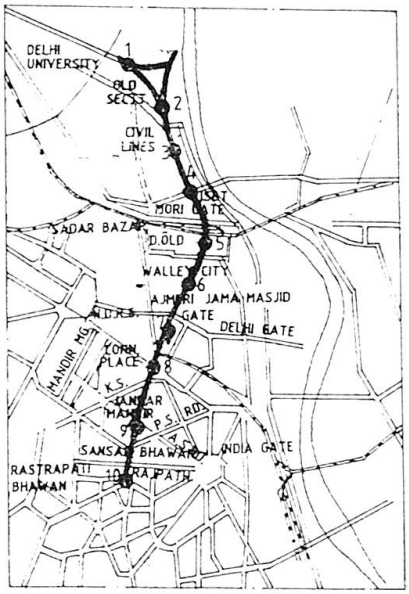
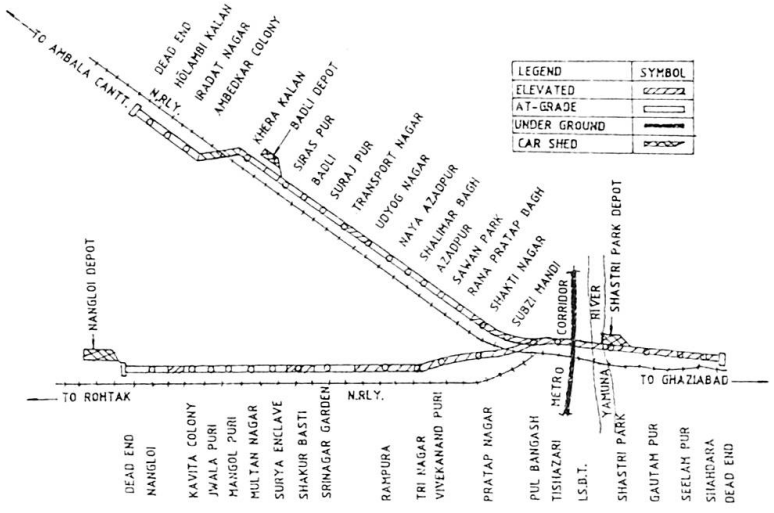


Fig. 3 Key Plan of Metro Corridor



LEGEND	SYMBOL
ELEVATED	
AT-GRADE	
UNDER GROUND	
CAR SHED	

Fig. 4 Key Plan of Rail Corridor

STATIONS OF METRO CORRIDOR

1. VISHWA VIDYALAYA
2. OLD SECRETARIAT
3. CIVIL LINES
4. ISBT
5. DELHI MAIN
6. CHAWRI BAZAR
7. NEW DELHI
8. CONNAUGHT PLACE
9. PATEL CHOWK
10. CEN. SECRETARIAT

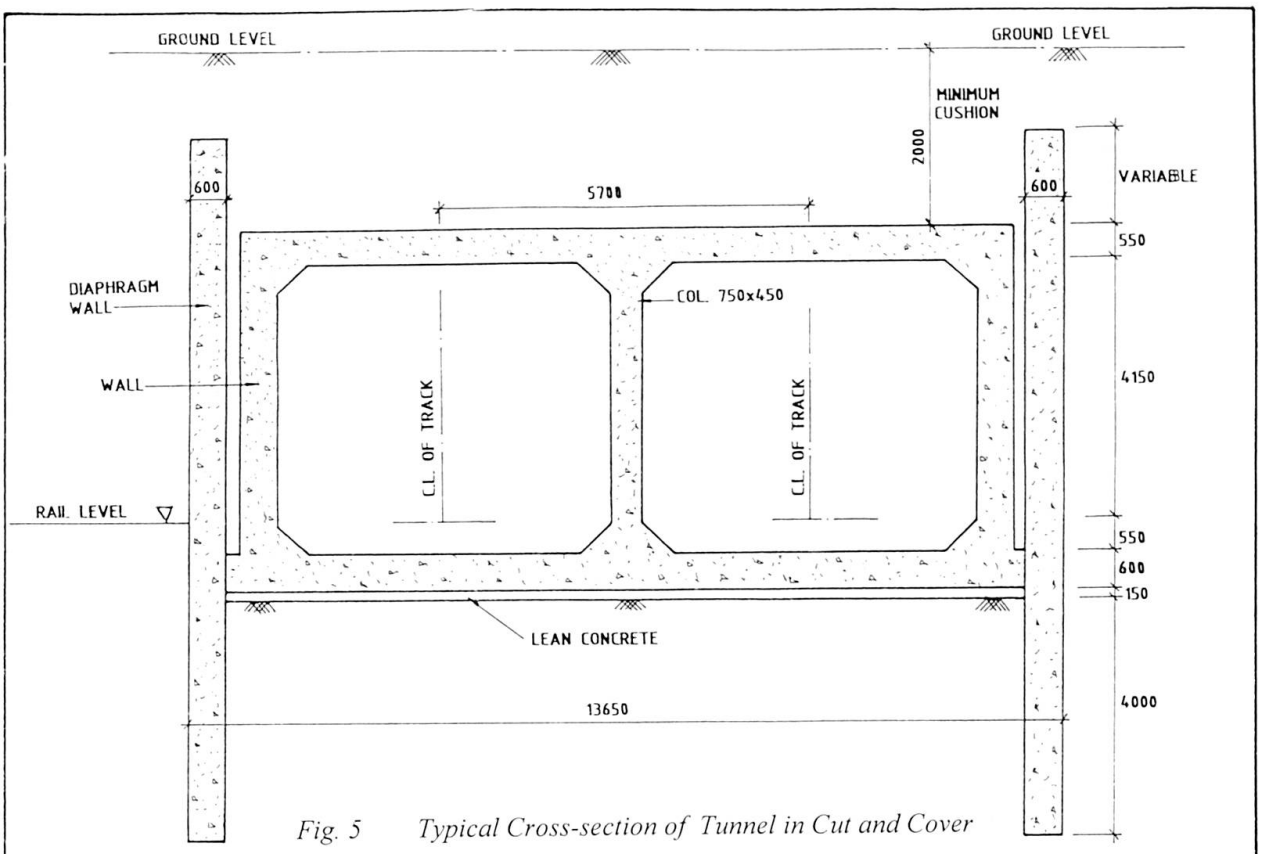


Fig. 5 Typical Cross-section of Tunnel in Cut and Cover

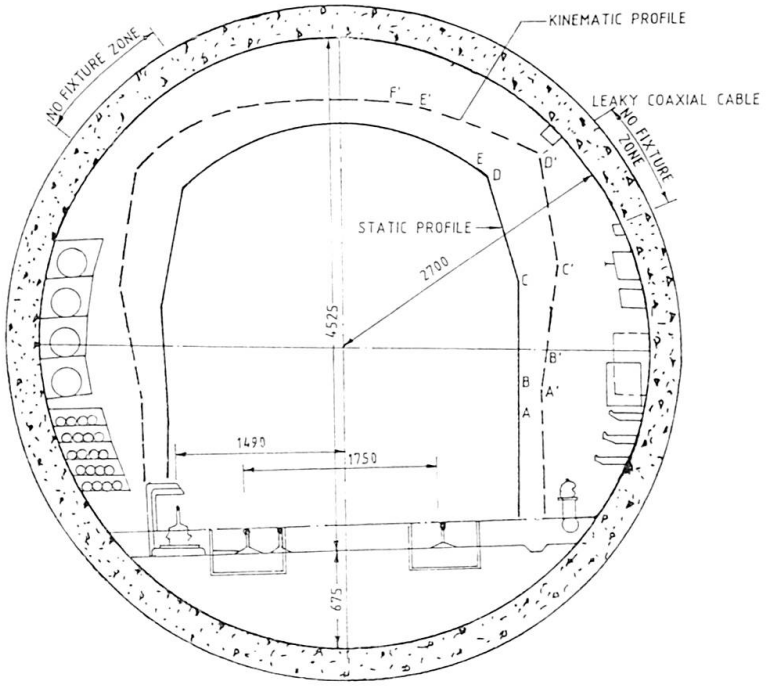


Fig. 6 Typical Cross-section of Tunnel in Rock Tunneling