Third Report

INDIAN ENGINEERING HERITAGE (RAILWAYS)

Indian National Academy of Engineering

June 2012

Third Report

INDIAN ENGINEERING HERITAGE

(RAILWAYS)

Indian National Academy of Engineering

June 2012

FOREWORD

India has rich engineering expertise and possesses extraordinary engineering accomplishments in diverse areas such as monuments; irrigation systems; bridges; metallurgy; engineering goods; engineering materials and textiles etc. The task of documenting these accomplishments is a mammoth one and the literature available in libraries of Archeological Survey of India, State Museums, Professional Societies and with individuals is fragmented, and sometimes not easily accessible.

Indian National Academy of Engineering (INAE) constituted Expert Study Groups on Railways, Civil Engineering and Metallurgy to compile information and documentation on the outstanding engineering achievements and create an Archive of Indian Engineering Heritage. Currently, it has three components, viz., Railways, Civil Engineering and Metallurgy which are steered by Shri V.K. Agarwal, Prof. CVR Murty and Dr. S Srikanth respectively.

The history of the Railways although more than 150 years, is very vast and needs to be preserved for posterity. There is a growing need to examine and collate the data available, and present a comprehensive historical perspective on the Indian Railways. A study of this nature helps in improving the awareness, preservation and appreciation of this wonderful and inspiring engineering heritage.

The First (2004) and Second (2008) Reports on Indian Engineering Heritage (Railways) prepared by the Study Group have already been published by INAE. These have covered various domains like Railway Gauge, Permanent Way, Bridges, Hill Railways, Locomotives and other Rolling Stock, Mechanical Workshops, Production Units, Electrification, Train Lighting and Air Conditioned Coaches, Signaling & Telecommunications, etc. This Third Report (2012) covers Rail Based Urban Transport Systems, Heritage Railway Buildings, Tunneling, and River Training and Bridge Protection Works.

The Study Group consists of two INAE Fellows (Shri V.K. Agarwal as Chairman and Dr. Y.P. Anand) and fourteen Senior Railway Retired Officers from different Railway disciplines who are eminent professionals having more than three decades of experience in the relevant fields.

I am confident that this Third Report on Indian Engineering Heritage (Railways) will be well received by the Engineering Community and interested professionals.

Dr. Baldev Raj
President INAE

PREFACE

THIRD REPORT – JUNE 2012

The work of **INAE Study Group – Indian Engineering Heritage (Railways)** has already been published by the Indian National Academy of Engineering under Two Reports titled :

1. First Report – Indian Engineering Heritage (Railways) – 2004.
2. Second Report – Indian Engineering Heritage (Railways) – January 2008.

The Second Report was an all comprehensive Report having Fourteen Chapters covering the various facets of the historical development of technology on Indian Railways in various areas like Railway Gauge, Permanent Way, Bridges, Hill Railways, Locomotives and other Rolling Stock, Mechanical Workshops, Production Units, Electrification, Train Lighting and Air Conditioned Coaches, Signalling & Telecommunications, etc.

Evers since the publication of the Second Report (Jan. 2008), the Group has been working to finalise those areas which had not been covered earlier and, in this regard, this Third Report covers the following areas in Four Chapters :

- **i) Rail Based Urban Transport Systems**
- **ii) Heritage Railway Buildings**
- **iii) Tunneling**
- **iv) River Training and Bridge Protection Works**

The Group presently consists of two INAE Fellows (Shri V. K. Agarwal as Chairman & Dr. Y. P. Anand) assisted by 14 other Senior Retired Railway Officers from different Railway disciplines who also are Members / Fellows of various Professional / Management Institutions. All of them have more than three decades of technical experience in the relevant fields. The Group meets about 4-5 times in a year and is very conscious to observe austerity in all its activities.

The current List of the 16 Members of the Group is as under :

* 1.	Shri V. K. Agarwal	– Former Chairman Railway Board
* 2.	Dr. Y. P. Anand	– Former Chairman Railway Board
3.	Shri S. S. Khurana	– Former Chairman Railway Board
4.	Shri R. R. Bhandari	– Former Member (Mech.), Railway Board
5.	Shri S. P. S. Jain	– Former Member (Engg.), Railway Board
6.	Shri V. N. Mathur	– Former Member (Traffic), Railway Board
7.	Shri S. C. Gupta	– Former Member (Elect.), Railway Board
8.	Shri R. K. Vir	– Former GM CLW
9.	Shri Hari Mohan	– Former DG, RDSO

10. Shri A. K. Jain – Former Addl. Member (Electrical), Railway Board
11. Shri Chandrika Prasad – Former Addl. Member (S&T), Railway Board
12. Shri M. M. Agarwal – Former CE, Northern Railway
13. Shri A. K. Gupta – Former CAO (R) DMW
14. Shri B. K. Agarwal – Former Adv. (L&A), Railway Board
15. Shri K. P. Singh – Former Exec. Dir. (W), Railway Board
16. Shri Vijay Kumar Dutt – Former Addl. Member (Elect.), Railway Board

* Fellow Indian National Academy of Engineering.

The Group is now studying the **History of the Role of Technology in Capacity Augmentation and Railway Development** for the various concerned areas listed below :

1. Track
2. Bridges
3. Other Civil Engineering facilities
4. Rolling Stock – Wagons
5. Rolling Stock – Coaches
6. Electrical Multiple Units
7. Diesel Multiple Units
8. Motive Power – Steam
9. Motive Power – Diesel
10. Motive Power – Electrical
11. Railway Electrification
12. Railway Workshops
13. Signaling & Train Control
14. Telecommunications
15. Operations / Operational Practices
16. Research & Technology Development - RDSO

During this Study, various aspects like Safety, Speeds, Environment, Information and Communication Technology (ICT), and Futuristic Trends will also be examined. The work is underway in this regard and it is intended to publish it in the next Report, viz, the Fourth Report.

(V. K. Agarwal)
Chairman of the Study Group

June, 2012

Contents

CHAPTER-I

RAIL BASED URBAN TRANSPORT SYSTEMS

I.1 GENERAL

With the growth of cities horizontally, people found it extremely difficult to find suitable accommodation within the municipal limits. This forced a large number of people residing outside the city boundaries which started growth of satellite towns. While a large population started living in these satellite towns, still they had to commute to the main city for work and commercial activities. This necessitated development of rail based suburban system connecting the satellite towns with the heart of main cities.

I.1.1 Development of Suburban System in India

I.1.1.1 While the first metro system in the world started as early as in 1838 in the city of London, in India, Mumbai had the privilege of having, first rail-based mass transit system in 1853 itself as the first Railway line was providing facility of commuting to its suburbs in Thane. The first length was doubled in 1865 and quadrupled in 1915. At about the same time, a 3.5 km double line section was laid on a parallel corridor from Mumbai Central to Grant Road in 1870. Electrification of these lines on the suburban portion was completed in 1925 and the first electric train started on 3rd Feb 1925.

I.1.1.2 Chennai (Madras) was the next city in India where suburban system was developed. In Madras, the southern intercity meter gauge line was commissioned in 1876, extending from Chennai Beach which was adjacent to the port, around which the town was growing. The section was electrified on 2.4.1931 with 1500V DC. This was the only electrified meter gauge section in the country. Incidentally, this section has now been converted to broad gauge. Detailed information in respect of urban and suburban rail based commuter systems is given in the following paragraphs.

I.1.2 Development of Urban Systems

It may be noted that while urban system indicates a system mainly limited within the municipal limits of the city, it is difficult to make a clear distinction between an urban and a suburban system, as these two systems tend to fuse together when the city grows rapidly outwards and suburbs grow towards the city as is being observed in most of the metro towns.

I.1.2.1 Urbanization

Since 1960 India's total population has increased three fold, and the urban share has risen from 17 percent to about 30 percent. This urbanization process has involved the largest shift of population that has ever occurred (with the exception of China). Almost 60 percent of the country's GDP comes from urban areas (2005 data). Such urbanization and surging economic growth has led to an inevitable rise in ownership and use of motorized vehicles across cities and towns. The average two wheeler and car ownership levels in metropolitan cities have, during the decade of 2000-2010, more than doubled, and motorized per capita trip rate has also increased by 60 percent.

These changes in travel patterns are placing heavy pressures on the available transport infrastructure and on the institutions in charge of road construction and maintenance, traffic management, road safety, and public transport services. The most visible consequences include greater traffic congestion, increased air pollution, and more traffic accidents. Such changes are also accompanied by a number of less visible, but equally costly, consequences, such as increased travel time, reduced predictability of travel time, more hazards and impedances for pedestrians and, most importantly, **increased greenhouse gas (GHG) emissions.** While GHG emissions from India's urban transport sector currently (2011) are relatively low (less than ten percent of India total), the urban transport sector is becoming the fastest growing sector in terms of consumption of fossil fuel. It is projected that if the current urbanization and motorization trends continue, GHG emissions from urban transport could be eight to ten times higher than the current level by 2030.

Recognizing the commonality of many of the transport problems that urban areas are facing, the policy makers have been forced to encourage increased use of public transport by making it safe, affordable, quick, comfortable, reliable and sustainable for the growing number of city residents travelling to jobs, for education, recreation and such other needs. This has inevitably led to adoption of "Rail Based Mass Rapid Transit System' commonly known as 'Metro System' ".

Though the first Metro System was started in Kolkata, owned and operated by Indian Railways, it acquired a certain level of acceptability and maturity only after it was planned and started in Delhi. The citywise details of Metro Systems are given in subsequent Paragraphs.

I.2 MUMBAI

I.2.1 Mumbai Suburban System

I.2.1.1 General

I.2.1.1.1 Mumbai is the commercial capital of India and has the maximum floating population. It is also the biggest metropolitan town of India. Because of the very high cost of real estate, a large number of people reside in the nearby suburban townships and come to the downtown of Mumbai for work and business. This puts the city's public transport system under great pressure. The traffic is shared equally by the rail based system and public buses.

I.2.1.1.2 The metropolitan town of Mumbai is served by the largest system of suburban railway system and falls both under Central Railway and Western Railway Administration which are headquartered at Mumbai and are also responsible for running of mainline long distance trains. Mumbai has five distinctly identified suburban corridors serving the needs of daily commuters as described in the following paragraphs.

I.2.1.2 Central Railway (CR)

I.2.1.2.1 **Chhatrapati Shivaji Terminus (CST) to Kalyan**, a distance of 54 Km. This corridor is having 26 stations. The subsection between CST and Kurla (15.4 Km) is served by 3 pairs of lines, of which 2 are fast lines and 1 is slow line. The fast lines are also shared by main line trains. The subsection between Kurla and Thane (18 Km) is having 2 pairs of lines and another pair is under construction. The section between Thane and Kalyan is having 2 pairs of lines. Some of the suburban trains also go beyond Kalyan, upto Karjat (100 Km) towards Pune and upto Kasara (121 Km) towards Nasik.

I.2.1.2.2 **Chhatrapati Shivaji Terminus to Panvel (49 Km)** having 24 stations. This line is also known as Harbour line and serves the main areas of Navi Mumbai. There is only 1 pair of track exclusively used by the suburban trains.

I.2.1.2.3 **Wadala to Andheri (12 Km).** This section provides connectivity between the Central Railway and Western Railway systems and has 8 stations served by 1 pair of track.

I.2.1.2.4 **Thane –Turbhe –Vashi (22 Km)** – This section has been recently upgraded to run suburban trains and is having six modern suburban stations served by one pair of track. The first suburban train on the section was run on 24.8.2004.

Map of Mumbai Suburban System including Versova-Andheri-Ghatkopar East-West corridor under construction

I.2.1.3 Western Railway (WR)

I.2.1.3.1 Churchgate to Virar (60 Km). This is the main line section of WR and has got 2 pairs of lines between Churchgate to Borivali (34 Km). Recently, the section between Borivali and Virar (26 Km) has also been quadrupled. There are 26 stations between Churchgate and Virar. Some of the suburban trains also go up to Dahanu Road, a station 64 Km beyond Virar.

I.2.1.4 Traction Voltage

The main line trains as well as suburban trains in and around Mumbai are run at 1500 volt DC supply upto Pune and Igatpuri on Central Railway and upto Virar on Western Railway. The first electric service started on C.Rly. in 1925 and on W.Rly in 1928, prior to which all services were on steam traction. The work of Conversion of traction voltage from 1500 volt DC to 25000 volt AC was sanctioned long back in the year 1996. While the entire routes on Western Railway have already been converted to AC traction (the last section converted in February 2012), it is slated for completion on Central Railway by end of 2012-13.

The entire suburban system is operated by standard Electric Multiple Units (EMUs), 3.66 meter (12 feet) wide stock. The rakes have got 9 cars and 12 cars with one motor coach in every 3 coaches (the other 2 being trailer coaches). There is a programme to convert most of the 9 coach rakes to 12-coach rakes, for which necessary infrastructural works are being executed. While most of the rakes are operated with 1500 volt DC power, some of the rakes, introduced recently are dual voltage rakes and can operate both with 1500 Volt DC and 25000 volt AC power, known as AC/DC rakes. The coaches are non-air-conditioned and have manually operated door shutters. All the coaches will eventually be replaced by stainless steel light weight air springed coaches under MUTP-II **Project.**

Existing coaches

New coaches under MUTP-II

Inside view of new coaches

I.2.2 Mumbai Rail Vikas Corporation (MRVC)

I.2.2.1 Central Government through Ministry of Railways and the Maharashtra Government have jointly set up a Corporation on July 12, 1999 for the planning and construction of some of the works and procurement of rolling stock to ease the heavily crowded Mumbai suburban system. A number of new works, as listed below, are under execution under Mumbai Urban Transport Project (MUTP)-II. MUTP-I was primarily for improving the road junctions and the Signalling system. The main objectives of the MRVC are as under :

- Integrate suburban rail capacity enhancement plans with urban development plan for Mumbai and propose investments;
- Implement the rail infrastructure projects in Mumbai suburban sections;
- Commercially develop Railway land and airspace in Mumbai area to raise funds for suburban railway development;
- Resettlement & Rehabilitation of Project Affected Households.

The requirement of funds for the above comes from the following sources:

- Budgetary support from Government of Maharashtra and Indian Railways;
- Revenue from commercial development of Railway land airspace;
- Borrowings to be decided with mutual consent of Government of Maharashtra and Indian Railways including from World Bank.
- Surcharge to be levied on commuters from a date to be mutually agreed upon between Government of Maharashtra and Indian Railways.

I.2.2.2 Important works planned under MUTP-II

	Unit (Rs.)
• Kurla-CSTM 5th and 6th lines	581 cr
• Thane Diva addl pair of tracks	109 cr
• Borivali-Mumbai Central 6 line	442 cr
• Harbour line uoto Goregaon	83 cr
• EMU procurement and manufacturing	2495 cr
• Maintenance facilities for EMUs	184 cr
• Stabling lines for EMUs	114 cr
• Resettlement and Rehabilitation (R&R)	105 cr

I.2.3 Mumbai Metro

I.2.3.1 While the north-south trips are well served by the existing network of Central and Western Railways there is no efficient mass rapid transit system for those commuters who want to travel in east-west directions. To give relief to east-west commuters, a study was undertaken under the Indo-German Technical cooperation during 1997-2000 which recommended a mass transit corridor from

Andheri in west to Ghatkoper in east. The recommendations were reviewed and updated by M/S CES appointed by MMRDA (Mumbai Metropolitan Region Development Authority) in the year 2003. Delhi Metro Rail Corporation (DMRC) were appointed to prepare a detailed report for the Project. The study estimated the maximum one way peak hour flow to be 17356 in 2008 and 30491 in the year 2031.

The Mumbai Metro Project has been planned in three phases. Phase I covers a total length of 62.68 km. It includes the 11.07 km Versova-Andheri-Ghatkopar route, the 20 km Colaba-Bandra section and 31.8 km Charkop-Bandra-Mankhurd route.

Phase II has been planned to cover the 7.5 km Charkop-Dahisar route, the 12.5 km Ghatkopar-Mulund route and 19.5 km BKC-Kanjurmarg via Mumbai Airport sections. Phase II will be executed in 2012-2017.

Phase III will include the development of the 18 km Andheri East-Dahisar East route, the 21.8 km Flora Fountain and Ghatkopar and an underground section route. Phase III will be executed in 2016-2021.

I.2.3.2 Salient Features

Versova-Andheri-Ghatkoper

Length - 11.443 Km from Versova to Ghatkoper with link to Airport (1.265Km)
Alignment

Fully elevated Stations Total 13 nos – Versova, DN Nagar, Azad Nagar, Andheri, WEH (Western Express Highway), Chakala, Airport Road, Marol Naka, Sakinaka, Subhash Nagar, Asalpha Road, Ghatkoper and Sahar Airport

Track Gauge - 1435 mm (standard gauge) as against broad gauge in main and all other suburban lines.

Gradient - 4% maximum

Curvature - 100 meter radius minimum

Platform length - 90 meters

Traction - 25000 volts AC

Signalling

Train Composition - 4 coach train units

I.2.3.3 Project Implementation

The first line (phase I) connecting the regions of Versova, Andheri and Ghatkopar (VAG) is under construction. As of September 2011, 80% of a three kilometre Versova-Azad Nagar section of phase I construction was completed, with that section expected to be operational by the end of 2012.

Reliance Industrial Infrastructure Limited (RIIL), as part of a consortium involving European rail operator Connex, the Mumbai Metropolitan Regional Development Authority, Hong Kong's MTR and France's Veolia Transport, won the build-own-operate-transfer contract for this route at a fee of INR 23.5 bn ($510 m).

This will see the consortium manage the first three metro lines for 35 years before being transferred to a new operator. The Indian Government is funding INR 6,500 m in viability gap funding. A special purpose vehicle, Mumbai Metro One, was created by RIIL for implementing phase I.

Phase II, which will connect Charkop, Bandra and Mankhurd, has been awarded to the consortium made up of RIIL, SNC Lavalin, Canada and Reliance Communication. The contract, in which the Consortium was the only bidder, was awarded in August 2009, at a fee of INR 110 bn (approximately $2.3 bn). Phase II route is expected to be operational by 2015

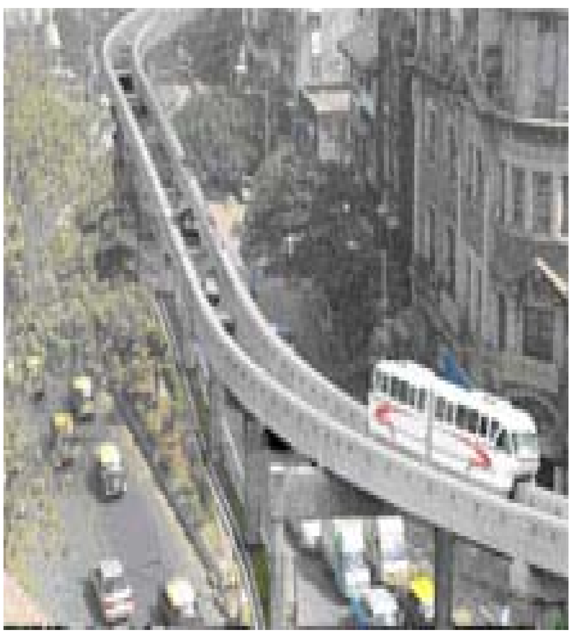
The third metro line (phase III) is still underway and consists of two elevated and 14 underground stations.

Construction of Versova-Andheri-Ghatkoper-1

Construction of Versova-Andheri-Ghatkoper-2

I.2.4 Mumbai Mono Rail Project

I.2.4.1 Mumbai is going to become the first city of India to have a Monorail System for mass transit of commuters. It is planned to connect Chembur with Jacob Circle via Wadala by a monorail system. The monorail has been justified here because of area being very congested clustered with high rise buildings and existence of narrow streets. The Project has been jointly undertaken by Mumbai Metro Region Development Authority (MMRDA) and Government of Maharashtra and is being executed by a consortium of Larsen and Toubro (L&T) Ltd India and Scomi Engineering Bhd. Malaysia. M/s Louis Berger Group, INC have been appointed as proof checking consultants. The work on the Project has already started and first trial run was accomplished in a small stretch of 108 meters near Wadala on 26th Jan. 2010. The trial run of the first section between Wadala to Bhakti Park , a distance of nearly one kilometer was accomplished on 18 February, 2012. The work in the first section between Wadala and Chembur is nearly complete and is expected to be operational by the end of May 2012. The remaining section between Wadala and Jacob Circle is likely to be completed by December 2013.



Artistc view of Mumbai monorail

Route map of monorail system

I.2.4.2 Salient features

- Length of corridor — Section 1 11.28 Km (Jacob Circle – Wadala)
  Section 2 8.26 Km (Wadala-Chembur)
  Total 19.54 Km
- Peak Hour peak direction traffic — 7400 (2016) 8300 (2031)
- Corridor ridership perday in Lakh — 1.25 3.0
- Design headway — 3 min
- Train Composition — 4 cars
- Train capacity — 568 passengers
- Design speed — 80 kmph
- Schedule speed — 31 kmph
- Journey time — Sec 1- 25 min Sec 2- 19 min
- Guideway — Two beams on single column structure, generally on median of the road
- 94% alignment on gradient
- 9 Km on curves in 19.54 Km
- Horizontal curve radius - 100 m (nominal), 50 m (min)
  Design life 120 years

I.2.4.3 Stations

- No of stations
  Section 1 - 11
  Section 2 - 7
  Total 18

I.2.4.4 Traction system

- Power supply — 750 volts DC power rails fixed on both sides of beam
- Traction substations — 5 nos, 6 MVA each
- Power demand — 13.39 MVA (year 2031)

I.2.4.5 Signalling system

- Computer based Centralised Train operation and Management
- ATC and line side LED signals
- ATP with Train Describer
- Traffic control at Operational Control Centres (OCC) and Control room

I.2.4.6 Communication system

- Optical fibre based
- Digital Trunk Radio Tech (TETRA) standards Communication between motorman, Central control/station, Depot, Maintenance parties, Security personnel.

- Telephone exchange of 500 lines
- Passenger announcement system from station and OCC
- Centralised clock system
- CCTV for surveillance

I.2.4.7 Future Planning

Eight more section have been planned as per following details

Section	Length in kilometres
Mulund – Goregaon - Borivali	30
Virar - Chikhaldongri	4.60
Lokhandwala - SEEPZ - Kanjurmarg	13.14
Thane - Mira-Bhayandar - Dahisar	24.25
Kalyan - Ulhasnagar - Dombivli	26.40
Chembur - Ghatkopar - Kopar Khairane	16.72
Mahape - Shil Phata - Kalyan	21.10
Thane - Bhiwandi - Kalyan[16]	30

Depending upon the resources, the above new sections have been planned to be completed by 2021.

I.3 DELHI

I.3.1 Delhi Metro Rail Corporation

I.3.1.1 Introduction

Delhi Metro Rail Corporation Ltd. (DMRC) was set up with the approval of Central Government on 3rd May, 1995 for the work of planning, construction and operation of a Mass Rapid Transit System (MRTS) in National Capital Region Territory (NCRT) of Delhi. DMRC has a 50:50 share of the Government of Delhi and the Central Government. DMRC started working on the basis of the Report on Integrated Multi Modal Mass Rapid Transport System (IMMRTS) of Delhi. However, prior to the report of IMMRTS, a lot of work was done towards the planning of a mass rapid transport system for Delhi. Planning Commission requested Central Road Research Institute (CRRI) for a traffic survey. Railway Board set up the Metro Transport Project Organization (MTPR) for Delhi alongwith other metro towns in 1971. This organization conducted engineering survey alongwith various routes including suburban lines to Faridabad, Ghaziabad, Khurja, Panipat and Rohtak.

I.3.1.2 Phase -1

DMRC took up the work of 55.3 km of route length in the first phase which included an underground alignment of 11 km between Vishwa Vidyalaya and

Central Secretariat and 44 km of surface / elevated alignment connecting Shahdra to Nangloi and Holambi Kalan. Physical work on the project started on October 1,1998 and the first stretch of 8.3 km length – partly surface and partly elevated connecting Shahdra and Tis Hazari was commissioned on December 24, 2002. However, the surface / elevated route got further modified and replaced by a different route connecting Shahdra to Rithala (22 km) and Barakhamba to Dwarka (22.8 km). During course of time, sub-sections were added to these routes, which finally became 65.10 km long. Different routes commissioned in Phase 1 are given in Table 1:

Table 1

Line Name	Connecting Stations	Length (in km)	No. of Stations	Date of commissioning
Red Line (Surface/Elevated)	Dilshad Garden – Rithala	25.15	21	December,2004- June, 2008
Yellow Line (Underground)	Vishwa Vidyalaya – Central Secretariat	10.84	10	December 2004
Blue Line (Elevated and partly underground)	Indraprastha – Dwarka Sub City	32.10	31	December 2005

I.3.1.3 Phase-2

Under Second Phase, a number of new alignments and extensions of some alignments of Phase 1 were planned, all of them have already been commissioned Detailed position as available at present is shown below in Table 2.

Table 2

Line Name / Number	**Connecting Stations**	**Length (in km)**	**No. of Stations**	**Date of commissioning**
Yellow Line	Vishwa Vidyalaya – Model Town – Jahangirpuri	6.36	5	October 2009
Yellow Line	Central Secretariat – Qutab Minar – Huda City Centre (Gurgaon)	27.45	19	September 2010
Violet line	Central Secretariat – Nehru Place - Badarpur	20.16	15	October , 2010—January 2011
Blue line	Dwarka Sector 9 – Sector 21	2.26	2	December 2009
Blue line	Indraprastha – Mayur Vihar – NOIDA Sector 32 City Centre	15.07	11	Nov 2009
Blue	Yamuna Bank – Anand Vihar	6.17	5	January 2010
Green	Inderlok – Kirti Nagar - Mundka	18.46	15	April 2010
Airport Express	New Delhi Rly Station – IGI Airport-Dwarka Sec 21	22.7	4	February 2011
Blue	Anand Vihar – Vaishali (Ghaziabad)	2.57	2	July 2011

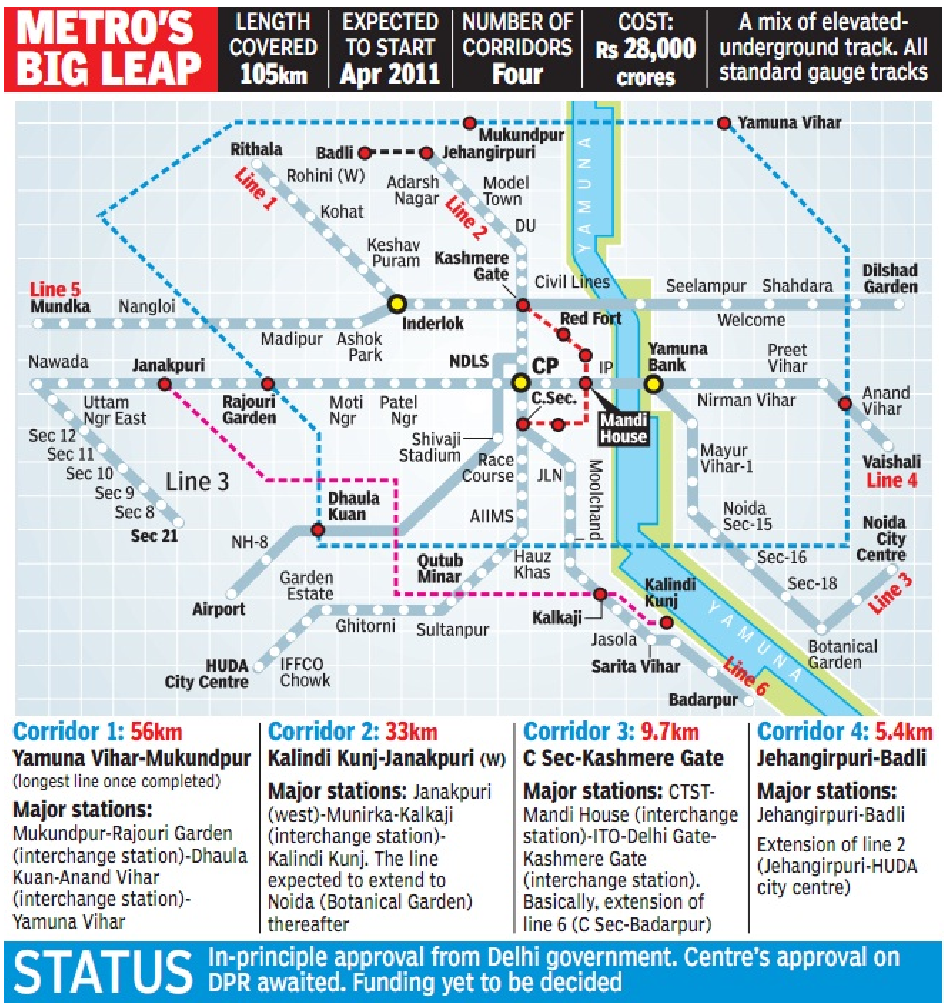
I.3.1.4 Further Phases

Phase 3

Under Phase 3, four corridors are under considerations of which ‘in-principle approval has been obtained. These phases are:

1. Mukundpur-Yamuna Vihar: Length-56 km,
2. Kalindikunj-Janakpuri (likely to be extended to Botanical Garden in Noida)- length-33 km
3. Central Secretariat –Kashmere gate-length-9.7 km
4. Jehangirpuri-Badli- length- 5.4 km

Diagram of the Phase 3 network is given below:



Phase Four (Target = 2021)

This phase has a 2021 deadline. Following lines will be constructed / extended in this phase :

Table 4

1	Sarai Kale Khan ISBT – Anand Vihar – Dilshad Garden – Yamuna Vihar – Sonia Vihar	22 km
2	Sarai Kale Khan ISBT – Nehru Place – Palam – Reola Khanpur	28 km
3	Mukundpur – GTK By-Pass – Pitampura – Piragarhi – Janakpuri – Palam	20 km
4	Ghazipur – Noida Sector 62	7 km
5	Dwarka Sector 21 – Chhawla	6 km
6	Arjonda – Kheri	5.5 km

Total Length = 108.5 km

I.3.1.5 Construction Challenges

I.3.1.5.1 Learning from the experience of Kolkata Metro, a number of innovative methods have been adopted to reduce the problems faced by citizens during construction. Construction areas have been bounded by erecting steel curtain walls all along the routes well in advance. As most of the construction work is along the existing heavily crowded roads, great attention has been paid to the traffic management and steps have been taken to reduce congestions by diverting the road traffic to adjoining roads and making some of the roads as one way. Construction activities have been limited at site by resorting to use of pre-cast pre-stressed girders wherever possible. In the stretch having under ground alignment, Tunnel Boring Machine (TBM) has been used for the first time in the country. It has been possible to achieve a maximum progress of 409 meters in a month with the TBM, apart from eliminating the problems associated with open excavation which has been limited to the construction of underground stations.

Tunnels with circular cross section can be excavated by Tunnel Boring Machines in all types of soil without causing any disturbances to the surface structures.

Cutting End View of a Tunnel Boring Machine

Tunnels as large as 20 m in diameter have been bored by TBMs. Pre-cast elements are placed immediately behind excavation as tunnel lining. As many as 14 TBMs have been used In DMRC at a time. Transportation of surplus muck has been restricted only during night hours. Each truck carrying muck is required to clean its tyres before it enters the city roads.

Inside View of Metro Tunnel

I.3.1.5.2 Construction of Extradosed Bridge

India's first Extradosed Bridge has been built between Metro Stations Pragati Maidan and Indraprastha where the DMRC tracks cross over the tracks of Indian Railways New Delhi-Mathura main line.

The Extradosed Bridge derived its name from the French word *"extra dosse."* It is a mix of typical cable stayed bridge and a normal grider bridge. This bridge is having an overall length of 196.3 meters with the main span over the railway line being 93 meters long. The bridge has been designed by French company Systra. The construction of the bridge involves a technology where the bridge is constructed without disturbing the rail traffic underneath.

A train passing below an extradosed bridge under construction

A similar bridge has been constructed near Mool Chand crossing on Central Secretariat-Badarpur corridor, a 21.16 km long section. This bridge is 167.5 meter long with three large spans; central span being 65.5 meter across and the other two side spans being 51.5 meter across.

I.3.1.5.3 Segmental Construction

Most of the DMRC alignment is on elevated structure where the road traffic is running very close to the metro alignment. With a view to have minimum disturbance to the road traffic, segmental construction has been adopted in most of the stretches which gives the benefit of minimum interruption to the road traffic, fast speed of construction and maintaining a higher standard of quality in construction.

View of Segmental Construction

Under this method, pre-cast segments of the bridge are brought together and hung with the help of an erection gantry which is supported on auxiliary supports constructed around the piers. After all the segments are brought in position, external force is applied to the steel cables by post tensioning

The method is very fast thereby economical as the casting of segments is done in advance under controlled conditions in casting yards.

View of an Elevated Metro Station

I.3.1.6 Track Gauge

The matter of selection of a proper gauge for the system has always been a tricky job. Britishers adopted broad gauge (5'-6") in India than what was existing in England (Standard Gauge of 4'-8 1/2") on account of local conditions in spite of the fact that locomotives and carriages of standard gauge were readily available. Delhi Metro System also had a lot of controversy on this issue. Indian Railways, the authority on technical matters of Delhi Metro, suggested adoption of broad gauge of 1676 mm (5'-6") so as to have inter-changeability with the existing system of Indian Railways where a number of suburban trains are operated to cater to the need of a large number of commuters residing in satellite towns around Delhi. Further, Ministry of Railways argued that broad gauge would enable the system to carry a very large number of commuters which is the basic requirement of MRTS. The matter was finally decided by the Group of Ministers in their meeting held on 4th Aug, 2000. in favour of broad gauge. In view of this, all initially planned routes of Delhi Metro are with broad gauge with the exception of Airport line connecting IGI Airport with New Delhi Railway Station, Central Secretariat – Badarpur and Kiritinagar/Inderlok – Mundka routes which are planned with standard gauge of 1435 mm (4 feet – 8-1/2 inch)

I.3.1.7. Rolling Stock

The Rolling Stock of Delhi Metro is provided with latest state-of-art technologies to ensure high level of reliability and minimum maintenance. Some of the salient features are:

1. Car bodies of stainless steel to eliminate corrosion repairs during service life of 35 years.
2. Bolsterless bogies with air suspension ensuring same height of doors with respect to platforms under varying passenger loads in the car
3. Excellent steering capability of bogies to negotiate sharp curves up to 300 meters, common on Metros
4. Microprocessor controlled braking system ensuring optimum blending of pneumatic and electric braking and maximum regeneration
5. Disc brakes in lieu of tread brakes in recent cars
6. Stainless steel brake piping and other components in car body
7. VVVVF propulsion equipment with three phase induction motor drives ensuring high reliability, minimum maintenance and energy saving by way of regeneration
8. Passenger information system with automatic voice announcement and passenger communication with driver in emergencies

9. Materials inside car and cables meeting international standards against smoke, toxicity and fire
10. Integrated train management system monitoring, displaying and storing of the status of all important systems and equipment to assist drivers and maintenance staff in trouble shooting and maintenance
11. Micro processor controlled air conditioning system ensuring comfortable travel.

The rolling stock consists of stainless steel light weight coaches of 3.2 meter (10 feet 6 inches) width having a seating / standing capacity of 50 / 330 commuters in case of BG coaches and 2.9 meter width having a seating / standing capacity of 50/292 commuters in case of SG coaches. The coaches are provided with longitudinal seats thereby increasing the space for standees inside the coaches. There are also no equipments inside the coaches and thereby the passenger capacity in Metro coaches is almost same as suburban coaches of Indian Railways even though the width of the coaches is less. The coaches are air-conditioned maintaining an optimum temperature of 29 degree C. In the later series of cars the comfort level is improved by maintaining temperature of 25 degree C. Each train set consists of 4 coaches. However considering the density of commuters, the train sets are being augmented gradually to 6 coaches .

I.3.1.8 Traction Voltage

Detailed Project Report (DPR) prepared in 1995 for Phase I project of DMRC envisaged 750 V DC Traction System for the Metro Corridor (Under Ground corridor from Vishwa Vidyalaya to Central Secretariat). However, subsequently two other alternatives, of 1500 V DC and 25kv AC were brought under consideration.

Initially 1500 V DC Traction System for the Metro Corridor (MC) was decided due to constraint of tunnel dia. of 5.6 meters (with ±100mm radial construction tolerance and 900 mm track invert). 25kV AC Traction System voltage in the MC would have required a tunnel diameter of 6.2 meter.

As the work progressed certain developments took place. The civil contractor proposed to use a Tunnel Boring Machine (TBM) which could give a finished tunnel diameter of 5700 mm with ±75mm construction tolerance. Also the rolling stock contractor could design the stock with maximum height of 4048 mm against the earlier specified height of 4250mm. Considering that the height of the rolling stock reduced from specified 4250mm to 4048mm while the finished diameter of the tunnel increased from 5600 mm to 5700 mm the issue for adoption of 25kV AC traction system voltage in MC was examined de novo, as given below.

Electrical Clearances

IEC-60313 Standard adopted by many Railway Systems all over the world stipulates following clearances:–

	Clearances* (mm)	**Dynamic (mm)**	
Item	**Static**	**Normal Absolute Minimum****	
Live part to structure (Horizontal/vertical)	270	170	150
Live part to vehicle (Horizontal/vertical)	290	190	150
Contact wire height	4570	4570	

*Suitable allowance for pollution effect to be added
**Operating and climatic condition allows

However, the above clearances are applicable for flexible OHE, which includes provision for 70 mm pantograph push up in a 27 meter span at 160 kmph. This uplift of pantograph could be reduced to zero by using Rigid OHE.

The clearances required for 25kV electrified lines as per British Railway Standards are :-

Clearance in mm		
	Normal	**Reduced**
Static	200	150
Dynamic	150	125

With balastless track, no allowance is required for track maintenance. Thus with balastless track and rigid OHE, the minimum height of Contact wire in the tunnel could be taken as 4048 + 270 mm = 4318 mm.

After detailed analysis, it was established that with contact wire height fixed at 4318 mm. it would be possible to :

i. Achieve electrical clearance of 25 kV OHE as per IEC 60913

ii. Achieve safety clearances as per EN 50122

Considering the above factors, 25kV AC with rigid OHE was finally adopted, making it possible to standardize Power Supply, Rolling Stock as well as Signalling systems. It is for the first time that Rigid OHE was adopted in India.

I.3.1.9 Signalling and Telecommunication

The salient features of Signalling (Interlocking) and Telecommunication adopted by Delhi Metro are as under:

I.3.1.9.1 Siganalling System

The Delhi Metro uses cab signalling along with a centralised automatic train control system consisting of Automatic Train Operation , Automatic Train Protection and Automatic Train Supervision system . The Train Control and Signalling is based on “Distance to Go principle .Station Interlockings are Computer Based type . For example while Red & Yellow lines use Alstom Balise based CATC system , the Blue line has adopted Siemens electronic interlocking Sicas, the operation control system Vicos OC 500 and the automation control system LZB 700 M . Delhi Metro uses Multiple Aspect Light Signals including a Special Violet Aspect allowing only CATC operated train to continue when train path is not available.

Salient features of the system :

Computer Based Signalling (Interlocking) System**:**

- Most advanced computer based solid-state technology.
- The lines are divided into Signalling (Interlocking) zones, connected with adjacent zones and with the central location through optical fibre network.
- Capable of handling trains with a very small headway with facility of automatically setting the train routes.

Automatic Train Supervision system :

- Controlling and managing entire movements from one signal central location with facility to transfer control to the local station.

- Manages the train movement according to predefined timetable by automatically sending requests to computer based Signalling for setting of routes depending on the timetable requirement.
- Capable of rescheduling train time table automatically in the event of any incidence affecting normal timetabled train operation.

Automatic Train Protection System :

- Provides and ensures Safety to train movements working under the system by monitoring the actual running of train with the help of onboard train computer.
- Control train and apply emergency brakes automatically in the event of accidental rollback of the train or if the speed is exceeded beyond maximum permitted speed.
- Capable of managing running trains with headway as small as two minutes.
- Capable of managing running of train to a level where train- driver has no major role in operation of train (in ATO mode).
- Interfacing with other subsystems for providing / sharing information.

I.3.1.9.2 Telecommunication System

I.3.1.9.2.1 Radio Communication:

- Utilising Tetra communication technology, the latest and the most trusted technology the world over, for transfer of voice & data with encryption.

I.3.1.9.2.2 CCTV

- Close circuit TV system is used for surveillance on the Platforms and other strategic places.
- The CCTV system is also used to facilitate the driver of the train to view the closing of doors at platforms.
- The CCTV systems utilizes dedicated dark fiber to transfer images from one place to other in real time.

I.3.1.9.2.3 Clocks

- Digital and analog clocks are a networked system. They are synchronized with GPS for ultimate accuracy.

I.3.1.9.2.4 Passenger Information Display System :

- An integrated network system for displaying real time information about arrival & departure of train or on other important matters to customers on platforms.
- The system is linked with Automatic Train Supervision system to provide real time train arrival / departure information.

I.3.1.9.2.5 Passenger Announcement System :

- State of the art technology to facilitate automatic as well as manual and pre-recorded announcements in the desired paid and unpaid areas.
- The automatic announcements are linked with Automatic Train Supervision systems to provide real time announcements regarding train movements.

I.3.1.9.2.6 Mobile Coverage in underground & Tunnels :

- For convenience of its customers the Delhi Metro is providing mobile coverage of GSM & CDMA even at underground and tunneled sections, a facility normally not available in similar locations elsewhere.
- This is made possible by using special telecommunication cable known as Leaky Coaxial Cable and a tie-up with various service providers.

I.3.1.9.3 Automatic fare collection System

- Delhi Metro is using an integrated automatic fare collection system making the entry and exit of customers, a hassle free experience .
- Delhi Metro introduced for the first time in the world, the smart contact-less card & token for entry / exit to paid area
- The smart card has a stored value amount that can be recharged as and when required and the fare is automatically deducted from the stored value on exit.
- Special wide area flap gates, for wheel chair, to facilitate physically challenged person, have been provided at all stations.
- The gates are remote controlled and can be programmed to remain in permanent open position in case of any emergency.
- The system, besides generating revenue reports for the day / month, generates a host of other statistics regarding pattern and usage of system.

I.3.2 Commuter services in NCR (National Capital Region)

I.3.2.1 New Delhi being the capital town of the country, a large number of commuters come here from National Capital Region (NCR) for attending office and for commercial activities on a day-to-day basis, as housing is a major problem in the city of Delhi and New Delhi. Such commuters are using dedicated commuter trains such as Electric Multiple Units (EMUs) and also Main Line Electric Multiple Units (MEMUs) run on the main lines by Indian Railways. They also use conventional trains run specially for office goers in the morning and evening. Delhi is a major junction station where railway lines converge from 8 different directions. Details of commuter trains run in different directions are shown below in the Table 5.

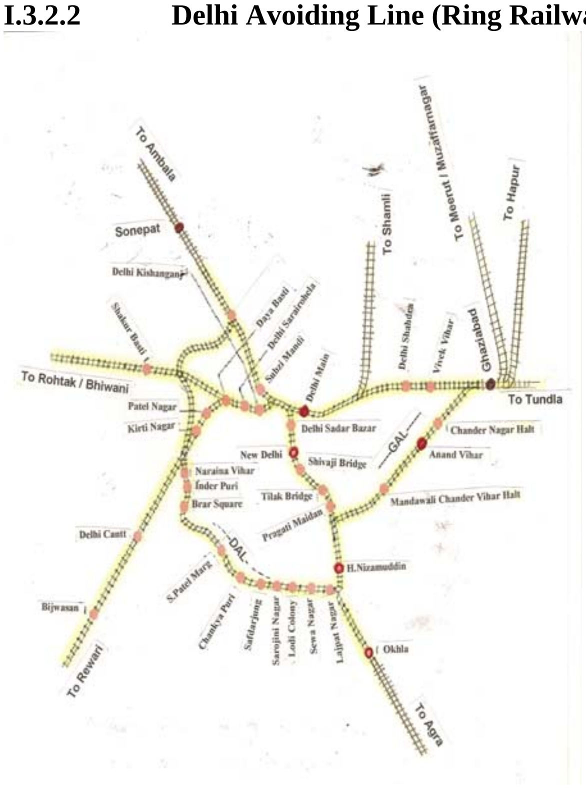
EMU service in Delhi area

Table 5

S.No.	Direction	Destination	No. of services	Type of Service
1	Tundla	Ghaziabad	21	EMU
		Dankaur	2	EMU
		Khurja	2	EMU
		Aligarh	3	EMU
1a	Tundla	Ghaziabad	2	MEMU
		Dankaur	1	MEMU
		Khurja	1	MEMU
		Aligarh	1	MEMU
2	Agra	Ballabhgarh	1	EMU
		Palwal	11+2	EMU+MEMU
		Kosi Kalan	2+1	EMU+Conv.
		Mathura	1	EMU
		Agra	1	Conventional
3	Ambala	Sonepat	1	EMU
		Panipat	1+5	EMU+MEMU
		Kurukshetra	3	MEMU
		Ambala (from Panipat / Kurushetra)	6	MEMU

4	Rewari	Rewari	10	Conventional
5	Rohtak / Bhiwani	Rohtak	1	DEMU
		Rohtak	2	Conventional
		Bhiwani	2	Conventional
		Jind	2	Conventional
6	Shamli	Shamli	2	DEMU
		Shamli	3	Conventional
7	Meerut / Muzaffarnagar	Muzaffarnagar	1	DEMU
		Meerut	2	Conventional
8	Hapur	Bulandshahar/ Hapur	1	Conventional
9	Ring	Clockwise	4	EMU
		Anti-clockwise	4	EMU

I.3.2.2 Delhi Avoiding Line (Ring Railway)



Delhi –Ring Railway and suburbs

A large volume of coal traffic moves from West & South directions via Mathura, Palwal to North direction towards Punjab. Earlier this used to move via New Delhi station causing great congestion over there. To obviate this problem, a direct line was constructed called as Delhi Avoiding Line (DAL) connecting New Delhi Mathura Line to Shakur Basti, taking off short of Nizamuddin and passing via Lajpat Nagar, Sarojini Nagar, Safdarjung, Brar Square and joining the Delhi Ambala line short of Shakur Basti. This line was completed at a cost of Rs.633.64 lakh and opened to goods traffic on 16.2.1969. The line is also known as Ring Railway though strictly it is not a Ring Railway.

I.3.2.3 Goods Avoiding Line (GAL)

A large volume of goods traffic moves from Eastern India via Allahabad – Kanpur to the Badarpur Thermal Power Station (BTPS) situated on Delhi Mathura Line. This was causing great amount of congestion in Delhi/New Delhi area. Therefore, a bye-pass line was required which could be used to move coal to the Badarpur Thermal Power Station without entering into Delhi / New Delhi area. To meet this requirement, a BG line was sanctioned between Ghaziabad and Tughlakabad including 2^{nd} Yamuna Bridge at a cost of Rs.351.44 lakh. This line takes off from Sahibabad station located on Ghaziabad-Delhi section and passes through Chander Nagar, Anand Vihar, Mandawali Chander Vihar Halt and takes a turn towards left after passing 2^{nd} Yamuna bridge and connects Tughlakabad yard after passing through Hazrat Nizamuddin and Okhla. The line was completed and opened to traffic on 15.11.1966 at a final cost of Rs.599.70 lakh.

I.3.2.4 Ring Railway

Part of Delhi Avoiding Line, Mathura Delhi line, Delhi Rohtak line form a complete ring around the central part of New Delhi. Originally, part of this line was single line. As mentioned in earlier paragraphs, the western portion of the ring was constructed as Delhi Avoiding Line, mainly for passing goods traffic from Southern part of the country to the northern part. Northern Railway is running skeleton services for the benefit of commuters though it is not very popular due to less number of services. During the Asian Games held in New Delhi during the year 1982, the western portion of the DAL was provided with another line making it double and also electrified. As on date, four commuter services using EMUs are running both in clock-wise and anti-clock-wise direction.

I.4 KOLKATA

I.4.1 Kolkata Metro

I.4.1.1 Introduction

I.4.1.1.1 The need for having a high capacity rail-based public transport system was felt as the road traffic in the city increased by about 100% between 1960-70. The utilization of suburban rail net work also rose by 300% during this period. It was all the more necessary due to fact that the area of roads in Calcutta Metropolitan District area was only about 6.2% of the urbanized area, the least among other metro cities of the country.

I.4.1.1.2 A number of committees viz. Ginwala Committee (1947), S.N. Roy Committee (1953), Sarangapany Committee (1956) studied the problem and recommended provision of surface railway from Dumdum Junction to Chitpur and elevated railway from Chitpur to Majherhat over Calcutta Port Trust and surface railway on the existing Eastern Railway line from Majherhat to Dumdum via Kankurgachi Chord. A study of Mass Transportation was undertaken by Frieling of M/s Wilbur Smith Associates in 1964 recommended elevated railway line from Galiff street to Kalighat along the North-South alignment and from Howrah Station to Sealdah along the East West alignment. Mr Paul Garbutt of the London Transport Board recommended construction of high capacity North South elevated rapid transport railway from Dumdum to Kalighat via Belgachhia Road, Chittaranjan Avenue, and Chowringhee Road with interchange arrangements at Dumdum.

I.4.1.1.3 The Calcutta Metropolitan Planning Organisation (CMPO), the first Planning Organisation of the State Government for the city of Calcutta studied the problem and submitted its report in 1967 which established a need for grade separated rapid transport system in the North-South to East-West directions. The Planning Commission of the Govt. of India also appointed Metropolitan Transport Team to study the problems of public transport in four Metropolitan cities of the countries. The team in their report of Feb. 1964 also accepted the need for high capacity rapid transit system along with the two corridors suggested by CMPO and further recommended a techno economic study. They also recommended that Indian Railways should carry out the study. Accordingly, the Ministry of Railways sanctioned Metro Project (MTPR) to carry out these studies.

I.4.1.1.4 The MTPR Organisation started their studies in Dec. 1969. An agreement was entered into by the Govt. of India with the Government of USSR in terms of which M/s Techno Export of Moscow studied the problem from Nov. 1970 to Jan. 1971 and made a number of recommendations including the need for very high priority to be given to the construction of 16.4 km long Metro line from Dumdum to Tollygunge.

I.4.1.1.5 Government of India accepted the proposal for construction of Metro line 16.45 km long connecting Dumdum to Tollygunge and the project was sanctioned on 1st June, 1972 at a cost of Rs.140 crore. The foundation stone was laid by the then Prime Minister of India on 29th Dec. 1972.

I.4.1.2 Salient features of Metro Railway Calcutta:

I.4.1.2.1 Alignment and Gauge

The Metro Railway was planned as an underground railway due to the presence of a large number of buildings on the alignment connecting Dumdum to Tollygunge and also the road width was not adequate for providing supports for elevated railway line. The gauge selected for the line was Broad Gauge i.e. 1.676 mm (5’-6”). To keep the cost of construction low, the width of superstructure of the coaches was decided as for Metregauge. Average distance between the two stations was kept from 0.6 km to a maximum of 2.15 km with 15 underground stations and one elevated and one on Surface. The maximum sanctioned speed is 80 kmph. Maximum depth of stations from ground level to platform level is 12.854 M. Most of the length has been constructed with cut and cover method with rectangular twin box section having internal size of 8.19 M x 4.64 M on straight track with suitable widening on curves. The construction of cut and cover section has been done by first providing diaphragm walls of 600 mm thickness. A length of 1.232 km between stations Belgachhia and Shyama Bazar has been constructed with two separate bored circular tunnels, each accommodating single track, having internal diameter of 5.10 M. A minimum radius of curvature has been kept as 200 M between the stations.

The line has been further extended up to New Garia for which the work is in advance stage. A portion of extension up to Garia bazaar (Kavi Nazrul) has already been opened to public on 22ndAugust 2009.

I.4.1.2.2 Rolling Stock

The whole rake is through vestibule. Coaches came from Integral Coach Factory (ICF), of Indian Railways and the electrical from NGEF, Bengaluru (Banglore). ICF has specifically designed, manufactured and supplied these coaches for the Kolkata Metro. Doors of coaches are closed before train can start. With a view to keep the cost of tunnel to minimum, the body width of the coaches conforms to that of meter gauge coaches whereas the trolleys are as for broad gauge. Train composition consists of 8 coaches with two driving motor coaches and 6 trailer coaches. The designed acceleration of train is 1.1 M per second sq.

Inside view of a station - Kolkata Metro

I.4.1.2.3 Traction Voltage

Traction voltage is 750 volts DC with current collection from 3rd rail throughout the alignment including on the surface.

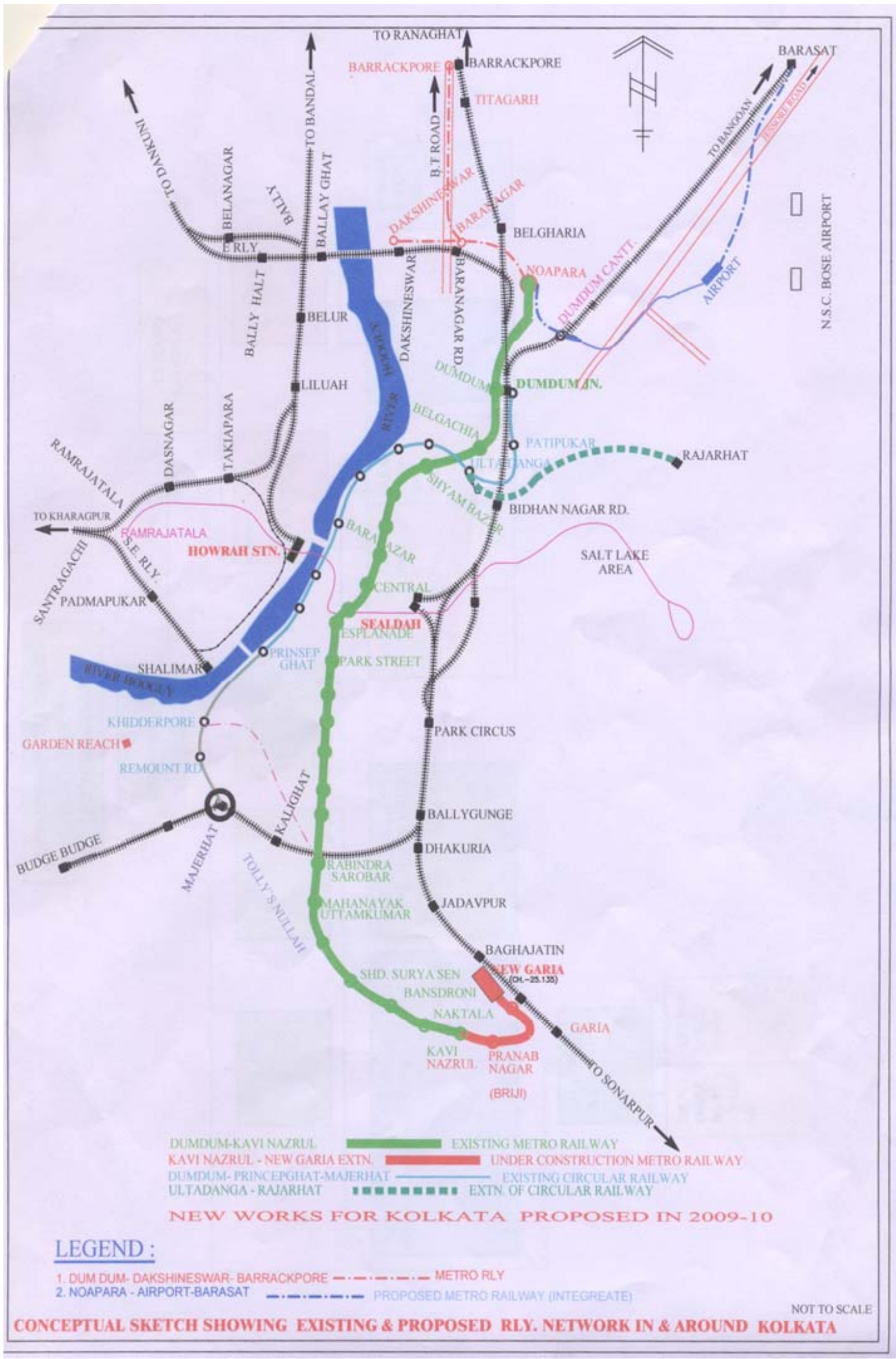
I.4.1.2.4 Signalling System

The Dumdum - Tollygunge line was opened on 24th October 1984 .Initial operation started with Colour light Signalling and absolute block signalling , which was followed by Automatic Signalling . The Control Centre of the metro is located at Metro Bhawan.

In 1990, Alstom's CTC and ATP was introduced Now the existing ATP system is planned to be replaced with ETCS system. Cab Signalling system has been provided with line-side signals as stand by. The operation of trains is through Continuous Automatic Train Control (CATC) comprising Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) with Absolute Block System in case of failure of CATC.

I.4.1.2.5 Telecommunication

A Train Radio Communication System has been provided for establishing direct communication between the Central Control and the running trains. For keeping the passengers informed about the train running, the systems installed are (a) Train Public Address System (b) Station Public Address System (c) Next Train Indication Boards (d) Centrally Controlled Clock system and (e) Closed Circuit Television.



Route Map of Kolkata Metro

I.4.1.3 Construction Phases

The construction of Metro line was done in stages and commissioning of various sections was done as under:-

	Sections	Kms	Date of Opening
(a)	Esplanade to Bhowanipur (Downline) (Bhownipur was renamed Netaji Bhavan on 15.8.97)	3.482	24.10.1984
(b)	Dum Dum to Belgachhia (Upline)	2.151	12.11.1984 (Temporarily closed to traffic in 1992 and reopened on 13.8.94).
(c)	Esplanade to Tollygunge (Up line) and Bhowanipur to Tollygunge (Dn line) excluding passenger service at Jatin Das. Park and Rabindra Sarobar stations.	7.640	29.04.1986
(d)	Opening of Jatin Das Park and passenger service.	-	02.10.1986
(e)	Belgachhia-Shyambazar (Up line)	1.625	13.08.1994
(f)	Esplanade-Chandni Chowk (Down line)	0.769	02.10.1994
(g)	Dum Dum-Shyambazar (Down line)	3.590	19.02.1995
(h)	Esplanade-Chandni Chowk (Up line)	0.769	19.02.1995
(i)	Chandni Chowk-Central (Up & Dn lines)	0.828	19.02.1995
(j)	Shyambazar-Girish Pap & Dn lines)	1.929	19.02.1995
(k)	Central-Girish Park (Up & Dn lines) (excluding passenger service at Mahatma Gandhi Road station)	1.508	24.09.1995
(i)	Mahatma Gandhi Road station	-	19.02.1996

I.4.1.4 Project Cost

As against the original estimated cost of ₹140 crore, the total cost of the project came to around 1700 crore due to various factors, mainly due to time over-run. The break up of the cost is as given below :

(Rs. in crores)

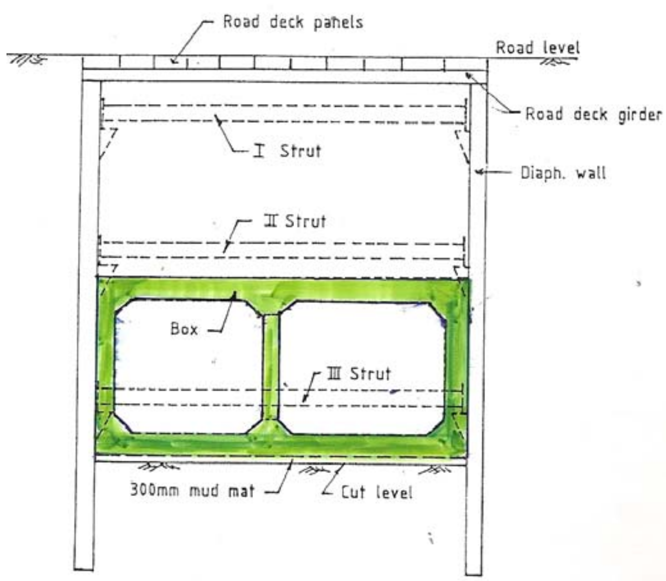
Civil Engineering	959.57
Rolling Stock	202.17
Electrical	188.54
Signal & Telecom	184.27
Other Charges	172.00
Total	1706.55

I.4.1.5 System Capacity

The Metro line has been designed for headway of 90 seconds. However, presently, the trains are being run at an interval of 6 minutes during the peak hours (9.00 to 11.00 hrs and 16.50 to 19.30 hrs) and 6 to 10 minutes during non-peak hours. The traffic as envisaged originally was 1.32 million in the first year of opening, 1.53 million after 5 years of opening and 1.73 million per day after 12 years of opening. As against this, the present volume of traffic being handled each day is about 4.2 lakh.

I.4.1.6 Construction Techniques

I.4.1.6.1 Most of the stretch (15.135 of 16.45 KM) is underground. Whole of the Metro tunnel except a small length of 1.066 Km was constructed as a rectangular single box tunnel using cut and cover method .RCC Diaphragm walls were provided on either side first to retain earth. The depth of cut varied between 14.85 meter and 12.65 meter and width varied between 26 and 9.6 meters. A typical cross section of the rectangular tunnel is shown below.



A TYPICAL X-SECTION OF BOX TUNNEL

It may be seen from the figure that the section of the tunnel has been provided within two diaphragm walls. Normally the diaphragm walls could have been part of the tunnel section but this could not be due to many reasons, one of the reasons was that the vertical joints between panels of diaphragm walls could not be made water proof. And at places even soil could be seen coming out. Another reason was difficulty in providing integrity between the vertical walls and the top and the bottom slabs reinforcement. The diaphragm walls were 60 cm thick in M20 concrete cast in 3.0 meter long panels in bentronite filled trenches. Grabbing of earth was done by Kelly Grabs and BW long wall drills. The Kelly grabs were provided with hydraulic controls for better cutting and grabbing efficiency. The verticality was controlled from the operator's cab. In some of the sections, over cuts in the top soil could not be avoided while grabbing. To minimize this, cement bentronite slurry in proportion of 20:1 grouting was done in weak soil pockets up to shallow depths prior to grabbing.

I.4.1.6.2 The depth of penetration of diaphragm walls below final cut level was generally kept as 4 meters. However, in some stretches, depth of penetration had to be increased to 7 meters based on type of soil. For these locations, diaphragm walls were redesigned. In some stretches, on the request of Kolkata Metro Development Authority, the depth of diaphragm walls was increased for future use as foundations for flyover supports on either side. Consequently, the diaphragm walls in such stretches were designed accordingly to take additional loads from flyovers.

I.4.1.6.3 At one location, one Kali temple was situated almost in the middle of the road. To save the structure, diaphragm walls were provided around the temple. At some of the locations, leaning of diaphragm walls towards the cut occurred. However, such incidents were very few. At one particular location, as many as five panels of diaphragm wall were out of alignment particularly at the base slab and track level. The maximum infringement in such locations was 88 mm. As there was no scope to shift the affected track inward, the only alternative left was to dismantle the leaning walls to obtain clear moving dimensions. To facilitate this, enveloping diaphragm was introduced at such locations, outside the affected portion of the alignment. The leaning walls were dismantled thereafter.

I.4.1.6.4 In the remaining length of tunnel, it was planned to construct two independent circular tunnels of 5.10 meter internal diameter in two different stretches. The first stretch was about 286 meter long between Belgachia Tram Depot and Chandi temple at the northern boundary of Chitpur railway yard. The second stretch was about 780 meter long between south end of Chitpur yard and Shyambazar station approach. The prime reason for adopting circular tunnels in this area was presence of Chitpur yard having several lines and also a canal running parallel to the yard where cut and cover method could not have been planned. Due to poor soil conditions the horizontal and vertical alignment in the second tunnel were disturbed badly. There was a sudden sag of about 300 mm within a distance of 40 meters. This required a permanent speed restriction of 25 km per hour. The defects were, however, corrected later and the speed restriction removed.

I.4.1.7 Track Fittings

Indian Railways did not have enough experience of track fittings for ballast less track in tunnels. The design was evolved in RDSO right from scratch and after a number of field and laboratory trials, two types of fittings i.e. M1A and M7 were adopted. M 1A fittings consisted of mainly a cast iron bearing plate fixed to base concrete with two 28 mm dia studs with a grooved rubber pad of 12 mm thickness placed below the cast iron plate. The rails were fixed with two 2 pandrol clips with another 4.5 mm thick rubber pad placed between the rail foot and cast iron bearing plate. The M7 fittings were similar to what is used in concrete sleepers, rails being fixed with two pandrol clips and the pandrol clips were in turn held by MCI (Malleable Cast Iron) inserts held in concrete base with a 10 mm thick rubber pad placed under the rail foot. Between the rail and concrete surface, a 10 mm thick resin leveling course was provided.

The problem with the above fittings was that they provided zero gauge adjustment. Wherever there was a gauge problem, the only alternate available was to change the bearing plate location. This involved lot of work. Therefore, alternative designs of fittings were developed permitting gauge adjustments.

I.4.2 Kolkata Circular Railway

I.4.2.1 This line encircles the entire city of Kolkata, starting from DUM DUM Jn in the north and passes through Tala, Kolkata terminal (Chhitpur) , Burrabazar, BBD Bag, Eden Garden, Princep Ghat, Khidirpur, Remount Road, Majerhat, New Alipur, Ballygunj, Park Circus, and finally back to Dum Dum Jn.

Previously a railway line existed between Dum Dum to Ultadanga for transport of wagons to Chitpur yard and some part between BBD bag to Majerhat existed for a long time for transport of goods and from port area to the godowns of Calcutta port along the Ganges. These were built during the early EIR period when the river Hooghly was navigable to this area. Gradually with the silting of Hooghly and inaccessibility of bigger ships, these lines went out of use. With these lines being rehabilitated and small patches created at a few places, it could establish a through connection between Dum Dum Jn and Pricep Ghat along the bank of Hooghly.

I.4.2.2 The original line was a single line track with loading and unloading sidings and wharfs. A few platforms were built and simultaneously reception facilities were constructed at some stations. The line was commissioned from Dum Dum Jn to Princep Ghat on 16-08-1984. The gap between Princep Ghat and Majer Hat was also sanctioned and constructed with a small stretch passing through the Calcutta Port area in the year 2003-04.

I.4.2.3 Earlier the trains were hauled by diesel engines. The entire line has now been electrified and four EMU trains of Barackpore – Sealdah section originally destined for Sealdah during office hours have been diverted to central business district of Kolkata directly avoiding Sealdah station. His has been received with overwhelming response from commuters. Eastern Railway runs EMU services on the Circular Railway which provides excellent connectivity through the city.

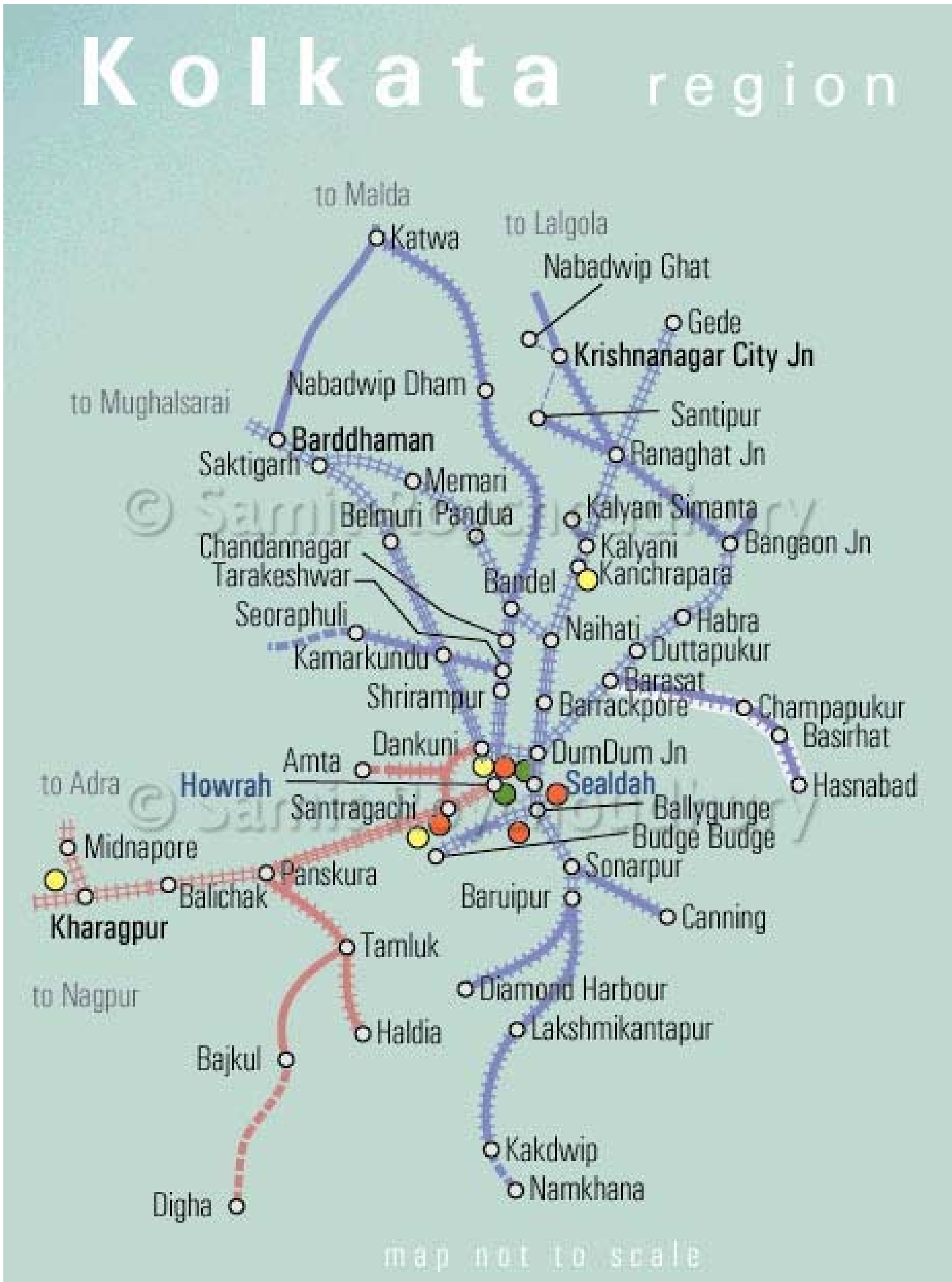
I.4.2.4 Kolkata Circular Railway has been extended from Dum Dum Cantonment to Netaji Subhash Chandra Bose International airport through a 3.8 KM long passing through Jessor Road , VIP Road and the Domestic terminal. These works were undertaken by Kolkata Metro Organisation.

I.4.2.5 Circular Railway stations

Dum Dum, Patipukar, Kolkata Terminal (Chitpur), Tala, Bagbazar Sovabazar, Burrabazar, BBD Bag, Eden Garden, Princep Ghat, Khideirpur, Remount Road, Majher Hat, New Alipur, Tollygunje, Mile 5B, Lake Garden, Ballygunje, Park Circus, Bidhan nagar Road.

I.4.3 Kolkata suburban lines

I.4.3.1 Kolkata suburban area including nearby satellite towns are well served by a good network of Eastern and South Eastern railway lines. The network was developed along with the development of railway system in and around Kolkata. The suburban services start mainly from three main line stations in Kolkata which are Howrah, Sealdah and Kolkata terminal – a newly developed main line terminal near Chhitpur.



Map showing suburban and main lines around Kolkata

View of Suburban EMU train

The extensive rail network stretches into the districts of North 24 Parganas, South 24 Parganas, Nadia, Howrah, Hooghly, etc.The Suburban railway system can be categorized as follows:

I.4.3.2 From Sealdah Station

I.4.3.2.1 Main Section

This line serves the northern suburbs on the eastern bank of Hooghly River and further east towards the very end of the international border between India and Bangladesh. The destinations facilitated by this line are Dum Dum, Barrackpore, Naihati in North 24 Parganas district along the banks of the Hooghly, Bongaon, Basirhat, Hasnabad in North 24 Parganas district towards the north east and towards the Bangladesh border and Kalyani, Ranaghat, Shantipur and Krishnangar in Nadia district.

I.4.3.2.2 South Section

This line operates on the southern parts of the city and serves the southern suburbs of Kolkata and the entire South 24 Parganas district. The areas served are Ballygunge, Jadavpur, Garia, Budge Budge, Sonarpur in the southern suburbs, Port Canning, Diamond Harbour, Lakshmikantapur, Kakdwip in the South 24 Parganas district.

I.4.3.3 From Howrah Station

I.4.3.3.1 South Eastern Railway

Operated by the South Eastern Railway, this section of the line serves the south western suburbs of Greater Kolkata. The destination stations are Santragachi, Andul, Amta in the south western part of Howrah district, Panskura, Haldia in the East Midnapore district and Kharagpur, Midnapore and Digha in the eastern and southern part of West Midnapore district.

I.4.3.3.2 Eastern Railway

Operated by the Howrah section of Eastern Railway, this line runs on the western banks of river Hooghly and serves the following areas:

- Belur, Bally in the northern part of Howrah district Rishra, Serampore, Chandannagar, Bandel in the eastern part of Hooghly district.
- Tarakeshwar in the central part of Hooghly district.
- Bardhaman.in the central part of Bardhaman district. From Bardhaman, another suburban service connects the cities of Durgapur and Asansol further to the west.
- Katwa.in the eastern part of Bardhaman district .

Howrah to Bardhaman is reached by two corridors popularly known as the Main Line and the Chord Line. The main Line runs through the towns of Serampore, Chandernagore and Bandel. Whereas, the Chord Line runs through the towns of Dankuni, Baruipara, Kamarkundu and Masagram.

I.4.4 East West Metro Corridor

I.4.4.1 Keeping in view persistent demands for a east to west corridor, the East-West Corridor joining Salt Lake area to Howrah Railway Station was sanctioned on 5^{th} June, 2008. The alignment, covering a distance of 13.77 KM runs from Howrah Station to Sale Lake Sector V, under the river Hoogly with 8 KM underground and 5.77 KM elevated. The project is being executed through a Joint Venture Company formed by the Central Government and the West Bengal Government. A Special Purpose Vehicle (SPV) has been constituted for the construction, maintenance and operations. The project is expected to be completed in six and a half years.

I.4.4.2 Salient features

Length of route	Under ground	8.0 Km
	Elevated	6.77 Km
	Total	13.77 Km
Estimated Cost	Rs 4078.4 Cr at	2007 prices
	Current	Rs 4676 Cr
Gauge	Standard	1435 mm
Stations	Under ground	six
	Elevated	six
Design PHPDT	2007	22770
Train composition	Initial	four coaches (2 MC+2TC)

Future	six coaches (3 MC+3 TC)
Train Headway	2 min
Operational Headway	3 min
Seating Capacity	1066/ 1626
Traction	Voltage 750 v DC
Third rail collection	
Coaches	2.88 m wide stainless steel
Signalling	Cab Signalling, continuous automatic train control
With ATP	
Telecommunication	Integrated system with optic fibre cable, CSADA train radio, PA System
Tunneling	by Tunnel Boring Machine (TBM) Station by cut and cover method
Target Elevated	by 31st March 2012
Full	by 31st Oct, 2014

I.5 CHENNAI

I.5.1 General

In Chennai, suburban rail system started developing in the nineteenth century itself, along with the development of the main-line rail net work. The rail based commuter system in Chennai consists of three wings namely, Suburban system, MRTS and Metro (under construction). These are discussed in detail in the following paragraphs.

I.5.2 Suburban System

The existing suburban system in Chennai has three distinct lines running parallel to the main line tracks. These lines are exclusively being used by local trains up to most of the distances. Details of these lines are given in the following paragraphs.

I.5.2.1 Chennai – Gummudipundi- Sullurpetta section

It is single pair of broad gauge line serving both Chennai and Chennai Beach stations and used for intercity and suburban services. Most of the suburban services are running up to Gummudipundi (46.8 km) while only a small number of limited services are going up to Sullurpetta (81 Km). A few MEMU (Main line Electrical Multiple Units) are terminating at Bitragunta, beyond Gudur.

I.5.2 2 Chennai- Arakkonam section (64 km)

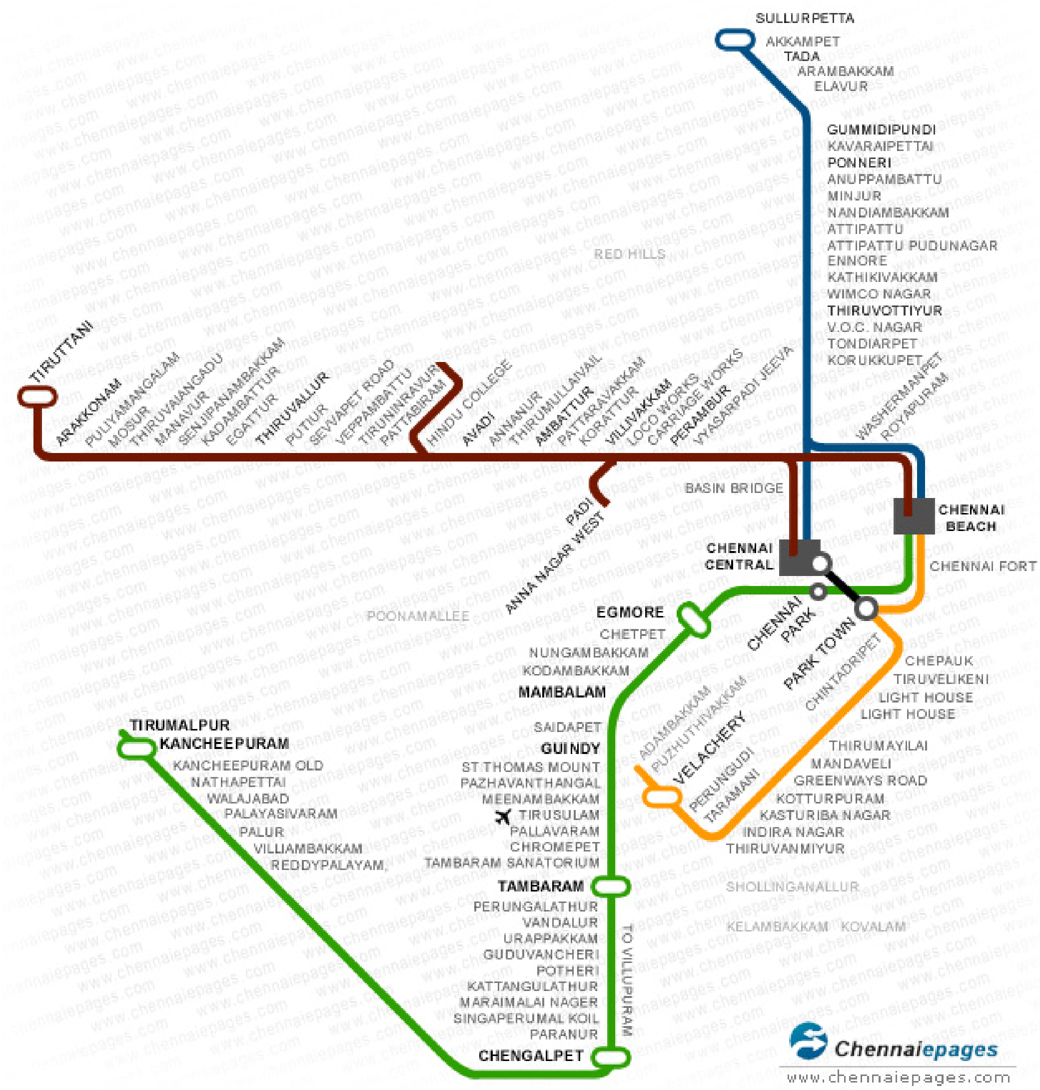
On this corridor, two pairs of broad gauge tracks are available, one pair used by suburban trains the other being used by inter city trains up to Pattabhiram (25 km).and three tracks beyond Pattabhiram and up to Trivellore (17km). This section has also been recently quadrupled. Further, beyond Trivellore, only one pair of track is available. A few number of EMU services go up to Thiruttani beyond Arakkonam.

I.5.2.3 Chennai Beach – Tambram (Meter gauge) section

This was the only electrified meter gauge suburban section up to 2006 in the country. It had one pair of tracks for suburban trains and a third line for inter city trains. The section up to Tambram was electrified with 1500 volts DC as back as in April 1931. The electrification was changed over to 25000 volts AC on 15th January, 1967. The estimated cost of conversion from DC traction to AC traction was Rs 1.82 crore. The intercity tracks were converted to broad gauge in the year 2002. An additional broad gauge track was laid beyond Tambram and up to Chengalpattu (25km). The meter gauge tracks up to Tambram have also been converted in to broad gauge in the year 2006. Suburban services are available up to Tambram and a few services also go up to Chengalpattu.

I.5.2.3.1 Electric Rolling stock

The electric service in 1931 was inaugurated with 17 nos three-coach Articulated Electrical Multiple Units supplied by English Electric Company. The vehicles were designed and constructed by the Gloucester Railway Carriage and Wagon Co Ltd in UK and electrical equipment manufactured and installed by the English Electric Company. Seven more such units were added in the fleet in the year 1933. A further addition by six four-coach units of Breda Electromeccania, Italy was also made in the year 1956. The trains were of triple articulated formation, 3 bodies being mounted on only four bogies, a type of construction which considerably reduces weight and enables a more rapid acceleration. After conversion of the traction to 25000 volts AC, the rolling stock shell of EMUs was produced in ICF (Integral Coach Factory, Perambur) with electrics imported from Japan.



Chennai suburban section including MRTS

I.5.3 MRTS Chennai

I.5.3.1 Background

The Madras Metropolitan Area (MMA) had experienced a large growth of population, from a bare 8 lakh in 1900 to about 58 lakh in 1991 and 70.5 lakh in 2001. To address the problem of growing difficulty in commuter's movement in MMA, the Tamil Nadu Government on recommendation of Metropolitan Transport Team (MTT) of the Planning Commission, in 1968 set up the Madras Area Transportation Study Unit (MATSU) to take up a comprehensive traffic and transportation study. The MATSU study identified eight transportation corridors of which the North-South-Eastern Corridor (N-S-E) , extending from Manali Road in North through George Town to Kasturba Nagar down south had the heaviest concentration of travel trips. After scrutinizing the MATSU's report,MTT recommended that Railways take up a techno economic feasibility study for a rail based Transit System in the N-S-E corridor.

A Rail based MRTS, with transfer link to the existing suburban system, along the Buckingham canal in the southern segment of N-S-E corridor, from the Central Business District (CBD) to Kasurba Nagar was recommended by this study. Due to financial constraints prevailing at that time, only a short length of the identified system between Chennai Beach and Tirumailai (8.97 km) was taken up as an extension of the BG EMU system as Phase I.

Map of Chennai MRTS and proposed Metro

Further an extension of Ph I was taken up from Tirumailai to Velachery (11.16 km) as Ph II. This work has already been completed and handed over to the Southern Railway for operation and maintenance.

The Government of Tamil Nadu further proposed the extension of the line up to St Thomas Mount (5km) at an estimated cost of Rs 415.59 crore (at 2003-04 prices) which covers the areas developed commercially and residential areas viz Puzuthivakkam and Adambakkam. The work is in progress and is likely to be completed by December 2012. The Government of Tamil Nadu is developing St Thomas Mount as an inter modal transfer point. Third phase of the project has been planned beyond St Thomas Mount to Villivakkam, a distance of about 17 kilometres. Work on this is yet to start.

View of elevated portion of existing MRTS

I.5.3.2 Phase I

I.5.3.2.1 Chennai Beach – Thirumailai (8.96 KM)

It is a 8.96 KM long double line section with 2.75 KM on surface and 6.21 KM on elevated alignment. The alignment has 8 stations and runs mostly along the Buchkingam canal, constructed long back for navigational purposes. The section between Chennai Beach and Chepauk was opened on 16.11.1995 and the remaining section between Chepauk and Thirumailai was opened two years later on 19.10.1997. Cost of this section was Rs.280 crore which was entirely borne by the Indian Railways.

I.5.3.2.2 Phase II – Thirumailai – Velacheri (11.166 KM)

Of the 11.166 KM length, 7.848 KM is elevated and the remaining 3.318 KM is on surface towards Velacheri. The section has 9 stations of which first 7 are on elevated structure, balance 9 on surface.

Total cost of this section was Rs. 734 crore which was shared between the State Government of Tamilnadu and the Central Government through Ministry of Railways in the ratio of 1 : 2. Government land was given free of cost at a nominal lease charge. One line (upline) of the section from Thirumailai to Thiruvanmiyar was opened to traffic on 26.01.2004 and the entire section was opened with double line operation on 19.11.2007.

Inside view of Tirumailai station

I.5.3.2.2.1 Phase II Extension

Velacheri to St. Thomas Mount, a length of 5.0 KM, double line fully elevated had been sanctioned in the Railway Budget of 2006-2007 on cost sharing basis similar to Thirumailai – Velacheri Section. Estimated cost of this section is Rs.416 crore as per survey report. The alignment follows on the median of inner ring road upto 3.585 KM for a small portion near Medavakkam road. This section has 3 stations, all elevated.

I.5.3.3 Track

The system has standard broad gauge double line track. The section rom Chennai Beach to Thirumailai has ballasted track. The balance section is on ballastless track in the elevated section.

I.5.3.4 Rolling stock

Rolling Stock is standard Electrical Multiple Units (EMUs) with traction voltage of 25000 AC, 3.66 meter wide stock, manufactured by ICF.

I.5.4 Chennai Metro

I.5.4.1.1 A feasibility study for the metro was carried out in 2003. Following approval in November 2007, Chennai Metro Rail Limited (CMRL) was set up by the Tamil Nadu state, as a special-purpose vehicle to implement the project. Delhi Metro Rail Corporation were engaged to prepare a Detailed Project Report (DPR). Initially two corridors have been proposed in Phase I. These are:-

Corridor No. 1	:Washermenpet to Airport	23.1 km
Corridor No. 2	:Chennai Central to St.Thomas Mount	22.0 km
	Total:	45.1 km

I.5.4.1.2 The approval of Government of India to the project was received on 20th January, 2009. Out of 23.1 km of corridor No. 1, 14.3 km from Washermenpet to Saidapet have been designed as under-ground and balance on elevated structures. Of 22.0 km of corridor No. 2, 9.7 km from Chennai Central to Anna Nagar have been designed as under-ground and balance on elevated structures.

The total cost of the project is estimated as Rs.14,000 crore with Central Government and State Governments together sharing 41%. Balance is proposed to be met through loan from the Japan International Cooperation Agency (JICA).

A five member consortium led by Egis Rail S.A. France have been engaged as the General Consultants for the project. The other consultants are (a) Egis India Consulting Engineers Pvt Ltd., India; (b) Maunsell Consultants Asia Ltd., Hong Kong; (c) Balaji Rail Road Systems Ltd., India and (d) Yachiyo Engineering Co. Ltd., Japan. Delhi Metro Rail Corporation have been appointed as the Prime Consultants for the Project.

Technical Details:

Track Gauge: Standard 1435 mm unlike 1676 mm of MRTS and suburban system

Track voltage: 25,000 volts. AC, overhead catenary

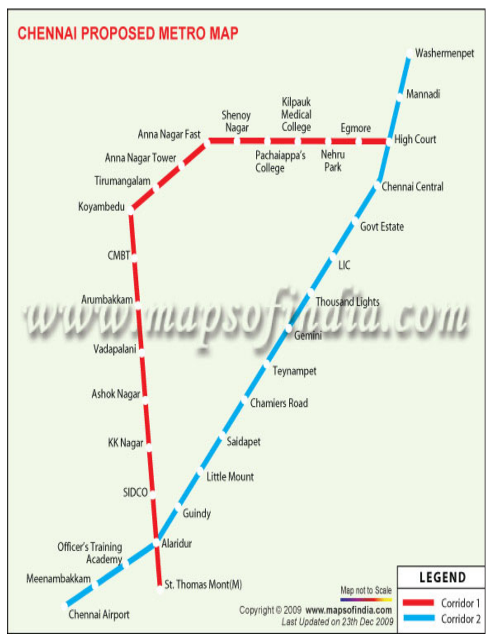
No. of stations:

Corridor 1: 13

(Washermenpet – Broadway (Prakasam Road) – Chennai Central Station – Rippon Building – along Cooum River – Government Estate – Tarapore Towers – Spencers – Gemini – Anna Salai – Saidapet–Guindy–Chennai Airport)

Corridor 2: 17

(Chennai Central – along EVR Periyar Salai – Vepery – Kilpauk Medical College – Aminjikaral – Shenoy Nagar – Annanagar East – Anna Nagar 2nd avenue – Tirumangalam – Koyambedu – CMBT – along Inner Ring Road – Vadapalani – Ashok Nagar – SIDCO – Alandur – St. Thomas Mount)



Route map of Chennai Metro

Around 57% of the lines will be on new elevated alignments, an approach widely used on modern Indian systems to allow for relatively rapid installation at lower cost than tunnelling.

I.5.4.2 Signalling and communications

The Metro will have a single centralised operation control centre and ATP (Automatic Train Protection) and ATS (Automatic Train Supervision). The telecommunication system will be multi-functional taking care of passenger information, security and safety aspects. A computer-based automated fare collection system has been planned for the system..

I.5.4.3 Targets

Construction work on line No. 1 has already started in May, 2009. The start of metro services is now envisaged to be in financial year 2014–15, by which time the state government intends to have a single authority installed for maximising the potential benefits of a multi-mode public transport system. As well as adding later phases, the Chennai Metro may replace heavy rail in pre-existing proposals for new rail links around the metropolitan area such as that between Avadi and Sriperumbudur.

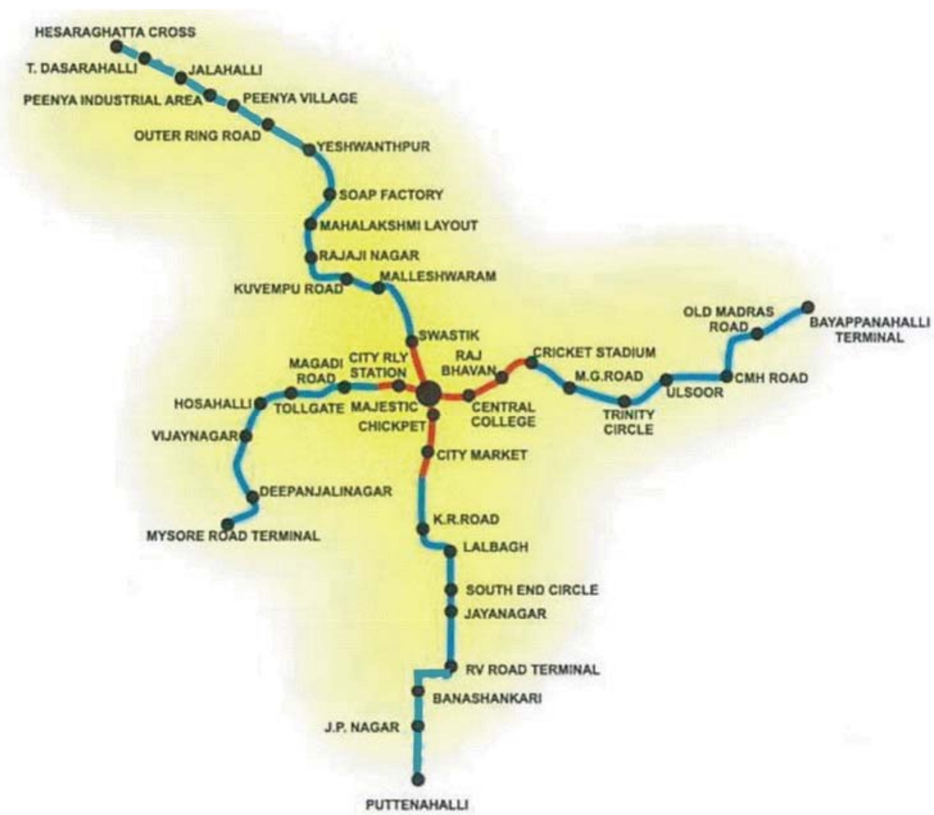
I.6 BENGALURU (BANGLORE)

I.6.1 Bengaluru Metro

I.6.1.1 General

Bengaluru is the IT capital of India. There have been several proposals of MRTS for Bengaluru city since last 24 years. In 1982, a study carried out by a Government Study group proposed a length of 12.20 km of MRTS at a cost of Rs.239.15 crore. Metropolitan Transit Project – Railways (MTP-R) carried out detailed study suggested in 1983, suburban services on the existing lines of Indian Railways for a length of 57.9 km and metro system on two corridors, in Phase-1, 12.9 km from Rajaji Nagar to Jayanagar and in Phase II, 11.2 KM from Hudson Circle to Krishnarajpuram. Another study was carried out by Rail India Technical and Economic Services (RITES) in 1988 which recommended a commuter rail system along with improvement to road system. Later, the State Government constituted the Banglore Mass Rapid Transit Ltd (BMRTL) in 1994, to implement the MRTS based on 1983 study. However, the project could not take off at that time. Thereafter, in 2003, Delhi Metro Rail Corporation (DMRC) in collaboration with RITES prepared a Detailed Project Report (DPR) for Banglore Metro Rail which proposed two corridors East-West and North-South, with a total length of 33 km. This project was sanctioned by the State Government in March 2005 followed by approval of the Central Government in April 2006. Total cost of the project is expected to be Rs.6395 crore covering Phase I with East West & North South corridors. In 2007, BMRCL announced that it would incorporate a northern extension (from Yeshwantpur to Hessarghatta Cross) and part of the southern extension (from RV Road to Puttenahalli) in Phase I, thus extending the length of Phase I network to about 42.3 km, with 40 stations. The objective of this was to connect the Metro to the Outer Ring Road at both ends, as also cover the industrial areas of Peenya in the North-West, thereby providing better connectivity and increasing ridership. In October 2008, the Government of Karnataka approved this extension, which would cost an additional Rs.1592 crore.

I.6.1.2 The Routes covered :



- The East-West corridor-known as ‘Purple Line’, covers a length of 18.10 KM starting from Byappanahalli to Mysore Road Terminal going via Old Madras Road, Indira Nagar, Cricket stadium, Vidhan Soudha, Central College, Majestic City Railway Station, Magadi Road, Hosahalli, Vijainagar and Deepanjali Nagar.

- The North-South corridor – known as ‘Green Line’covers a length of 24.2 km and starts from Hesarghatta Road and terminates at Puttenhalli and passes through Jalahalli, Pennya Industrial Area, Outer Ring Road, Yeshwantpur, Mahlakshmi, Rajajinagar, Kuvempu Road, Malleswaram, Swastik, Majestic, Chikpet, City Market, K.R. Road, Lal bough, South End Circle , Jayanagar, Banashankari and J P Nagar.

Out of 42.3 km, 6.76 km will be underground near City Railway Station, Vidhan Soudha, Majestic and City Market and the rest will be elevated.

I.6.1.3 Projected Capacity

The system is expected to carry 10.20 lakh commuters in 2011 and 16.10 lakh in 2021.

I.6.1.4 Coaches

The coaches would be light weight stainless steel, air-conditioned 2.88 m wide with self closing doors. Each train will have 3 coaches to start with, later to be augmented to 6 coaches with a capacity of 2068 passengers. The coaches are similar to DMRC (Delhi) in respect of technical specifications of the equipment except that the traction voltage and gauge are different. The coaches are designed to negotiate severe curves of 120 m, adopted on the metro alignment for the first time in India. The trains are designed to achieve acceleration of 1.1m/ s/s up to 30 kmph and braking rates of 1 m/s/s

Inside view of proposed coaches

Traction equipment for coaches are to be supplied by Mitsubishi and Hyundai Rotem would supply the rolling stock.

I.6.1.5 Traction & Gauge and track system

The traction voltage is 750 v DC with third rail for current collection. Gauge of the track is standard gauge 1482 mm, unlike Broad gauge for Delhi Metro. Directly Fixed Tracks system on concrete base with insulated pads is provided to ensure that the return currents are restricted to rails and stray currents are within limits to avoid corrosion of steel structures. Maximum train speed is proposed to be 80 kmph.

I.6.1.6 Signalling

The signalling and telecommunication of Bengaluru Metro has been planned keeping in mind the small headway of train operation and consequent safety requirement for effective, smooth and safe operation. The strain on drivers will be reduced by deploying the built-in safety features of speed regulation, braking and fast flow of information. Bengaluru Metro will use Electronic Interlocking (EI), Automatic Train Supervision (ATS) and Automatic Train Protection/Automatic Train Control (ATP/ATC)and Mobile Train Radio Communication (MRTC) systems to meet these objectives.

I.6.1.7 Power Supply

750 volts DC, third rail for power collection.

I.6.1.8 Financing

Cost of the Project is shared jointly by the Government of Karnataka and the Central Government. For arranging funds, 30% of the cost will be provided through equity shared by State and Centre in the ratio of 50:50. Balance cost will be through Subordinate and senior term loans.

I.6.1.9 Time of completion: Phase 1

The foundation stone of the project was laid by the Prime Minister on 24th June, 2006. However the actual construction could start only on 15th April , 2007 on the Mahatma Gandhi- Baiyyappanahalli stretch of the East West line (Purple line) . This portion has already been thrown open for public use on 20th Oct, 2011. Remaining elevated portion of the phase 1 is expected to be completed by December 2013 and the under ground portion by end of 2014.

Artistic View of an Elevated Metro Station

1.6.1.10 Phase –II

The detailed project report for Phase II was prepared by the Delhi Metro Rail Corporation. The high power committee (HPC Metro project on 21 February 2012. The Union Urban Development Ministry is expected to clear it shortly. The estimated total cost for Phase II is around 26,405 crore. Phase II covers a route of 72.095 km and adds 61 stations to the network. It is expected to reduce road traffic by 35%. Construction), in July 2011, gave in-principle clearance to proceed with Phase II. The Karnataka government gave in-principle approval to Phase II of the Namma of the second phase will be taken up in 2014 after completing the first phase by 2013 and it is expected to be opened for service from 2017.

Phase II consists of extensions of all four reaches of the Metro and 2 new lins.

New Lines

The RV Road to Bommasandra line, on the outskirts of the city, will have 16 stations -- RV Road, Ragigudda temple, Jayadeva Hospital, BTM Layout, Silk Board Junction, HSR Layout, Oxford College, Muneshwara Block, Chikkabegur, Basapura Road, Hosur Road, Electronic City-1, Electronic City-2, Huskur Road, Hebbagodi and Bommasandra. The cost of this route is pegged at 5,744 crore . The one between Gottigere-IIM-B and Nagavara will have 18 stations with six elevated and 12 underground stations. The elevated stations include Gottigere, Hulimavu, IIM-B, JP Nagar 4th Phase, Jayadeva Hospital and Swagath Road Cross. The 12 underground stations will be constructed near Dairy Circle, Mico Bosch, Langford Town, Vellara Junction, MG Road, Shivajinagar, Cantonment railway station, Pottery Town, Tannery Road, Venkateshpura, Arabic College and Nagavara. The estimated cost of this corridor is 11,014 crore.

Extensions

This corridor has 14 stations -- Jyothipuram, KR Puram, Narayanapura, Byappanahalli to International Technology Park Ltd -- Whitefield (extension of east-west line). Mahadevapura, Garudacharpalya, Doddanakundi, Visvesvaraya Industrial Estate, Kundalahalli, Vaidehi Hospital, Satyasai Medical Institute, ITPL, Kadugodi, Ujwala Vidyalaya and Whitefield

Hesaraghatta Cross to Bangalore International Exhibition Centre (BIEC) on Tumkur Mysore Road terminal to Kengeri (extension of east-west line). This corridor has five stations. Nayandahalli, Rajarajeshwari Nagar, Bangalore University Cross, RV College of Engineering and Kengeri

Road (extension of north-south line). This has three stations. Manjunathanagar, Jindal and BIEC terminal. The BMRC has asked BIEC to share the cost as it would be the main beneficiary of this extension

Cross to Anjanapura township, up to NICE crossing (extension of Puttenahalli north-south line). This corridor has five stations. Anjanapura Road Cross, Krishnaleela Park (Iskcon), Vajarahalli, Talaghattapura and Anjana township

I.7 HYDERABAD-SECUNDERABAD RAIL SYSTEM

I.7.1 General

Hyderabad and Secunderabad are the twin cities in the state of Andhra Pradesh. Hyderabad is also the capital town of Andhra Pradesh. It is also the fifth largest conglomerate of population in the country. The combined population of the cities of Hyderabad and Secunderabad is about 100 lakh (10 million). It is one of the fastest growing centre of Information technology, Bio science and also an important film production centre. Hyderabad has got one of the efficient system of road transport which is supplemented by suburban railway system, combined together is known as Multi Modal Transport System (MMTS). In addition to MMTS, the Government of Andhra Pradesh has sanctioned Metro network jointly with the Central Government which is under construction.

I.7.2 Hyderabad- Secunderabad Multimodal Transport System

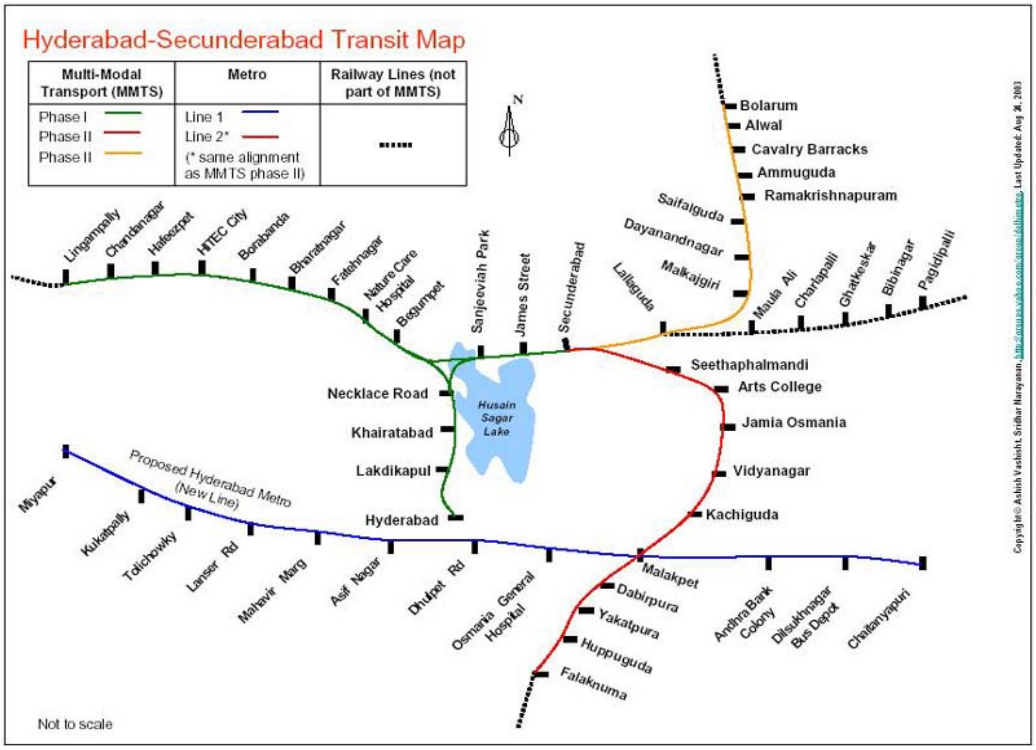
MMTS is the jointly sponsored Project of the State Government of Andhra Pradesh and the Indian Railways under which the existing broad gauge tracks of Indian Railways network in and around the twin cities of Hyderabad and Secunderabad have been used and additional halt stations provided to suit the requirements of commuters along with development of road transport system. The Project has been developed in phases, first phase is already completed.

I.7.2.1 MMTS Phase I

First train of MMTS was flagged off on 9th August, 2003. Rail services have been introduced on the existing tracks of Indian Railways. It has two legs: Hyderabad –Secunderabad - Lingampally, a length of 28.5 km and Secunderabad - Falknuma, a length of 14.5 km. To meet the local requirements of commuters, 10 new halt stations have been introduced which are in addition to the already existing 17 stations. The intra-distance between stations ranges from 0.75 km to 3.5 km. At present 92 services are being run daily with a headway of 10 minutes during peak hours. Cost of new works under Phase-I was Rs. 199.70 crore shared by the State Government and the Indian Railways equally The rolling stock comprises Electrical Multiple Units manufactured by the Integral coach Factory (ICF), Perambur run on 25000 volts AC traction.

MMTS Trains

View of Necklace MMTS station



Map showing the MMTS and Metro (under construction)

I.7.2.2 MMTS Phase-II

The routes proposed under Phase-II are as under

• Falaknuma – Umadanger – New Airport	20 km
• Secunderabad – Bolarum – Medchal	28 km
• Secunderabad – Ghatkesar	19.48 km
• Moulali – Sanathnagar (byepass)	21 km
• Moulali – Kachhiguda (chord line)	10 km
• Tellapur – Patanchuru	8 km

The cost of above mentioned proposals is expected to be ₹614 crore, excluding the cost of land required for new stations to be introduced.

I.7.2.3 Transfer Points

For the benefit of commuters, transfer points have been developed at important stations where connecting buses are available to different area adjoining the railway stations. Facility of common tickets has been introduced which are valid for both trains and buses.

I.7.3 Hyderabad Metro

I.7.3.1 Earlier Studies

I.7.3.1.1 To mitigate the commuters' problems in greater region of Hyderabad, Regional Engineering College, Warangal was appointed by HUDA to carry out comprehensive traffic and transportation plan known as Hyderabad Area Transportation Study (HATS) in 1983 along with short, medium and long term proposals, the study recommended LRT system for the Corridors for a length of 51.5 Km.

1. L.B.Nagar – Kukatpally
2. Khairatabad – Tollychowki
3. Falaknuma – Ranga Mahal via Charminar
4. M.J. Market – Airport

I.7.3.1.2 In 1988 M/s RITES carried out feasibility study for LRTS, Hyderabad and proposed implementation of 22.5 Km length on three Corridors as given below:

1. Bala Nagar – Khairatabad (9.5 Km)
2. Khairatabad – Charminar (7 Km)
3. M.J. Market – Dilsukh Nagar (6 Km)

I.7.3.1.3 In 1992 ILFS along with Government of Andhra Pradesh updated the cost and traffic figures for the LRT Corridors Kukkatpally Housing Board – Khairatabad, Khairatabad – Afjal Gunj and Afjal Gunj – Koha Pet fruit market. In 1994, the Government of Andhra Pradesh engaged RITES as Sub-consultant for introduction of LRT on BOT basis. However, the attempt failed due to BOT partner wanted major concession and major cost and revenue estimates. In 1999, Japan Trade External Organisation, carried out a feasibility study and recommended MRT on the route from Bala Nagar to Dilsukh Nagar (20.6 Km). The project cost at 1998 prices was ₹2338 Crore. They also recommended that implementation on BOT System is not feasible and Governments financial assistance is required with forty (40) years loan repayment period.

I.7.3.2 Proposed Routes

After study of five different proposed routes the following routes have been finally adopted on consideration of engineering feasibility, and other factors like cost and intensity of utilization.

Metro network

(i) Miyapur – Chaitanyapuri

(ii) Secunderabad Railway station – Osmania Medical College – Charminar - Falaknuma Railway Station

Section	Length (Km)	Number of Passengers (lakh)	Pass-Km (lakh)
Miyapur-Chaitanyapuri	25.57	7.33	79.07
Secunderabad – Charminar - Falaknuma	12.48	3.78	22.81
Total	38.05	11.12	101.88

I.7.3.3 Route Alignment

I.7.3.3.1 The Miyapur – Chaitanyapuri **corridor** starts from Miyapur on NH 9 and continues on NH 9 towards south and passes through JNTU College, Kukatpally Housing Board colony and Kukatpally. The alignment passes through the Bala Nagar industrial area and reaches Bharat Nagar flyover where it moves on the west side of the flyover to provide integration with MMTS station at Bharat Nagar. After crossing the South Central Railway tracks the alignment returns to the central verge of the NH 9 after the flyover and continues towards Khairtabad via Erra Gadda, ESI hospital, Sanjiva Reddy Nagar, Ameerpet, Punja Gutta and Erramanzil. All the areas are commercially developed and have residential colonies nearby. At Khairtabad integration with MMTS and road based traffic is provided. The alignment moves through the low lying area to avoid Visveswaraya flyover and passes in front of NTR Gardens alongside the Hussain Sagar. A station is provided at Secretariat to serve all the above recreation areas as well as the secretariat. The alignment moves towards Assembly via public gardens. An important station is proposed at assembly which will serve Public Gardens, Assembly and Stadium nearby. From here the corridor touches the Nampally station, Gandhi Bhawan, M J Market and reaches Osmania Medical college.

I.7.3.3.1.1 The interchange with the second corridor is planned at Osmania Medical College with the two stations provided one above another. The alignment touches Imliban Bus Stand (planned as Asia's biggest Bus Stand) and reaches Malakpet where again integration with MMTS is provided. From Malakpet the alignment passes through New Market, T V Tower and DilsukhNagar Bus Stand before reaching the terminal Station at ChaitnyaPuri. The 25.6 km long elevated corridor has 25 stations.

I.7.3.3.2 The second corridor is planned form Secunderabad railway station to Falaknuma via Charminar. The corridor is planned as elevated corridor for entire length. The terminal station is provided across the platforms of Secunderabad station and the alignment reaches median of the Bhoiguda road after crossing the railway's coaching yard. On Bhoiguda road it passes in front of newly constructed Gandhi Hospital and continues via Chikada palli Road and Narayan Guda Road. The alignment passes over Narayan guda drain by the side of road bridge and crosses Naryana guda flyover as double elevated. The alignment crosses the road to Kacheguda station and goes through Sultan Bazar and Koti road before reaching Osmania medical college where it goes above the first corridor. A link line is provided for rake interchange between the two corridors at this station.

I.7.3.3.2.1 The alignment continues through heavily built up area and passes adjacent to M G Bus stand and crosses Musi River and joins Purani Haveli road near Salarjung Museum. This road is being widened by the state government as part of pedestrainisation project in Charminar area. The alignment continues on Purani Haveli road with a station near Charminar and turns to join Sardar Patel Road after Charminar. It continues on Sardar Patel Road to Falaknuma via Shalibanda, Shamsher Ganj and Janganmetta. All these areas are part of the old city and are densely populated. The corridor is 12.6 Km long and is having 14 stations. A small deport is located at Falaknuma for stabling, inspection and minor repairs.


HYDERABAD METRO RAIL CORRIDORS
PHASE I
N
Miyapur
Shilparamam
JBS
Nagole
LB Nagar
Falaknuma

I.7.3.4 Technical Parameters

- Track gauge Standard Gauge 1435 mm
- Traction 750 volts, DC, third rail
- Trains Each 3-coach train will consist of two driving motor coaches and a trailer coach , while 6 coach will consist of 2 DMCs, 2 MCs (motor coaches) and 2 TCs. The capacity of 3-Car Train is 1000 passengers and of 6 Car Train is 2068 passengers. Trains will be air-conditioned and provided with automatic door closing and opening system.
- Rolling stock 2.88 m wide stainless steel light weight coaches with length of 20.8 m for trailer coach and 21.05 m for motor coach are proposed for the Hyderabad Metro. Train length for 3 coach train is 64.1 m while that of 6 – coach train is 128 m. The Axle load is about 15 t .
- Signalling : The trains will have state-of-the-art cab Signalling with continuous automatic train control and automatic train protection system. The trains will have passenger information and announcement system.

I.7.3.5 Estimated Cost

	(in Rs.)
Land	143.37 cr
Civil Engg works	1315.55 cr
Electrical works	347.03 cr
Signalling and Telecommunication	353.09 cr
Depot	128.39 cr
Rolling stock	679.50 cr
Genl charges	237.35 cr
Total	**3204.28 crore**
	(at April , 2003 level**)**

BIBLIOGRAPHY

1. The Kolkata Metro Dum Dum- Tollygunge Design & Construction – Phase I & II published by Metro Railway, Kolkata.

2. Travel Forecasts- 1981 & Justification for MRTS for Madras Metropolitan Area - Report-Sept 1973.

3. Mass Rapid Transit System , Chennai, Hand-Out – July 2008.

4. Miscellaneous documents downloaded from Internet and from other sources.

5. Information collected from the Office of Director Technical, Bengaluru Metro Rail Corporation.

6. Information collected from The Office of The Principle Chief Engineer South Central Railway.

7. Information Collected from the Office of Divisional Rail Manager, Delhi Division and the Principle Chief Engineer , Northern Railway.

8. Information collected from The Executive Director, Projects, Railway Board, Ministry Railways.

9. Information collected from the Office of The General Manager, Central, Western and Southern Railways.

CHAPTER - II

HERITAGE RAILWAY BUILDINGS

II.1 A plan for a rail system in India was first put forward in 1832, but no further steps were taken for more than a decade. In 1844, the Governor-General of India Lord Hardinge. allowed private entrepreneurs to set up a rail system in India. Two new railway companies were created and the East India Company was asked to assist them. Interest from investors in the UK led to the rapid creation of a rail system over the next few years. The first train in India became operational on 22 December 1851, and was used for the hauling of construction material in Roorkee. A year and a half later, on 16 April 1853, the first passenger train service was inaugurated between Bori Bunder, Bombay and Thane covering a distance of 21 miles (34 km). This was the formal birth of railways in India.

II.1.1 The British government encouraged new railway companies backed by private investors under a scheme that would guarantee an annual return of five percent during the initial years of operation. Once established, the company would be transferred to the government, with the original company retaining operational control. The route mileage of this network was about 9,000 miles (14,500 km) by 1880, mostly radiating inward from the three major port cities of Bombay (Mumbai), Madras (Chennai) and Calcutta (Kolkata). By 1947, the year of India's independence, there were forty-two rail systems. In 1951 the systems were nationalized as one unit, becoming one of the largest networks in the world. Various semi-independent kingdoms (Indian states) built their own rail systems and the network spread to the regions covered by these states. After independence all these were merged into the Indian Railway system.

II.1.2 With the coming of the Railways, there came up railway stations, offices and service buildings as well as residential colonies. While most of the service buildings and residential buildings were low cost functional brick and stone structures, the companies vied with each other to build imposing office buildings and railway station buildings in all the larger cities.

II.2 Since the Railways first came up in Bombay area, it naturally followed that the first imposing heritage buildings of the Railways came up in this area. The Victoria Terminus is the first heritage structure which came up. This building housed the office of the Great Indian Peninsula Railway Company and now houses the headquarters of the Central Railway. This building was started in 1878 and it was completed and thrown open to the public on New Year’s day 1888.

Victoria Terminus Building at Mumbai

II.2.1 A statue of Queen Victoria adorns the conical tower. There are intricate carvings of Gargoyles and Lions. But many of the carvings are at such an awkward height that you can see them only from the upper deck of a Double Decker bus. The ceilings are very high and exude a sense of space and freedom so that even when the hallway is crowded with passengers there is no sense of claustrophobia. The magnificent monument was designed by EW Stevens. The decorative carved details were executed by native carvers from models supplied by Mr. Gomez and the students of the Bombay School of Art. These are amongst the best portion of the decorative work. The Buildings are faced with a light buff coloured Coorla stone with dressings, cornices and moldings etc. in Porbandar and Seoni stones.

II.2.2 The total cost of the whole building was about 27 Lakhs of Rupees. All the work was entirely executed by native labour entirely to the satisfaction of the architect.

II.3 Another attractive station building completed in 1988 and listed as a grade I heritage structure is the Bandra Station at Bombay.

Bandra Railway Station

II.3.1 In Bombay area another important Railway Heritage building to come up was the headquarters of the Bombay-Baroda and Central Indian Railway, now the headquarters of the Western Railway. This building was designed by FW Stevens assisted by his son Charles Stevens. This building was completed in 1897 at a cost of over Rs.7 Lakhs. The composition of the tower is in a square – octagonal-round sequence. Crowning the central gable is a fine figurative group of sculptures representing engineering, which were executed in the studio of Roscoe Mullins of London.

Western Railway Headquarter

II.3.2 This building is largely Neo-Gothic in style but the white façade and profusion of small domes bring to mind the Indo-Saracenic architecture of Southern India.

II.4 Almost simultaneously and in quick succession came up other grand office buildings in Madras and Kolkata. The building in Madras (now Chennai) is in Indo-Saracenic architecture of Southern India while the South Eastern Railway Headquarters at Garden Reach generally follows the Neo-Gothic style.

Southern Railway, HQ

II.5 The Headquarters of other Company Railways were more or less in functional buildings. After regrouping, the Central and Western Railways occupied the above buildings in Mumbai while Southern Railway and South Eastern had their own land mark buildings.

The Northern Railway which came up with the split of North Western Railway which had its headquarters in Lahore and merger of some Company Railways, has its headquarters in Baroda House near India Gate New Delhi which was the residence of the Maharaja of Baroda.

The Headquarters of Eastern Railway at Fairlie Place, Kolkata are in an old building but this building is more functional in style. Other railway headquarters have been constructed in recent years and are modern buildings which do not qualify for consideration as heritage buildings at present.

The Construction Office of Northern Railway is however in a building which was reconstructed in the 19th century as the residence of the Dy. British Resident who came here in 1803. Below the building still stands a Mughal Tehkhana.

Office of Northern Railway Construction Organisation

II.5.1 Side by side and closely following the office buildings came up grand buildings to house the railway stations at the larger cities. There are two large and imposing station buildings at Madras (Chennai) i.e. the Central Station and the Egmore station. These are shown in the photographs below:

Madras Central Railway Station

Egmore Railway Station

II.5.2 The architectural forms in these buildings are a mixture of functional, and Indo-Saracenic, with a touch of South Indian Temple Architecture. The land mark in Madras Central Station is the Victorian Clock Tower.

II.6 The important station buildings in the Eastern Zone which came up in the late 18th Century are Howrah and Asansol. These buildings have a predominance of Arches with a touch of contemporary British Architecture and local trappings:

Howrah Railway Station **Asansol Railway Station**

II.7 In Northern India, a large number of Railway Stations have a distinctive architectural style as at Kanpur, Delhi, Lucknow, Amritsar, Jaipur and many others, the important ones with distinctive style are shown below:

Delhi Main Railway Station **Lucknow Railway Station**

II.7.1 The Delhi Main Railway Station was constructed in 1867 and has been classified by INTACH as a building with ‘A’ Architectural value. This is amongst the earliest Railway Stations built in India by the British. The building has several Gothic features. The two story building has deep verandas on both floors and though the original building is in a good condition many modifications and additions have been done. Semi octagonal turrets rise from the corners of the building.

II.8 The Lucknow Railway Station is one of the most imposing stations in the country and though built in Gothic style has a plethora of domes of different sizes which is a feature of Mughal and Indo-Saracenic form of architecture.

II.9 The other railway stations which were of heritage significance in Bombay area but which no longer exist or are not in use are Colaba and Ballard Pier. The old Churchgate building which was an imposing structure opened in 1875 also no longer exists.

Old Ballard Pier Station

Old Churchgate Station 1875

Frontier mail leaving from ballard pier station

Old Colaba railway station which was closed in 1930

II.10 The Railway stations on the quaint but Historic Hill Railways must not escape mention. The small yet impressive buildings at Shimla, Barog, Palam pur, Wellington and Ooty, Ghoom and Darjeeling would merit mention. The Shimla and Ghoom stations are shown in the photographs below:

Shimla Railway Station **Ghoom Railway Station**

II.11 There are numerous office and service buildings which would qualify as buildings having architectural and heritage value all over the country but all these cannot be covered in this limited effort.

II.12 Railway Architecture in India has broadly developed over the last one and a half centuries based on the following major architectural styles:

- Neo-Classical
- Romanesque
- Italianate
- Gothic Revival
- Indo Saracenic

II.12.1 The Neo Classical style is based on Ancient Greek & Roman Styles. The buildings have magnificence of scale, there is prominent use of columns, use of Geometric form & Symmetry, Blank Walls and use of Triangular Pediment. The buildings of this form show simplicity as a reaction to ornate styles. Prominent buildings constructed to this style include Royapuram Station constructed in 1856 and BNR House at Kolkata.

II.12.2 The Romanesque style of buildings have round arches, thick walls, large towers, decorative arcading, symmetrical plan and overall simplicity.

Prominent buildings constructed to this style include Chennai Central and Agra Fort Stations. The Italianate style of architecture is based on Roman and South European styles of the 18th and 19th centuries and uses cornices, engraved panels and decorative ornate styles. Prominent buildings constructed to this style include E.I.R. offices, Fairlie Place, Kolkata.

II.12.3 The Gothic Revival style of architecture uses Pointed or Ogival Arches, the ribbed vault, Flying Buttresses, Use of Pinnacles, Towers and Spires, Decorative Carvings such as gargoyles, Quatrefoil and clover-shaped openings, Battlements and shaped parapets. In buildings constructed to this form there is Emphasis on verticality. Large Windows with Stained Glass are normally provided. Mumbai VT (CSTM) and Colaba station buildings were constructed using this style of arch.

II.12.4 Indo Saracenic style of architecture makes extensive use of Onion /Bulbous Domes, Overhanging Eaves, Pointed & Cusped Arches, Miniature Domes, Towers or Minarets and Chhatris and Open Pavillions. Lucknow Railway station (Charbagh) and BNR Head Quarter Buildings are examples of this style of architecture.

II.12.5 After 1920, the Railway buildings constructed follow modern buildings styles. Examples are Bombay Central and Nagpur Railway stations. The Northern Railway Head Quarter building Baroda House, though not constructed as a Railway building also can be classified in this style.

II.12.6 A few Railway buildings are of Gabled style with sloping roofs examples are Junagarh, Shimla and old Churchgate building at Mumbai.

BIBLIOGRAPHY

1. Monuments of the Raj by PN Chopra and Prabha Chopra.

2. The Heritage building of Bombay by Rajan Narain and Sunil Vaidyanathan.

3. Delhi – the Built Heritage – a listing by INTACH

4. Issues of the Architectural digest.

5. Archives of the Rail Transport Museum New Delhi.

6. Indian Railways – A 100 years.

CHAPTER - III

TUNNELING

III.1 Tunneling in India dates back to pre-historic times. The earliest tunnels discovered in India were mainly escape tunnels built by various kings to move from their Forts to safer places. Modern tunnel construction started mainly in the 19^{th} century when tunnels were constructed for the extension of railway lines to cross hill ranges and also for irrigation purposes. Tunnels were also built below ‘passes’ in mountainous terrain for crossing roads and highways at lower elevations to facilitate traffic movement.

III.2 Railway Tunnels

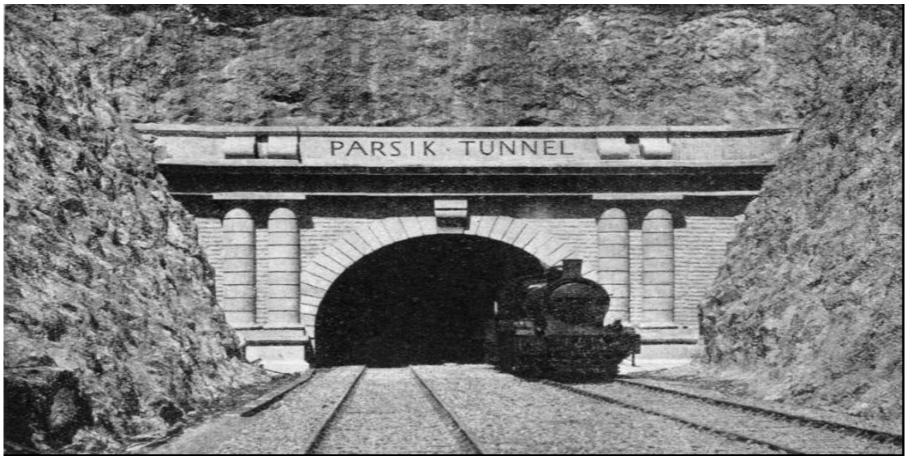
III.2.1 Railway tunneling in India started in the nineteenth century. In hilly terrain, to reach up to the destination generally a maximum ruling gradient of 1 in 100 is provided on Broad Gauge (BG) and grades steeper than this require extra efforts by pusher engine. This gradient would mean laying of hundreds of kilometers of track to skirt hills depending on the contours. This can be avoided by tunneling which directly reduces the length of the alignment as it avoids first elevating to the saddle, following the contours and then come down to the other side of the hill. Trains cannot go up steep gradients and as a result the railway lines had to either go around hills following the contours or through deep cuttings so that the Railway would stay relatively flat. When the ground became too steep or high for a cutting to be dug successfully, tunnels were built**.**

III.2.2 As on 1st April 2010 there were 348 railway tunnels in India. A large number of new tunnels are also under construction on Udhampur – Quazikund section of the Udhampur – Srinagar – Baramulla (USB) project.

III.3.0 Railway Tunnels on Main Line Sections of Indian Railways (IR)

III.3.1 These railway tunnels were constructed in the 19^{th} and early 20^{th} centuries, especially in the Western Ghats, Vindhyas, and the foothills of the Himalayas. Most of these were bored into hard rock strata in peninsular India. The dimensions were limited to accommodate single or double line broad gauge railway tracks.

III.3.2 The first tunneling project taken up by Indian Railways was the construction of the Parsik tunnel on the Mumbai-Thane section, which was bored over a hundred years ago.



Parsik Tunnel

III.3.3 Mountstuart Elphinstone and John Malcolm laid a railway line from Mumbai to Pune through Bhor Ghat, making it a rail route with 28 tunnels, and several bridges. This Ghat route opened Mumbai to the Deccan and was commissioned in 1856.

Banker Tunnel on Mumbai – Pune Section

III.3.4 On this route, between Monkey Hill and Thakurwadi, there are 13 BG tunnels with lengths varying from 32.229 m to 260 m. Between Monkey Hill and Nagnath there are 8 tunnels, the longest being 1267.34 m. Two more tunnels on this section also have lengths over 800 m. From Monkey Hill to Khandala there are 5 tunnels the longest being Tunnel no. 26 which is 2156 m long.

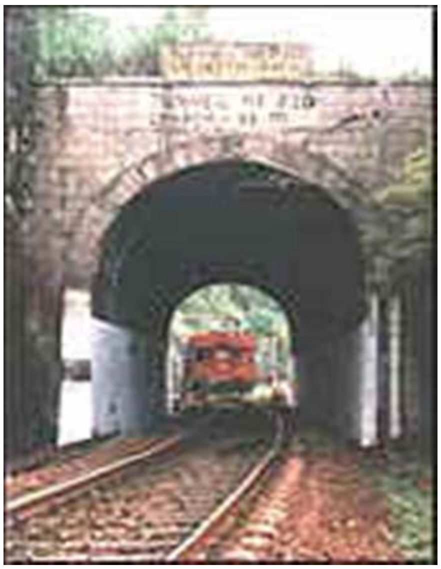
III.3.5 There are 46 tunnels on the Kasara Ghat section of Bombay Division of Central Railway. These are mostly in hard rock and are unlined. These tunnels were excavated manually, or by controlled blasting after manual drilling of holes in the face of the full or part heading.

III.3.6 On a number of other important BG main line sections, where the line was passing through hilly terrain, Indian Railways constructed a number of tunnels. Tunnels in hard rock were unlined and in degraded rock were lined with brick arches, CC and stone masonry. On Itarsi – Nagpur section, there are 11 tunnels, the longest being 555.4 m. These tunnels were constructed between 1910 and 1919. All these tunnels are in degraded rock and are lined with CC/Stone masonry. On Jabalpur Division of West Central Railway, there is one tunnel of 280 m length while on the Bhopal Division there are four tunnels the longest being Budhni tunnel which is 280 m long and was constructed in 1968. There is one tunnel 365 m long on the Jhansi Gwalior section named Sandalpur Tunnel 365 m long which was constructed in 1971 and one tunnel between Raja ki Mandi and Agra which is 323 m long.

III.3.7 On Eastern Railway, the Monghyr tunnel near Jamalpur which is 279 m long was constructed between March 1856 and June 1861. Two tunnels on the Gaya- Gomoh chord line measuring 300 m and 188 m were constructed in 1903 to 1906 in hard rock. The heading was driven by hand. The cost of construction of these tunnels at that time was Rs. 847.30 per m and Rs. 1129 per m respectively.

III.3.8 On Northern Railway, there are two tunnels on Laksar-Dehradun section which were constructed during the period 1897 to July 1901 at a per meter cost of Rs. 442.97 and Rs. 420.27 respectively. These tunnels were constructed in alternate strata of hard and soft rock.

III.3.9 The oldest tunnel in South Eastern Railway is Saranda Tunnel which was completed in Sept'1892 and later extended to 1100 m. On the Kottavalasa–Kirandul (KK) Line (445 Km), there were 61 tunnels of which 46 having a length of 12.76 Km were bored and 15 tunnels with a length of 1.44 Km were constructed by cut and cover. Of these tunnels 9.81 Km were lined and 4.39 Km in hard rock were unlined. Koraput Rayagada Railway Line has six D shape tunnels totaling a length of 5.912 Km. The longest is Tunnel no. 4 which is 0.8 Km long. There is also one length of 2.928 Km which is really a continuation of eight closely spaced tunnels. Five of these tunnels were tunneled by TBM, Heading and Benching as these were located in Hard Rock of Chama kites and Khondolites Groups, Boulders and Lateritious Conglomerate in Solid and Disintegrated form as well as Ordinary Soil. Tunnel no. 2 (600m) was constructed by Fore-polling, advanced grouting to control seepage and by shielding in some places, since the location had very poor dis-integrated rock

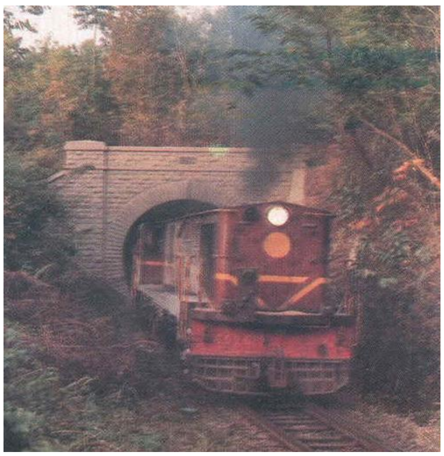


Tunnel on KK-Line

Tunnel on Mangalore Hassan Line

III.3.10 On Southern Railway, there are 16 tunnels on Metupalayam-Ooty Section, the longest being 137 m. On Shoranur – Mangalore Section, there are two tunnels the longest tunnel at Kankanadi being 589 m long. Tenkasi-Quilon section has 33 tunnels constructed between 1971 and 1979.

III.3.11 On North East Frontier Railway, on Lumding Badarpur section, there are 37 tunnels the longest tunnel being 581m. These tunnels were constructed between 1898 and 1903, at an average cost of Rs. 2000 per running meter. All these tunnels were constructed with section fit for meter gauge (MG) clearances. Now as per the Uni-gauge policy of Govt. of India, this stretch has also been sanctioned for conversion to BG. For providing broad gauge clearances, meter gauge tunnels have not been found fit and hence 16 new tunnels have been planned varying from 90 m to 3235 m in length involving total tunneling length of 10.3 km.




Tunnels on Lumding – Badarpur Section

N.F. Railway construction organization has recently commissioned the important link to Agartala, Capital of Tripura, from Manu. This new line involved construction of 3 long tunnels measuring 1.126, 1.926 and 1.967 km respectively. All these tunnels are for Broad gauge train movement though presently track connectivity has been provided for meter gauge as gauge conversion of Lumding-Badarpur section is in progress.

III.4 Tunnels on Narrow Gauge (NG) Hill Railways

III.4.1 A number of Railway Tunnels were constructed in the lower Himalayan ranges to connect resorts like Shimla, Matheran, and Darjeeling etc. These were all on narrow gauge.

III.4.2 Kalka – Shimla Railway

The Kalka-Shimla Railway built to connect the summer capital of India in 1903 at an altitude of 2076 meters offers a panoramic feast to experience the grandeur of the picturesque Himalayas from the Shivalik foot hills. The 96.54 kilometer line, built on a 2'6" (762 mm) gauge, was opened for traffic on November 9, 1903. Kalka-Shimla-Railway runs through 102 tunnels, some of which have hoary tales to tell. Mr. Barog, the engineer, who was responsible for designing a tunnel near the present Barog railway station, commenced digging the tunnel from both sides of the mountain, which is quite common as it speeds up construction. However, he made mistakes in his calculations and while constructing the tunnel, it was found that the two ends of the tunnel did not meet. Barog was fined an amount of 1 Rupee by the British government. Unable to withstand the humiliation, Barog committed suicide. He was buried near the incomplete tunnel. The area came to be known as Barog after him

III.4.2.1 This tunnel (Barog tunnel) is 1143.61 meter long and remained the second longest tunnel on Indian Railways for a long time. It is a straight tunnel, passing through fissured sand stone. This tunnel was completed by H.S. Harrington, Chief Engineer in Railways at that time in September 1903 at a cost of Rs. 8.4 lakh.

Barog Tunnel

Train at Tara Devi Tunnel

III.4.2.2 Another tunnel at Taradevi, (493 m long) cutting through a hill on the peak of which is a famous temple, tells of the local superstition of the day that the Goddess would never permit it's construction. When construction was half through, great excitement arose from reported sighting of a huge serpent in the tunnel that had emerged to stop the work. However, the reptile turned out to be a long iron pipe running along the tunnel to carry water. This tunnel was completed at a cost of Rs. 3.04 lakh.

III.4.2.3 The two other important tunnels of this section are Koti Tunnel (No. 10) 2276 feet (695 m) built at a cost of Rs 3.83 lakh and completed in October 1903 and Inverarm Tunnel (No. 103) 1135 feet (346 m) which was completed in September 1903 at a cost of Rs. 1.96 lakhs. This tunnel passes through Shale stone and in 1949 a 65 feet long (19.8m) crack was noticed and, the damaged portion was rebuilt.

III.4.2.4 Technology and Procedures adopted for tunneling on this and other hill railway lines at that time were as under :

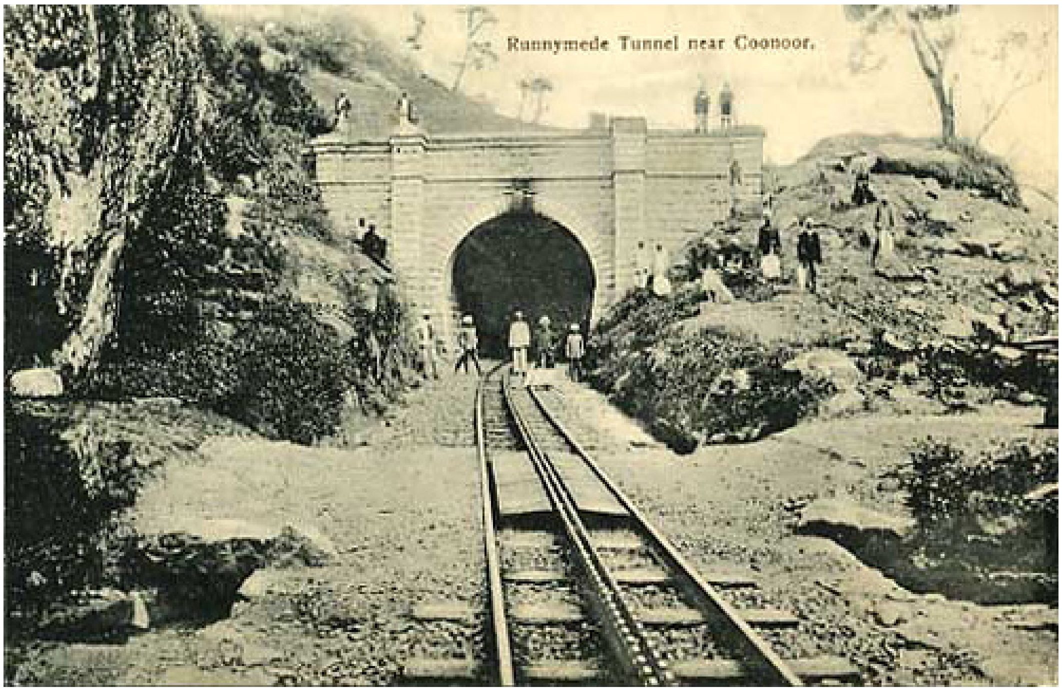
- The advisability of running a top or a bottom heading was first considered. A top heading proved to be better and safer course excepting in very long tunnels.
- Heading being the expensive item in a tunnel, it was considered advisable to keep the smallest convenient dimensions compatible with fast working. Heading of 7 feet (2.1m) high and 5 feet (1.5m) width worked well in most cases.
- In driving heading – the timbering was inserted in at once and all interspecies tightly packed with stones as the roof timbers are put in place.
- Headings were timbered with sleepers of sections 10”x5” (25 cm x 12.5 cm) and afterwards these sleepers were used for laying the track.
- The heading having been driven, before starting the ‘OPENING OUT, a good supply of plank bars of 18 feet (5.5m) length and 1’-3” (38 cm) diameter or so was arranged. These crown bars were fitted well so that all the weight of heading planks was taken by the crown bars.
- Centering was then erected as in ordinary open arch; centering ribs being fitted as tight as possible.
- The arch was then turned, concrete rammed in at the back of the haunch width of the opening.
- The arch having been turned, the remainder of the tunnel was very simple. Side walling and inverting followed.
- The large mirrors used for lighting tunnels have effected a great saving in expenses. A mirror 4 feet x 2 feet (1.2m x 0.6m) located 500 feet (150m) inside the tunnel, was found to render it light as in day for 9 months out of 12 from sunrise to sunset.
- For artificial lighting, the use of acetylene gas made from calcium carbide was very satisfactory and nearly as cheap as castor oil or candles.

III.4.3 The Kangra Valley Railway

This narrow gauge line from Pathankot to Shanan (160 Km) was constructed between 1926 and 1929 at a cost of Rs. 296 lakh. The line includes two tunnels – Dhundni 250 feet (76m) and Daulatpur Tunnel – 1075 feet (327m) in length. The Daulatpur tunnel was completed in March 1928 at a cost of Rs. 5.17 lakh.

III.4.4 The Nilgiri Mountain Railway

This 46 Km narrow gauge Railway connects Mettupalayam and Ooty. There are 16 tunnels in this sections of which 10 are unlined as they are cut through solid rocks. Tunnel no. 5 is called a half tunnel where the rock top hangs precariously.



Runnymede Tunnel near Coonoor-a classic picture by Mr. Boeshinger

III.4.5 The Neral – Matheran Toy Train

Covering a distance of 20 Km and has a few small length tunnels in hard rock including the 'One Kiss' tunnel which is well known.

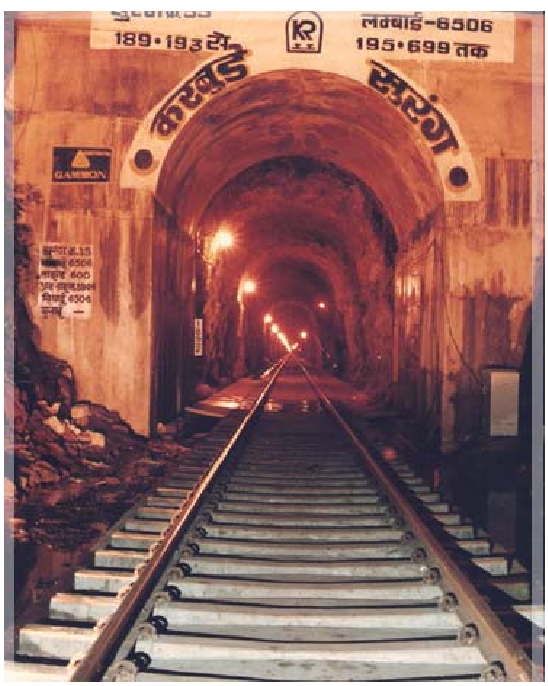
III.4.6 Darjeeling Himalayan Railway

The Darjeeling Himalayan Railway is a narrow gauge 2 ft (610 mm) railway from New Jalpaiguri to Darjeeling in West Bengal built between 1879 and 1881 and is about 86 kilometers long. The elevation level is from about 100 m (328 ft) at New Jalpaiguri to about 2,200 meters (7,218 ft) at Darjeeling. Since 1999 this Railway has been a World Heritage Site as listed by UNESCO. There are however no tunnels on this Railway

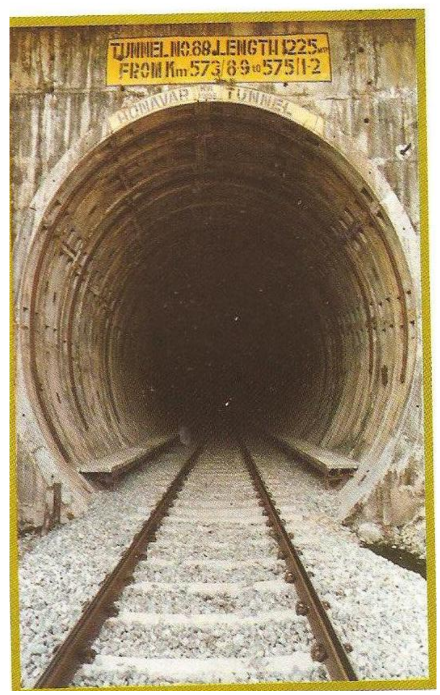
III.5 The Era of Long BG tunnels in India - Konkan Railway and the Railway lines in Jammu Kashmir.

III.5.1 Konkan Railway

The era of long BG tunnels came to India with the construction of the Konkan Railway. The 760 km long Konkan Railway project, completed in 1997, involved construction of 92 tunnels covering a total length of 83.6 km. Nine of these are longer than 2 km. The longest operational rail tunnel in India is the 6.5 km Karbude tunnel on the Konkan Railway. Five of the 9 tunnels are longer than 3 Km each and are Nathuwadi 4.839 Km, Sarwade 3.429 Km, Tike 4.077 Km, Berdewadi 4 Km, and Barsem 3.343 Km. It was for the first time in India that such massive tunneling work was attempted in Railway construction. The work on the Konkan Railway project was started in July 1990 and the project was commissioned on 26 January 1998.



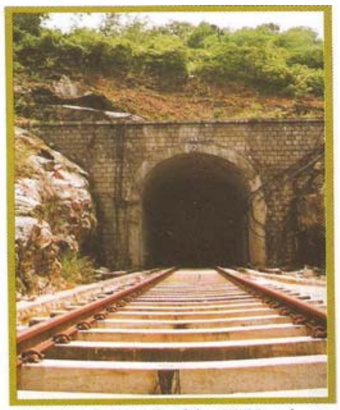
Karbude Tunnel



Tunnel at Honnawar

III.5.1.1 Geologically, the entire Konkan region falls into two zones. In the first zone from Roha to Kankawali, soils consist of dark colored volcanic lava flow and laterite. These soils are mainly basaltic and tunneling through this zone is comparatively easy. In the second zone from Kankawali to Mangalore, the formation consist of phylities, quartzite, garnet staurolite and kyanite. There are also laterite deposits, which are, however, more ferruginous than bauxitic. In some tunnels in Goa and in Karnataka, the tunneling media was extremely soft and innumerable difficulties were encountered making such tunneling very expensive and time – consuming.

III.5.1.2 Soil investigations were done for all tunnels and a fairly accurate nature of strata involved was obtained prior to commissioning the work. However in soft soil the behavior when mixed with varying quantities of water could not be judged resulting in unforeseen problems



The North Portal of the 2950m. long Karwar Tunnel

The shield for Honnawar Tunnel with arrangements for jacking.

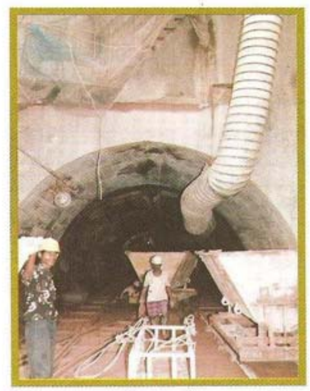
III.5.1.3 On the Konkan Railway tunnel cross sections had to essentially satisfy the clearance requirement as per Schedule of Dimensions of Indian Railways. Additional lateral clearance of 100 mm was provided to take into account construction tolerances. Height of tunnel was decided based on requirement of 25 KVA Over Head Electrification. The design of supports and concrete lining thickness were worked out based on over burden and lateral pressure and the nature of the soil.

III.5.1.4 The construction was carried out using appropriate technology. In hard rock, full face method was followed while in soft soil tunnels, due to supports, the portal was fixed at convenient points ahead of tunneling. Drilling jumbos and special loaders, imported from Sweden, were used giving a progress of about 45 to 70 meters per month. For muck removal electro hydraulic digging arm loaders were imported from Sweden. From this project onwards, India saw the utilization of hydraulic jumbos, raise climbers along with road-headers. New Austrian Tunneling Method (NATM) technology and Tunnel Boring Machines (TBMs) also made their entry at that time. From the year 2000 and later, tunnel construction in India has become much closer to state of the art.

III.5.1.5 The provision of long tunnels necessitated special arrangements for ventilation and lighting in all tunnels over 2 Km long. Shafts / adits were provided in 5 out of the 9 tunnels on the Konkan Railway. Forced ventilation systems by installing centrifugal fans with 150 KW capacities were installed.

III.5.1.6 As of now, the longest operational rail tunnel in India is the 6.5 km Karbude tunnel on the Konkan Railways.

Hydraulic drilling jumbo for ATLAS COPCO ready to go into operation on rock tunnel face.



Honnawar Tunnel excavation through shaft.

III.5.2 Jammu – Udhampur Rail Link

The section has 20 tunnels with a total length of 10.59 Km. Nine of these tunnels were constructed with conventional method of tunneling and have 225 thick lining. These tunnels are in sand, clay stone, sand stone, silt stone and shale. The loose rock at the portals has been stabilized by shotcreting. The remaining tunnels were constructed using cut and cover technology with small portions constructed by conventional method. The longest tunnel (T-7) on this section is 2.444 Km and two other tunnels (T - 15 & 16) are more than 1 Km in length.

III.5.3 Udhampur – Katra Section of Udhampur-Srinagar-Baramulla (USB) Project

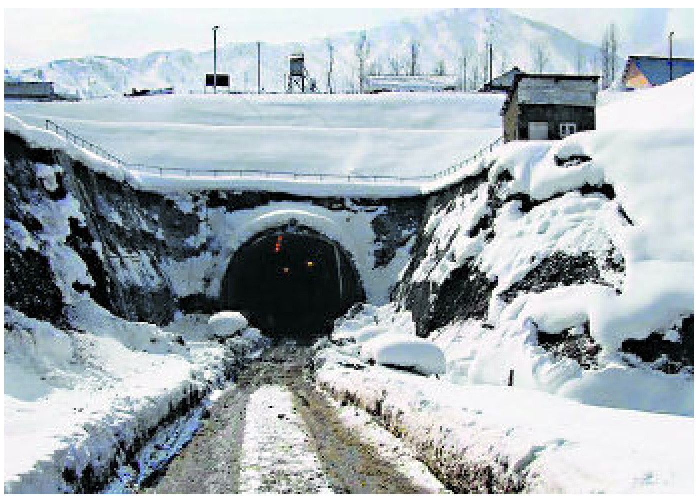
This section has 10 tunnels having a total length of 10.59 Km, the longest T-1 being 3.1 Km long, the next T-3 being 2.549 Km long and 4 more tunnels more than 1 Km long. All these tunnels are D shape and have been provided with conventional lining. The method of tunneling adopted was provision of RS Joist at various spacing + lagging + backfill + lining. All these tunnels required provision of support during construction as these tunnels were located in poor quality sand rock, clay stone, sand stone with seepage and compacted wet sand rock.

III.5.4 Katra – Qazigund Section of Udhampur-Srinagar-Baramulla (USB) Project

III.5.4.1 The Katra-Qazigund section involves 103 km of tunnels out of the total 129 km line. Almost 65 to 70 major and minor tunnels will be constructed on this section.

Railways have successfully completed construction of the second 1483 meter Sangaldhan tunnel, in 28 months. Earlier breakthrough of the first tunnel of 1671 metre length at Sangaldhan was achieved on 29th July 2010. This tunnel passes through strata of poor geology, consisting of Muree formation. The excavation was done using drill and blast method. The tunnel excavation was done from two ends

III.5.4.2 Also nearing completion is the longest Railway tunnel being constructed in India. The 11-kilometre-long "Pir Panjal" tunnel between Banihal and Qazigund in Jammu and Kashmir has more or less been complicated and track linking is in progress. The tunnel is programmed to be commissioned by December, 2012.



A View of the 11-kilometre-long "Pir Panjal" tunnel between Banihal and Qazigund in Jammu and Kashmir – Construction nearing completion.

The countdown for the commissioning of India's longest railway tunnel in the Kashmir Valley has started, with the completion of tunneling work from opposite ends. The 11-kilometre-long "Pir Panjal" tunnel between Banihal and Qazigund is part of the 340-km-long railway project in Jammu and Kashmir, which will link the Valley with the rest of the country.

III.5.4.2.1 The tunnel is an engineering marvel It is being built along a route dotted with difficult geological features such as hard rocky surfaces, deep gorges and seemingly inaccessible steep slopes. The tunnel boasts state-of-art safety and design features.

III.5.4.2.2 Minute attention has been paid to ventilation, fire-fighting and drainage. Steps have been taken to prevent water-logging too. The tunnel has five working faces, instead of the usual two, and this has brought down construction time from seven years to five years.

III.5.4.2.3 Estimated to cost Rs.647 crore, the tunnel has many firsts to its credit such as the extensive use of road header (a tunneling machine) and the adoption of the New Austrian Tunneling Method (NATM) on a large scale anywhere in the country.

III.5.4.2.4 In the New Austrian Tunneling Method, the surrounding rock or soil formations of a tunnel are integrated into an overall ring-like support structure. Thus the geological stress of the surrounding rock mass is used to stabilize the tunnel itself.

III.5.4.2.5 The tunnel also has a three-meter-wide road running parallel to the tracks inside. It can be used in times of emergency to ferry trucks or ambulances.

III.6 Metro Railway Tunnels

In recent times, with the rapid urbanization and growth of mega cities, the growing demands of commuter traffic have necessitated taking up of rail based mass rapid transit system projects in many cities. Such systems are either elevated or under-ground, or even at-grade. Under-ground lines require construction of tunnels.

III.6.1 The rationale on going under-ground in metros

Underground system is adopted in stretches where adequate land is not available for construction of a system on the ground or as an elevated one, and where environmental or aesthetic considerations do not permit over ground lines. In this system, the underground railways are provided at a depth which is generally more than 25m deep. The railway line is constructed in a tunnel. The main reason of taking the railway so deep (i.e. more than 25 m) is because there is no interference of water supply mains, sewerage system, telephone lines, gas line, etc. which are normally within 10 m of natural ground. However the actual depth to be adopted will depend on existing underground facilities like road subways, underground metro lines which will require to be crossed etc.

III.6.1.1 The railway stations of an underground system are generally of cylindrical shape. Normally, electric traction is used in such systems due to the need to avoid smoke and environmental pollution. Escalators, lifts and staircases are provided for facilitating passenger entry and exit. In order to provide safety to passengers the doors of the compartments have to be closed before trains can start.

III.6.1.2 The main advantages of the underground system are that train services can run fast and unobstructed as there are no road crossings or such other similar problems. As the movement of train is fast, the capacity of the underground railways to deal with traffic is very high. No land is wasted and large area of the cities, which would have otherwise been used for surface railways, are available for better land use. This system also provides safety during aerial attacks particularly during war.

III.6.1.3 The limitations of the underground system are mainly that they are very costly and require heavy financial resources. Special care has also to be taken for drainage and ventilation of the underground system. During construction stage, many essential services have to be diverted causing inconvenience to the residents of the areas where the construction is taking place.

III.6.2 Kolkata Metro

The Kolkata (Calcutta) Metro, run by the Indian Railways was the first underground railway to be built in India, with operations starting in 1984. The line runs from Dum Dum in the north and continues south through Park Street, Esplanade in the heart of the city till the southern end to Kavi Nazrul. The first phase of this line with a length of 16.45 Km was completed in 1995. The tunneling was done mainly be cut and cover except in small stretches where shield tunneling was done. However where the metro alignment passed under residential building or a canal the “driven shield tunneling method” was adopted.

III.6.2.1 Services from Dum Dum to Tollygunge started finally in 1995, and full services from Dum Dum to New Garia commenced on October 7, 2010.The under-ground railway was conceived, planned, designed and constructed by the Indian Railways, using Indian talent, expertise and resources which have helped achieve self sufficiency in this new field of technology.

III.6.2.2 The main features of the Kolkata metro project are mentioned below:

- Cut and cover method of construction using diaphragm walls and sheet piles.
- Use of extensive decking to keep the traffic flowing over the cut while constructions in progress underneath.
- Shield tunneling using compressed air and airlocks.
- Ballastless track using elastic fastenings, rubber pads, epoxy mortar and nylon inserts.
- Air-conditioning and ventilation system for environmental control of stations and tunnels.
- Third Rail current collection system for traction.
- Underground substations with dry type transformers and SF-6 circuit breakers.
- Tunnel- Train VHF- radio communication system.
- Micro-processor-based train control and supervisory remote control system for substations.
- Automatic ticket vending and checking system.

III.6.2.3 While most of the metro railway was constructed by the cut and cover process, the Shyambazar – Belgachia stretch was constructed by tunnelling. No TBM was used in Kolkata metro rail construction, rather high pressure tunneling system were adopted. In this system high pressure nitrogen/air mixture were pumped inside the tunnel . Digging was carried out by hand held drilling machine and steel cages were installed in place of excavated mud. It was a slow labor intensive process but they were forced to adopt such techniques because subsoil of Kolkata is all mud (soft clay). The location between Tala and Shyambazar was also dug out this way. High pressure air caused nitrogen narcosis to the diggers and they had to follow the same breathing protocol as a diver does. Nowhere in India, such mud digging tunneling operation has been tried before; it was infact a new technology for the project.

A view of the Kolkata Metro Station

It has since been decided to extend the Kolkata Metro system by adding an East-West corridor a ₹4,874 crore project which includes connection of Kolkata with Howrah by an underwater metro line. The total length will be 14.67 km (8.9 km underground and 5.77 km elevated).

III.6.2.4 The underwater metro plan was first thought of when the first metro service was inaugurated in Kolkata in 1984 by former Prime Minister Indira Gandhi. The route is to cover 12 stations and go under the river through a tunnel. Foundation Stone for the Project was laid on 22 February 2009. The East-West Metro will run from Salt Lake Sector 5 (in the east) to Howrah Maidan (in the west). Unlike line 1, which is operated by the Indian Railways, line 2 will be constructed and operated by a new company - Kolkata Metro Rail Corporation. Between Mahakaran & Howrah, the metro will run 100 ft (30 m) under the Hooghly River (first underwater metro in India)

III.7 Delhi Metro

III.7.1 Delhi metro is not a part of the Indian Railways but since it is a rail based mass transit system using technology akin to that used in construction of under-ground railways, brief details are given below

III.7.2 The construction of the Delhi metro was sanctioned in September 1996 and the first leg was completed and commissioned in 2002. Delhi Metro now has a total of 31 underground stations with a total length of the underground corridor which is presently 48.06 kilometers.

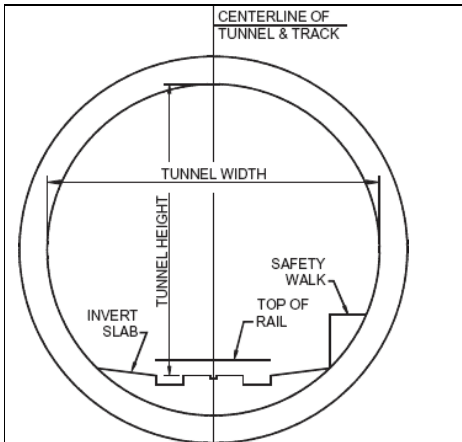
In Phase 3, being taken up now there will be 28 underground stations and under-ground corridors of 41.044 kilometers. The decision to construct more underground corridors was taken this time to ensure that the construction work causes minimum inconvenience to the people. By constructing so many underground stretches, Delhi Metro Rail Corporation (DMRC) will also be able to avoid causing any damage to the existing infrastructure such as flyovers and roads.

III.7.3 Tunneling using the latest technology was done in a big way in Delhi Metro where 13.17 Km underground Metro was constructed in phase I and 29 Km in phase II. This work was done between 1998 and 2006. The tunneling was done at depth of 20m. TBM was used for tunnels and cut and cover for station. Rock boring machine were used for rocky areas and EPBM (Earth Pressure Boring Machine) for tunneling in soft soil. NATM was used for Chawari Bazar station where space was a major constraint.

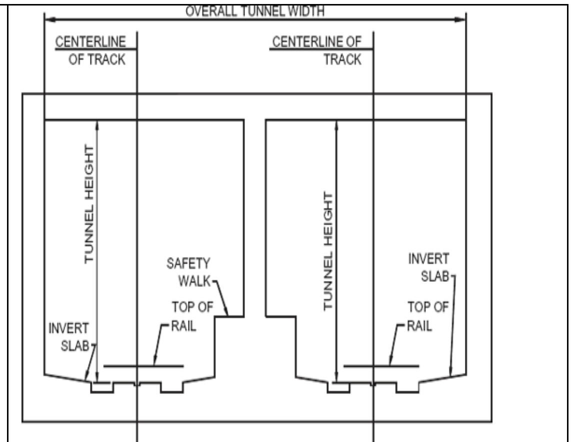
Deep Tunnel Work on Delhi Metro in Progress

III.8 Tunnel Sections usually adopted in Railway Tunnels

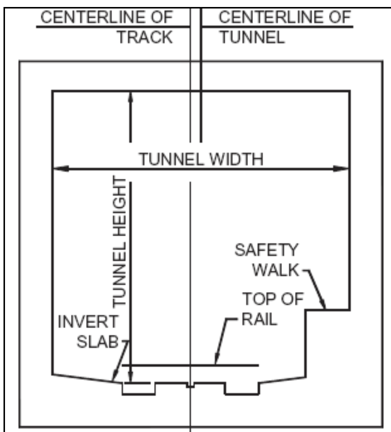
There are four main shapes of Railway tunnels - Circular, Rectangular, Horseshoe, and Oval/Egg. The different shapes typically relate to the method of construction and the ground conditions in which they were constructed. Some tunnels may be constructed using combinations of these types due to different soil conditions along the length of the tunnel. Another possible Railway tunnel shape is a single or twin box for bi-directional traffic.



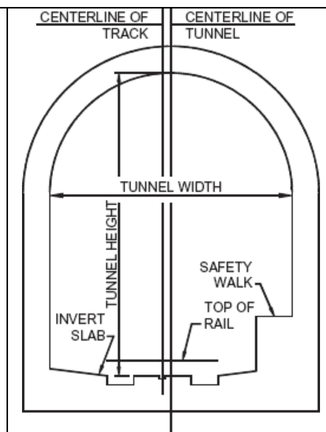
Circular tunnel with a single track and one safety walk



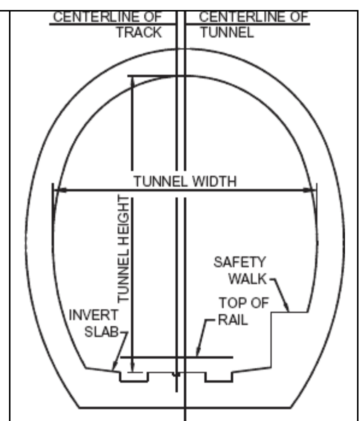
Double box tunnel with a single track and one safety walk in each box.



Single box tunnel with a single track and one safety walk



Horseshoe tunnel with a single track and one safety walk.



Oval tunnel with a single track and one safety walk

Tunnel cross sections have to essentially satisfy the clearance requirement laid down in the Schedule of Dimensions of Indian Railways. Beyond the fix structure dimension line an additional lateral clearance is generally provided to take into account construction tolerances. The height of the tunnel is decided based on the requirement of OHE. Extra clearances are provided to suit ventilation and lighting requirements of long tunnels and for tunnels on curved tracks. On narrow gauge and meter gauge sections, the cross section is correspondingly smaller to suit the size of rolling stock on those gauges.

III.9 Use of different technologies for tunneling in different situations

1. Cut & Cover
2. Shield Tunneling
3. Tunneling using drill and blast systems
4. Use of tunnel boring machines
5. New Austrian Tunneling Method (NATM)

III.9.1 Cut & Cover

This is a simple method of construction for shallow tunnels where a trench is excavated and covered with an overhead support system strong enough to carry the load of what is to be built above the tunnel. Two basic forms of cut-and-cover tunneling are available:

a. *Bottom-up method*: A trench is excavated, with ground support as necessary, and the tunnel is constructed in it. The tunnel may be of in situ concrete, precast concrete, precast arches, or corrugated steel arches; in early days brickwork was used. The trench is then carefully back-filled and the surface is reinstated.

b. *Top-down method*: Here side support walls and capping beams are constructed from ground level by such methods as slurry walling, or contiguous bored piling. Then a shallow excavation allows making the tunnel roof of precast beams or in situ concrete. The surface is then reinstated except for access openings. This allows early reinstatement of roadways, services and other surface features. Excavation then takes place under the permanent tunnel roof, and the base slab is constructed.

III.9.2 Shield Tunneling

In soft soil and where deep tunnels are excavated, a tunneling shield is normally adopted. In early shield tunneling, the shield functioned as a way to protect laborers who performed the digging, and moved the shield forward, progressively replacing it with pre-built sections of tunnel wall. Later shields were used for preventing slippage of earth from the sites into the excavated trench till the tunnel is constructed. The shield can then be moved forward to the next section to be taken up. The deep tunnels for Kolkata Metro were built in this way. The shield also can divide the workface into overlapping portions that each worker could excavate.

III.9.3 Tunneling using drill and blast systems

This method is used in hard rock. It can be used for full face as well as for header excavation. Drilling jumbos go to the tunnel face and drill a set of holes in the portion to be tunneled. These holes are then charged with controlled explosives and simultaneously blasted. There after special loaders excavate the spoils and the work proceeds cyclically ahead. This method can also be followed while in soft soil tunnels, with supports and the portal being fixed at convenient points ahead of tunneling. This method was extensively used on Konkan Railway where Drilling jumbos and special loaders, imported from Sweden, were used giving a progress of about 45 to 70 meters per month. For muck removal electro hydraulic digging arm loaders were imported from Sweden.

III.9.4 Use of Tunnel Boring Machines (TBM)

1. Tunnel boring machines were first used for Railway tunnels in the USB Project, and on DMRC. Tunnel boring machines are used as an alternative to drilling and blasting methods in rock and conventional 'hand mining' in soil. TBMs have the advantage of minimizing the disturbance to the surrounding ground and producing a smooth tunnel wall. This significantly reduces the cost of lining the tunnel, and makes them suitable to use in heavily urbanized areas. The major disadvantage is the upfront cost. TBMs are expensive to construct, and can be difficult to transport. However, as modern tunnels become longer, the cost of tunnel boring machines versus drill and blast is actually less—this is because tunneling with TBMs is much more efficient and results in a shorter project completion time.

2. Modern TBMs typically consist of the rotating cutting wheel, called a cutter head, followed by a main bearing, a thrust system and trailing support mechanisms. The type of machine used depends on the particular geology of the project, the amount of ground water present and other factors.

3. In hard rock, either shielded or open-type TBMs can be used. All types of hard rock TBMs excavate rock using disc cutters mounted in the cutter head. The disc cutters create compressive stress fractures in the rock, causing it to chip away from the rock in front of the machine, called the tunnel face. The excavated rock, known as muck, is transferred through openings in the cutter head to a belt conveyor, where it runs through the machine to a system of

conveyors or muck cars for removal from the tunnel. In fractured rock, shielded hard rock TBMs can be used, which erect concrete segments to support unstable tunnel walls behind the machine. In soft ground, there are two main types of TBMs: Earth Pressure Balance Machines (EPB) and Slurry Shield (SS). Both types of machines operate like Single Shield TBMs, using thrust cylinders to advance forward by pushing off against concrete segments. The cutter head does not use disc cutters only, but instead a combination of tungsten carbide cutting bits, carbide disc cutters, and/or hard rock disc cutters.

III.9.5 **The New Austrian Tunneling method (NATM)** was developed between 1957 and 1965 in Austria. The main idea is to use the geological stress of the surrounding rock mass to stabilize the tunnel itself. The main features on which NATM is based are: Mobilization of the strength of rock mass, achieving shotcrete protection by applying a thin layer of shotcrete immediately after face advance, measurements - Every deformation of the excavation must be measured, providing flexible support with a primary lining that is thin and reflects recent strata conditions. The tunnel is strengthened by a flexible combination of rock bolts, wire mesh and steel ribs, and quickly closing the invert and creating a load-bearing ring is important. It is crucial in soft ground tunnels where no section of the tunnel should be left open even temporarily. This method is being used on DMRC and is also proposed to be used in the East West Corridor of Kolkata metro

BIBLIOGRAPHY

1. www.iricen.gov.in
2. Wikianswers.com
3. Wikipedia.org
4. www.tunnelsindia.com
5. www.rites.com
6. www.worldheritagesites.com
7. www.IRFCA.org
8. Papers of World Tunnel Congress 2008
9. www.konkanrailway.com

10. “The story of Konkan Railway in India. How the ideas have worked” by E.Sreedharan.

11. Directory of Tunnels Publication No 306 of Tunneling Assn of India issued by CBIP in 2008.

12. History of Tunnels in India pub No 307 of Tunneling Assn of India issued CBIP 2008.

13. A treatise on Konkan Railway published in 1999 by KRCL.

14. ‘Tunnels on Indian Railways’ by RDSO 1998.

15. Railways Works Engineering by MM Agarwal.

16. Highway and Rail Transit Tunnel Inspection Manual 2005 edition of the US Department of Transportation.

CHAPTER – IV

RIVER TRAINING AND BRIDGE PROTECTION WORKS

IV.1 River training and management is an essential part of bridge planning. In Northern India and North East India the rivers generally originate from the Himalayas and are perennial in nature due to melting snow and monsoons. Some of the rivers carry silt and tend to meander within the Khadirs. The Khadirs are high land masses on either side of the river. As an example, a river may have an actual width of flow as 500 m but the Khadirs may be 4 km apart between which river meanders. By careful planning a river may be bridged by a 500 m long bridge instead of a 4 km long costly bridging. This requires development of river guiding systems but these may not be possible in every situation.

IV.2 In Indo-Gangetic plains, rivers flow through alluvial deposits which are scoured away easily. The rivers thus become unstable and the location and line of flow can change. Only a part of their beds are occupied by the dry weather live channel, but, in the monsoons, they get in spate occupying longer width, though a substantial part of river may be fairly shallow.

IV.2.1 In the North-East the slope of river beds are steeper than in Indo- Gangetic plains. These rivers have high velocity, carry a lot of silt and often tend to change course and shift laterally due to deposit of silt in river beds raising the bed level. Bridges over such rivers can be built by adopting proper river training measures to stabilize the water channel.

IV.2.2 Rivers in Central and Southern India flow through well defined waterways, the beds and banks are firm (often rocky) and rivers are generally stable. These do not require elaborate river training works.

IV.3 Railway engineers have been careful in locating bridges and bridge engineering involving River Training took shape due to pioneering efforts of many eminent engineers.

IV.4 A solution to selecting site for locating a bridge was thought of by observing a wide river passing through a stable narrow gorge of a smaller but deeper section. Artificial narrowing of the river has been found to be desirable, feasible and economical. The comparative costs of bridging the full width of a river and of a bridge of constricted width together with the protective works needed, bring out the economy (see Table 1) that can be achieved. The river has also to be made to flow axially under the bridge otherwise it starts attacking the protection works and the embankments.

Table I : Cost of Bridges with and without Constriction by Guide Bunds

S.No.	Name of river and location of bridge	Width of river along bridge line when it was constructed (in m)	Length of bridge (in m)	Total cost of the bridge with out guide bunds in Rs. 1,00,000	Length of guide bunds (in m) Left bank Right bank	Total cost of the actual bridge with guide bunds in Rs. 1,00,000	Total cost of the bridge if river would have been spanned without guide bunds in Rs. 1,00,000
1.	Krishna at Vijayawada	1,463	1,138	35.18	900 665 (Total - 1565)	40.32	45.24
2.	Chenab at Sherashaha	3,657	1,114	22.49	1200 1332 (Total - 2532)	31.47	73.80
3.	Ganga at Garhmukteswar	1,706	712	13.80	510 720 (Total - 1230)	20.00	33.04

IV.5 The method of constricting a river for the construction of a bridge and of controlling it so that it flows, as far as possible, axially through the bridge by means of a system of guide bunds was first introduced by Bell in 1888, while constructing the bridge on the river Chenab at Shershaha (the Punjab, Pakistan). The waterway provided was about 1,114 m as against the Khadir width of 3,657 m.

IV.5.1 The Guide Bund system was adopted in almost all the bridges across alluvial rivers, which, because of the attendant advantages, has become a standard practice. However, the guide bunds have been found to be incapable of providing complete protection, especially when there are no permanent Khadir banks to limit the river meanders within themselves and prevent them from shifting erratically. Whatever be their length, the guide bunds cannot preclude the river from cutting into the bridge approaches, as was apprehended at the Garhmukteshwar Railway Bridge over the river Ganga in 1955.

IV.5.2 The method developed during recent years, consists in making use of the natural curvature of flow associated with the meanders. If an existing river meander is stabilized by means of natural or artificial control points, such as outcrops of hard materials or pitched islands which cause deep scour along them and thus peg the river to themselves, it is easy to position a bridge so that permanent stability of the river channel in the vicinity of the bridge is obtained. An outstanding example where a bridge has been constructed with two natural control points is the Dufferin Bridge, now called the Malaviya Bridge near Varanasi over river Ganga. Amongst all the bridges spanning the river Ganga, this bridge alone is not provided with any training works. Here kankar outcrops exist on the left bank and again on the right bank a few miles upstream. The river has been held at these points permanently and thus, the river approach to the bridge is stabilized.

IV.5.3 Similar favorable conditions rarely obtain. A river is often held permanently at a point on one bank, but not on the other. The solution then is to construct the bridge at a suitable place to be tested on a model downstream of the natural control point, so that the control point and the bridge become two obligatory points which the river will not leave and the river meander gets stabilized at the bridge.

IV.5.4 In river training, the ultimate aim is to attain a state of equilibrium and stability with the aid of training measures. However, aggrading and degrading rivers are not very amenable to river training on account of their inherent instability.

IV.6 The various types of River Training works in vogue are –

- Guide Bund systems
- Groynes or Spurs
- Deflectors
- Bed bars
- Embankments
- Bank protection and boulder pitching on banks
- Pitched Islands

A combination of above methods can be adopted as warranted.

IV.6.1 Guide bunds are artificial embankments (Permanent structures) meant for guiding the river flow past a bridge, without causing damage to the bridge and its approaches. Groynes are structures which extend from bank into the river and are used for protecting the bank and training the river to follow a desired course. [See Fig. 1 and Fig. 2]

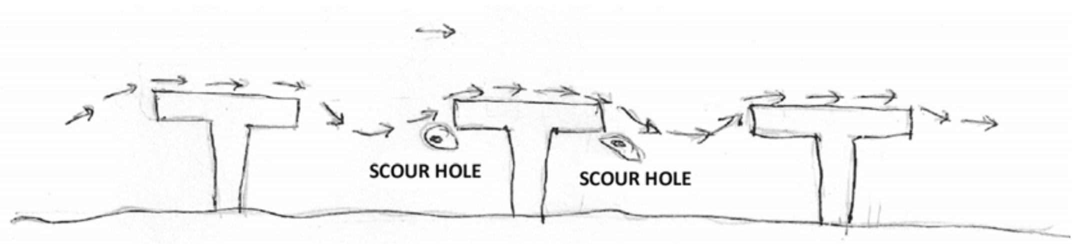


Fig 1: 'T' HEADED GROYNES

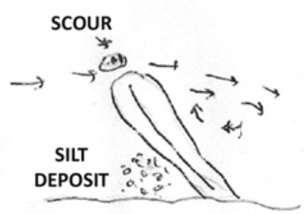


Fig 2 (a): REPELLING GROYNES

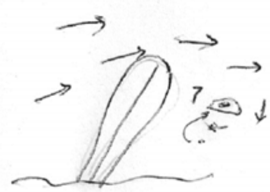


Fig 2 (b): ATTRACTING GROYNES

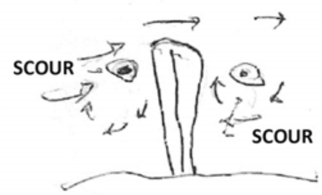


Fig 2 (c): DEFLECTING GROYNES

IV.7 Some examples of river behavior and training works near bridge sites in bridge construction are discussed in the following paragraphs:

IV.7.1 Sutlej bridge at Firozepur (Punjab)

This bridge was constructed in the year 1886. However, river flow was quite strong and the protection system (Guide system for river to flow axially through bridge) consisting of pair of parabolic earthen bunds with spurs of stone jutting out at right angles were badly damaged in 1889 floods. These were then replaced by Bells guide bunds which proved successful in controlling the river at the bridge. Bells guide bunds are still a good method of river training at bridge sites.

IV.7.2 Ganga bridge at Garhmukteshwar (U P)

Here the bridge is located at a place where, over time, the river started shifting towards the left bank due to curvature and bend in the river and this threatened the railway embankment and the bridge. A model study was immediately got done through Central Water and Power Research Station (CWPRS), Pune. Their findings and action thereon protected the bridge. The railway line had to be receded. The left guide bund on upstream side was also extended by 488 m. [See Figures 3 and 4]

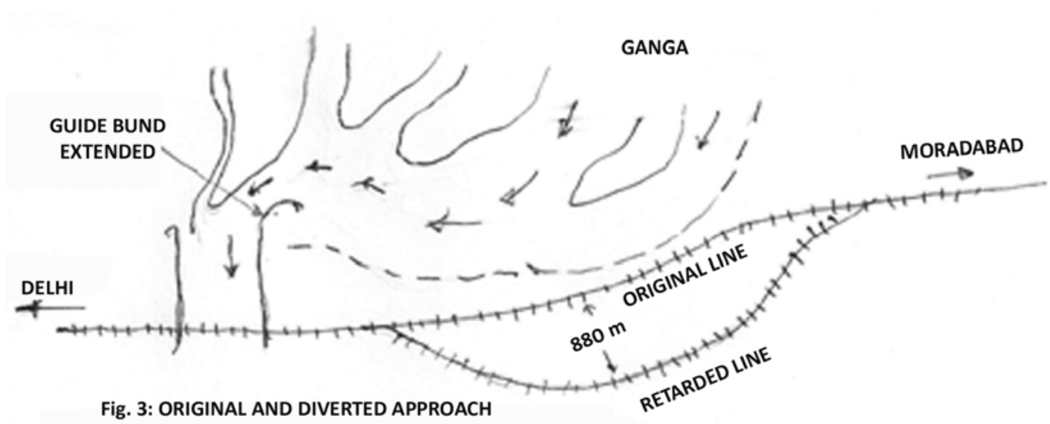


Fig. 3: ORIGINAL AND DIVERTED APPROACH OF GANGA BRIDGE AT GARHMUKTESHWAR

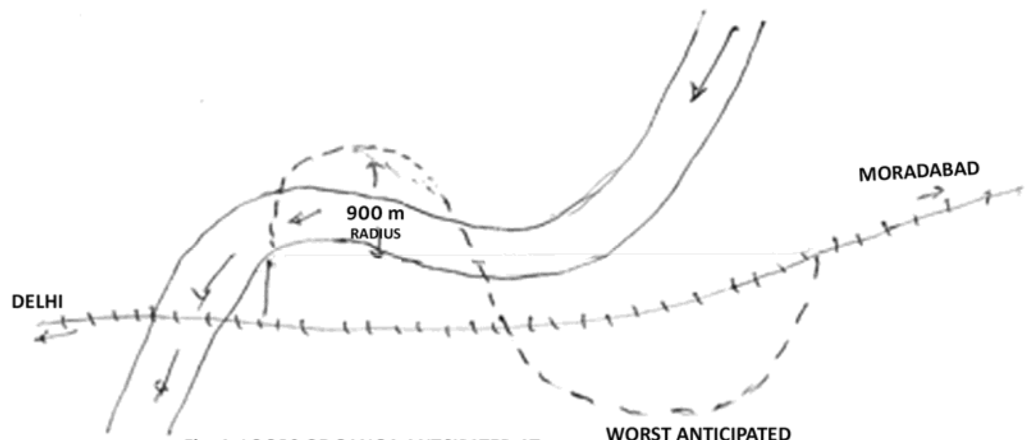


Fig. 4: LOOPS OF GANGA ANTCIPATED AT GARHMUKTESHWAR

IV.7.3 Ganga Bridge – Mokamah (Bihar)

The river has a width of 8 km at both upstream and downstream of Mokamah. At Mokamah the river flows through a stable channel of only 4.4 km and the bridge is sited here. This bridge was built after Independence [1947]. Advantage has been taken of the right bank made up of clay, where bank is stable. Guide bund is provided for the left approach. The guide bund was a good river control measure. The bridge was constructed safely and Mr. H. K. Sethi, the Chief Engineer in charge was awarded with ‘Padma Shree’.The river under bridge was constricted from 3658 m to 1720 m. [See Fig. 5 and Fig. 6]

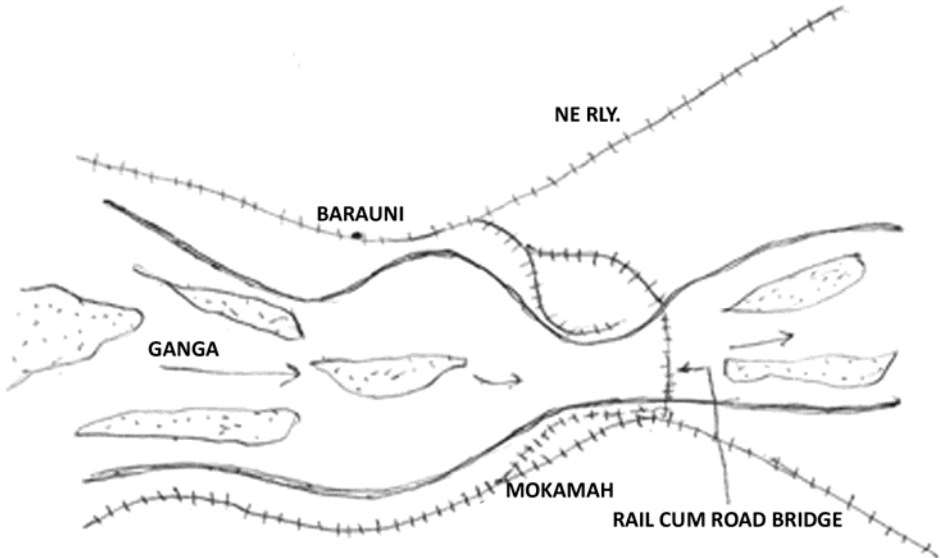


Fig 5: GANGA NEAR MOKAMAH

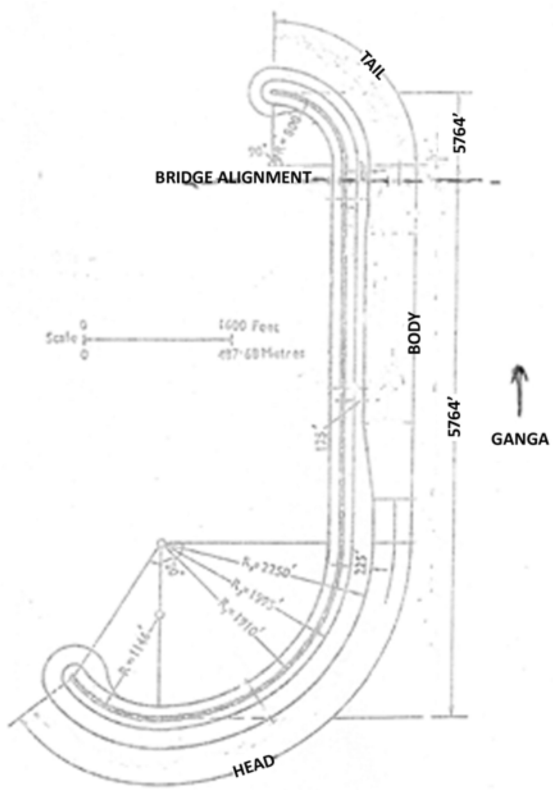


Fig. 6 : Details of guide bund of rail-cum-road bridge over river Ganga at mokamah

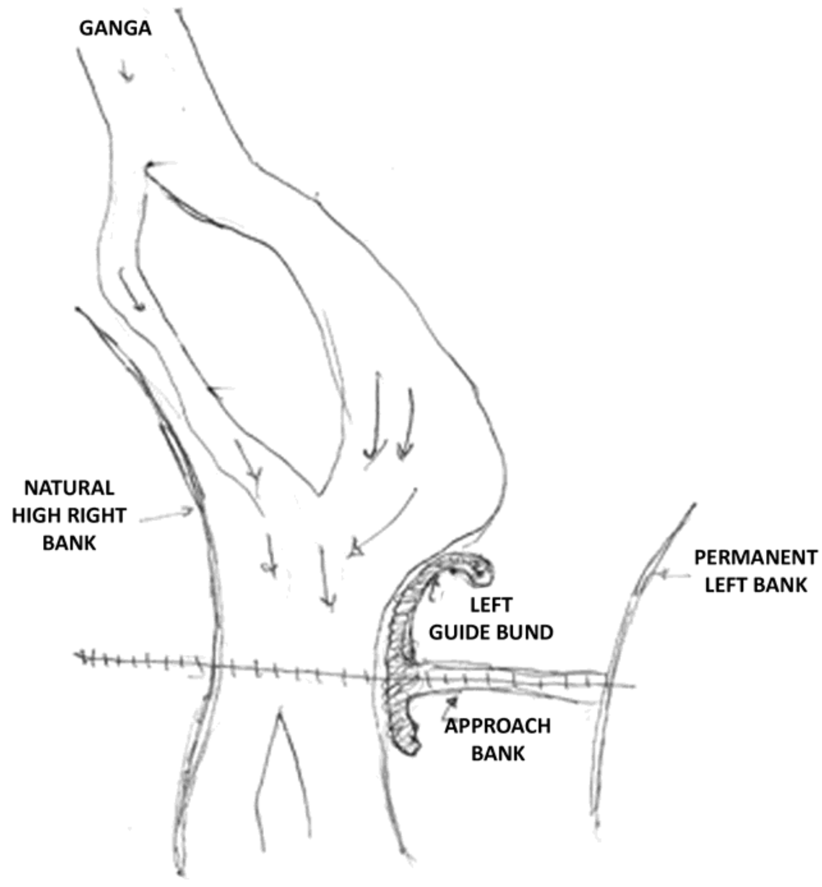


Fig 7: CURZON BRIDGE OVER GANGA AT ALLAHABAD

IV.7.4 Curzon bridge (over Ganga) at Allahabad (UP)

The bridge was opened to traffic in 1905, located 646 miles [1034 km] from its source. Here the right bank is firm and inerodable and is very suitable to locate a bridge. The bridge is provided with training bund only on the left bank. A new railway bridge has also been constructed in 1994 close to the old bridge. An approach bank has been constructed on left side to minimise bridging length to around 1 km. [see Fig. 7]

IV.7.5 Ganga bridge at Kanpur

Here the right bank is high and firm. The river is well controlled by it. The left bank is low and the river spills widely causing floods. A training bund has been provided on the left side to control the river.

IV.7.6 Luni river bridge at Samdari (Rajasthan)

Luni river originates from hills near Ajmer and has many tributaries and finally falls in the Arabian sea. The flood width in monsoon in general is 945 m. The river was constricted to a width of 395 m at the bridge site. When river is constricted by stable embankment, in floods the beds should scour to get the extra depth. If this does not happen, the water level goes high and can cause severe floods on upstream side.

IV.7.6.1 The river bed consists of large diameter sand. In abnormal rainfall of 1944, the flood discharge became very high. The river bed for adjusting the flood should have eroded by 2.1 m but this did not happen and water level on upstream rose by 1.8 m. Large breaches were caused in guide bunds and in the railway embankment. Subsequently 91 m of waterway was added by additional spans and new guide bunds upstream and downstream of bridge were provided based on a model study at CWPRS Pune. This example brings out the need for proper evaluation of ground characteristics.

IV.7.7 Bridge over river Gandak at Chitauni - Bagha (Bihar)

The River Gandak originates in Nepal. After leaving Tribeni, the river flows for a few kilometers westward, then southward between U.P. and Bihar flowing through West Champaran and Saran Districts of Bihar. The river joins the Ganga river near Patna. Out of its total length of 580 km from the source to the outfall, it flows 45 km in U.P., 274 km in Bihar and the rest in Nepal.

IV.7.7.1 Owing to steep bed slopes, the river has a fairly good velocity of flow. One of the major characteristics of a river flowing in alluvial plains is frequent change in its course in a wide Khadir. The flow also gets braided along with meandering. This is the main reason for attack to the main lands and cause for the flood devastation. The river has oscillated over a wide range in course of years and the main channel which hugged the left bank, since 1924 has shifted to right bank. This was the main cause of the outflanking the bridge and causing wide devastations in 1924.

IV.7.7.2 A railway bridge was constructed in 1911 at Bagha (UP) connecting Chitauni for the meter gauge line of N E Railway. However, proper model study was not got done at that time. Protective groynes pointing downstream were a failure and bridge was abandoned after breaches in 1924 and the line remained closed for a long time.

IV.7.7.3 The control points for the river are : first, the Valmiki barrage built in 1966 near Triveni; second is Birbhar Spur about 7 km upstream of the bridge built in 1954 and is approximately 1.6 km long; third is the Road Bridge at

Domariaghat 135 km downstream of this rail cum Road Bridge. Over the years, the right bank has also been protected with revetments and spurs as flood control measures. The bridge has become another control point for the river. The bridge is also providing flood protection in a stretch of 5 km upstream and 5 km downstream on both sides of river.

IV.7.7.4 New Railway Bridge over river Gandak was recommissioned in 1995 with two elliptical guide bunds (each about 1.8 km long) between which a bridge of 14 spans of 61 m clear span was constructed. The road bridge is over the rail bridge. A model study was done in 1990 in U P Irrigation Research Institute, Roorkee and CWPRS, Pune based on which the design of protection and river training works were planned and executed. As always, a lot of ingenuity and strategy was involved in execution. The width between Khadirs (existing railway track on right, high ground on left) is around 9 km. The bridge is 898 m long, approach banks were constructed between bridge and high banks on either side. The right approach bank is 3 km long, the left approach bank is 5.14 km long. Approach Banks are regular railway embankments, protected with added river training works. The river training works for the bridge included diverting various river channels into main stream, correction of the direction of flow so that river could flow axially through the bridge. These tasks were huge and had to be executed in one dry spell. The river training was done by cutting pilot channels, putting up bamboo porcupines (bamboo cages with sharp ends) filled with sand bags, sal balli piles between which shrubs and sand bags were layered, permeable spurs to gently slow down flow and induce siltation in desired locations. The purpose of river training in river Gandak was to enable construction of guide bunds and approach banks. Once the guide bunds and approach banks were constructed, the ultimate training of river is done by the guide bunds themselves. The protection works and training works have also resulted in reclaiming 50 square km of land which used to lie under river water.

IV.7.7.5 Construction of the two guide bunds and their approach embankments along with 8 foundations for bridge were completed in 150 days in a war-like effort in dry season. This is considered as a marvelous engineering feat and is a fine example of professional achievement by Railways.[see Figures 8,9, & 10]

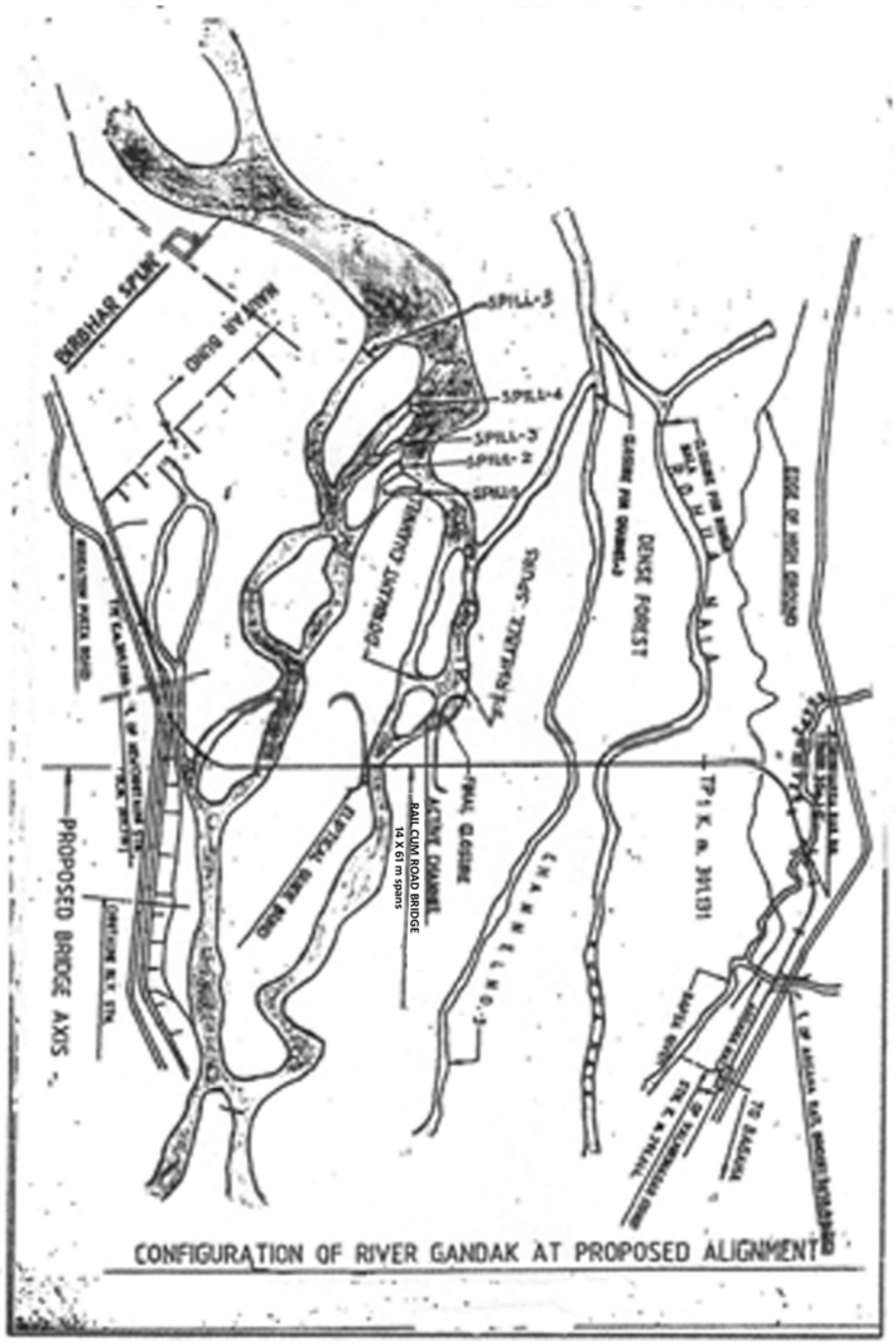


Fig. 8 : Gandak, 1992 before bridge

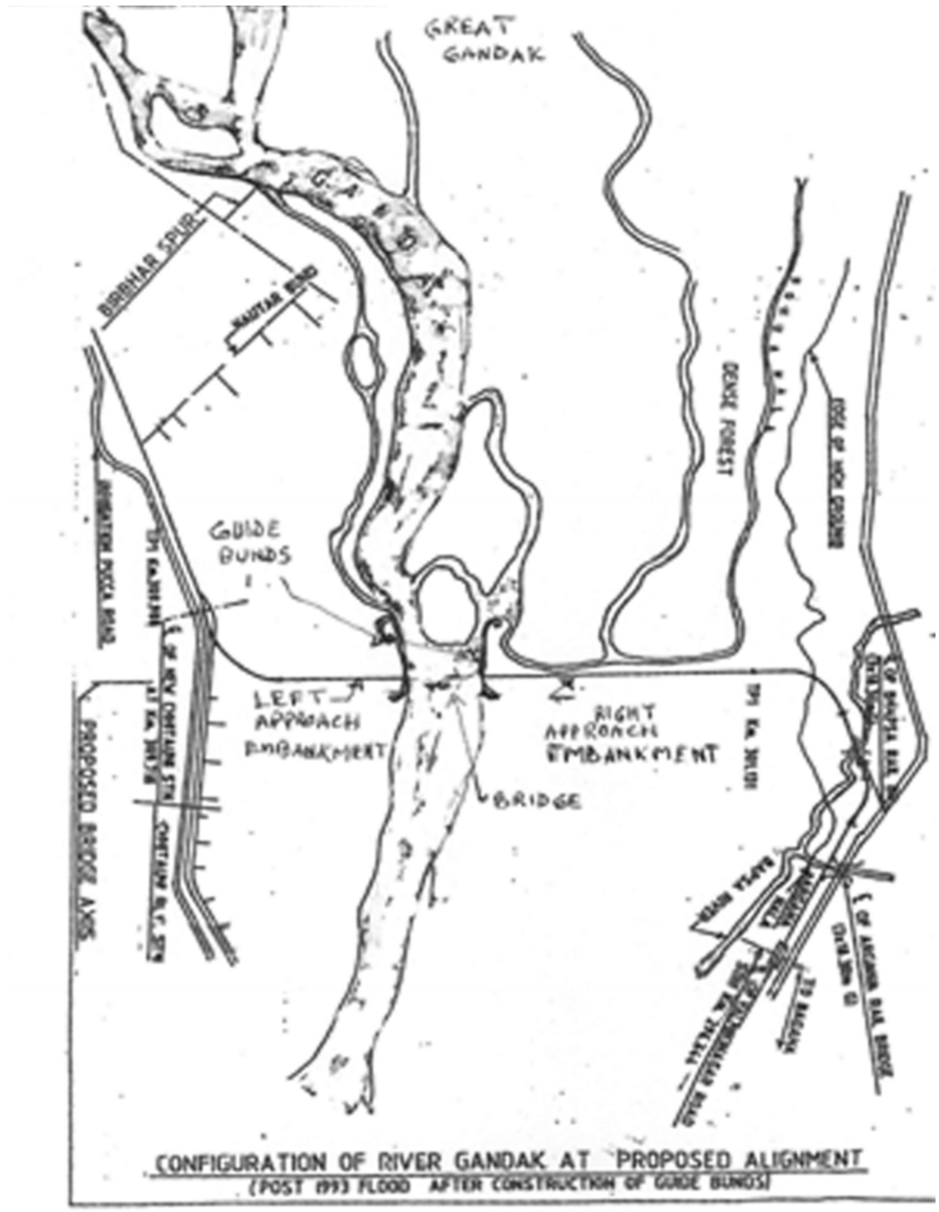


Fig. 9 : Gandak, 1995 after bridge

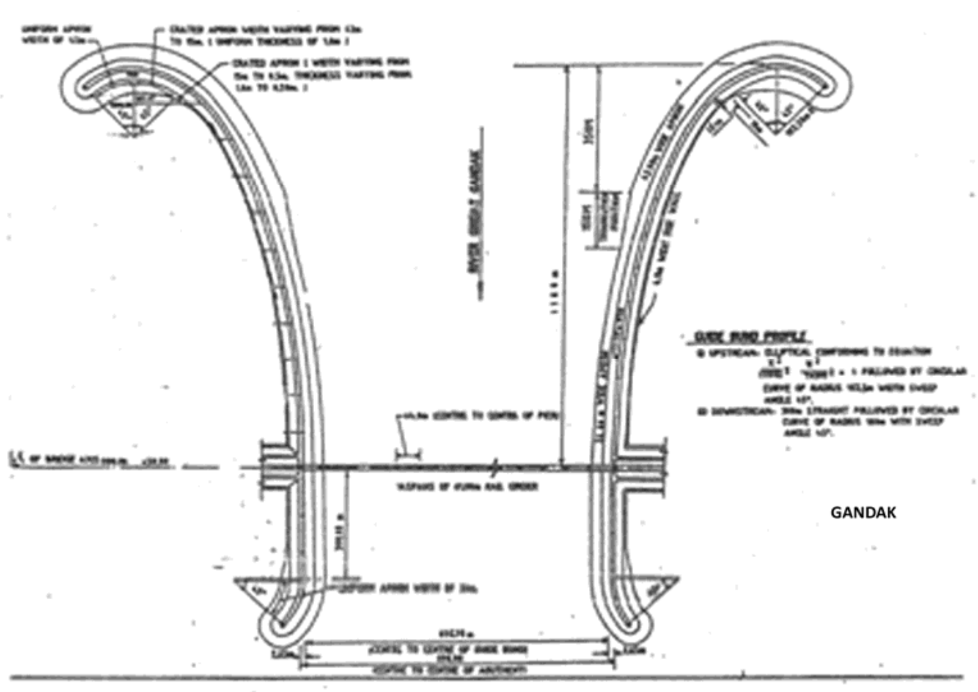


Fig. 10 : Details of elliptical guide bunds

IV.7.8 Brahmaputra Bridge at Jogighopa (Assam)

The total length of Brahmaputra River is 2900 km flowing from China to Bay of Bengal. The width of the river at this bridge alignment is about 3.10 km. The bridging from the bank to bank would have been uneconomical. Moreover, in a braided river like Brahmaputra, the stability of the river cannot be ensured without firm control points on both the banks. The river is fixed in position by series of hills on both North and South banks. Two guide bunds have been provided to ensure the stability of the river and to protect the approach banks. The bridge is 2.284 km long between the guide bunds. The length of the north guide bund along its alignment is 850 m whereas axial length of the south guide bund is 478 m. The radius of the upstream north guide bund curve at start is 250 m and that of the south guide bund is 100 m. In both the guide bunds, tail end is having a radius of 100 m. The sweep angle for north guide bund is 90 degrees and that for south guide bund is 60 degrees. The top of the guide bunds is 9 m wide and about 3.50 m above the highest flood level.

IV.7.8.1 IS: 8408 also lays down the criteria for design of different components of guide bunds. Considering the importance of the bridge, the heaviest sections for pitching and apron have been provided. University of Roorkee conducted the liquefaction studies of the river bed material; based on the same, a 3.0 m wide berm has been provided on the rear side at pond level. The pond level for the guide bund has been worked out after adding the afflux and the velocity head. A free board of 2.50 m above pond level and 3.50 m above highest flood level (HFL) has been maintained throughout the length of the guide bund. The top width of the earth core of guide bund is 9.0 m excluding the boulder pitching on the edges. The slopes adopted in general for guide bunds are 1:2.5 on the river side as well as on the rear side. [see Fig. 11]

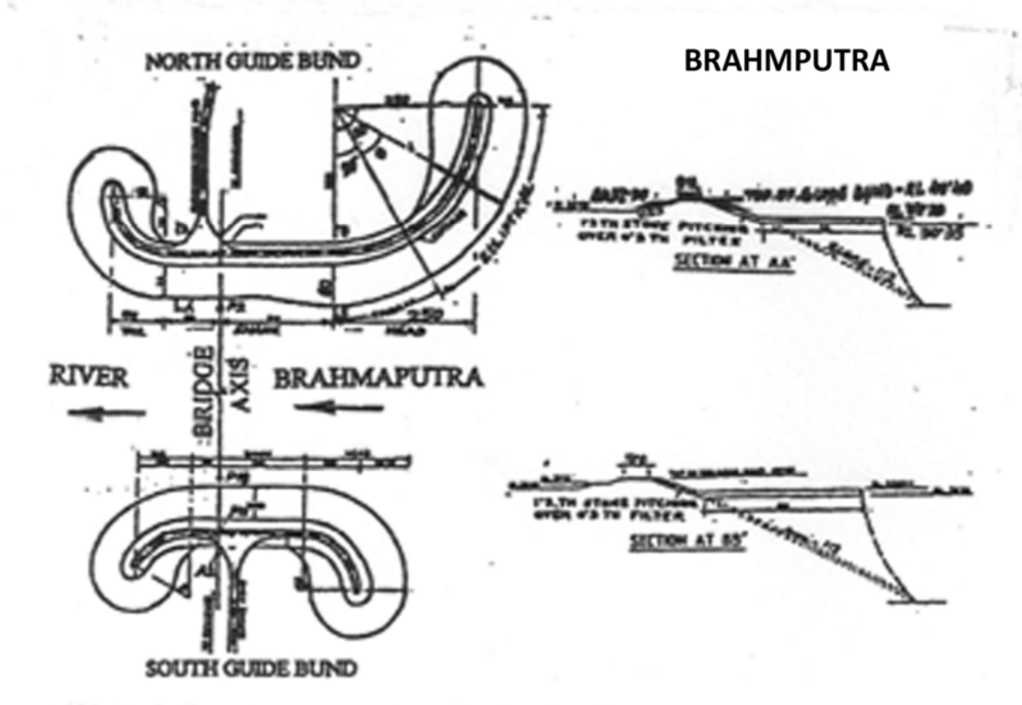


Fig. 11 : Jogigopa – details of guide bunds

IV.8 Brief Description of River Behavior and River Training in Submountaneous Regions in North East to Safeguard Railway Bridges

IV.8.1 Sites for bridges are so chosen that frequent changes do not occur in river course and where tendency for aggradation or degradation is minimum. Care is also taken to avoid problem of bank erosion and difficult foundation conditions. Usually river training is contemplated where the alignment of the river section is abnormal e.g. splitting of the river into several branches, development of sharp bends and formation of wide and shallow shoals. Hilly streams near foothills of the Himalayas are having very steep slopes and carry enormous quantities of boulders, shingles etc. As such it is extremely difficult to stabilize their course.

IV.8.1.1 In monsoons following can happen :

- Change of course of river thereby eroding the river beds, flowing parallel to railway track and reducing the distance between the railway track and the river, ultimately leading to breaches.
- Rising of bed level due to silt deposits thereby reducing the vertical clearance under the bridge, resulting in water hitting the bridge girder and damaging the bridge.
- Rising of bed level due to silt thereby reducing the slope and ultimately outflanking the guide bunds and marginal bunds leading to water breaching the railway embankment and flowing outside the bridge.
- Continuous erosion of the river bed near bridge piers/ abutment causing deep scour holes around piers which reduces the grip length of the piers/abutment and endangers the bridge.

IV.8.1.2 As these reaches of rivers are very close to foot hills, so some amount of aggrading is anticipated but the huge aggrading which has been shown by some of these rivers is due to the contribution of all the above factors except for the sudden intrusion of sediment by some tributary. Due to deforestation in the area, the amount of silt load has increased and discharge has been reduced due to reduction in rainfall. A number of marginal embankments have been constructed by flood control/ irrigation departments at upstream and downstream of these rivers to contain the rivers, to protect habited areas/cultivated land adjacent to the rivers. These are often fragile and are breached when river develops abnormally high discharge and over-topples them. Due to river easily branching out and forming different channels the flow in old channel decreases. Due to reduction in the flow, the energy gradient available for flow gets reduced so the silt carrying capacity of water also gets reduced. Initially the sediments which were deposited in a large area are now limited to the area bounded by marginal embankment which lead to very fast rise in the ground level of area bounded by marginal embankments. The adjacent area remains as it is, often lower than the river bed. Whenever any marginal embankment is out flanked/ breached, the river adopts a new course of steeper gradient and the main flow is diverted to new course, which leads to breach of railway embankments in the path of the channel. After breaching embankments, wherever a river gets a proper gradient it joins the original channel down-stream. The frequent breaches by rivers like Kumutia and Gai are due to this. The river training and protecting the bridges are more difficult in these circumstances.

IV.8.2 Bridge Over River Gai – 4x45.72 m Br. No. 360 (Assam)

The meter gauge bridge was opened for traffic in the year 1966. The clearance in between the bottom of girder to bed level of the river was 3.35 m in 1966 which got reduced to only 0.85 m in 1990. The breach of right irrigation marginal bund took place at 245 m upstream from the railway track in a length of about 125 m. The entire GAI river started flowing away from the bridge No. 360. The flood waters over topped the Railway track in a length of about 845 m and breached the embankment at Km 380/13-14 and Km 381/3-4, half a km from the bridge. The traffic was restored by construction of two temporary wooden pile bridges No. 359/A of span 2x11 m+1x12.2 m and bridge No. 359/B of span 5x12.20 m + 6x9.15 m. The work of repairing the right marginal bund was taken up by Irrigation Department and the water was diverted through bridge 360 by the Railway by cutting a pilot channel in the 3rd span. But the aggrading nature of the river is so high that the pilot channel got silted in the first phase of rainfall and further silting of bed kept on taking place as a result of which the guide bund got further breached and the water overtopped the Railway track. The bed of wooden pile bridge No. 359/B also started silting up due to continuous flow of water laden with silt. In fact in the entire length of the track of about 900 m where water was flowing during monsoons, the bed level rose and became very high and the difference between rail level and bed level was just about 1 m. Due to aggradation of bed of Br. No. 359/B and its surrounding, overtopping of Railway track, breaches took place in the following years, 1990, 1991,1994,1996 and 1998.

IV.8.3 River Kumutia Bridge No. 347 M G 4X150 m (Assam)

The river originates from Arunachal Pradesh, touches the plains at 17 km upstream of Railway track. The river does not flow in a well defined channel, but oscillates between its two main channls, Moridhal in east and Kumutia in west and a number of small channels in between these two main channels. Many different courses were adopted by the river from the year 1955 to 1998 . In 1955 the course was of river Jaidol, in 1959 courses of river Moridhal and Kumutia, in 1971 river Moridhal, in 1975 again Kumutia. The river keeps breaching the irrigation marginal bunds and affecting railway track almost every alternate year through new developments in flood plains, silting on downstream, unstable nature of river channel, and it is difficult to train, control and channelise. A number of temporary wooden pile bridges had to be constructed over the new locations of flow of the river after breaching railway embankments and shifts in alignment of river were around and upto 2 km from the existing bridge. In 1998 the river was flowing for 5 km parallel to railway track, upstream of the line. Such developements are not likely to happen in other regions.

IV.8.4 River Simon Bridge No. 376 MG 7x45.70 m (Assam)

Due to continuous scouring of the river bed at the bridge site, grip length of one of the foundation well was reduced, endangering the safety of the bridge. The short term measures were taken to protect the degradation of river bed in year 1984 and 1990 by providing sausage crated boulders around the worst affected piers which are functioning well except for some repair from time to time and now the bed of river has also stabilised. The eastern guide bund was breached near the mole head in 1991-92. The track at Km 410/2-6, about 210 m towards east, had breached in 1995 monsoons due to meandering and a permanent diversion was laid for restoring the traffic.

IV.8.5 River Diana Bridge 7x45.72 m (Assam)

Bridge over river Diana (Br. No. 180) is situated just near the hills of Bhutan. The river bed upstream spreads over 4 to 5 Km width. The meandered river water is trained by providing divergent left guide bund and right guide bund. In 1993, due to high velocity flood flow, left guide bund was breached for 250 m and the river started flowing outside the banks. The water now flowing at a different position hit the railway embankment and track got breached for a length of 32 m making the bridge abutment fully exposed. The breached length of track was repaired. In 1998, the guide bund breached again, the entire river started flowing parallel to the track. However, the track was restored after 3 days. [see Fig. 12]

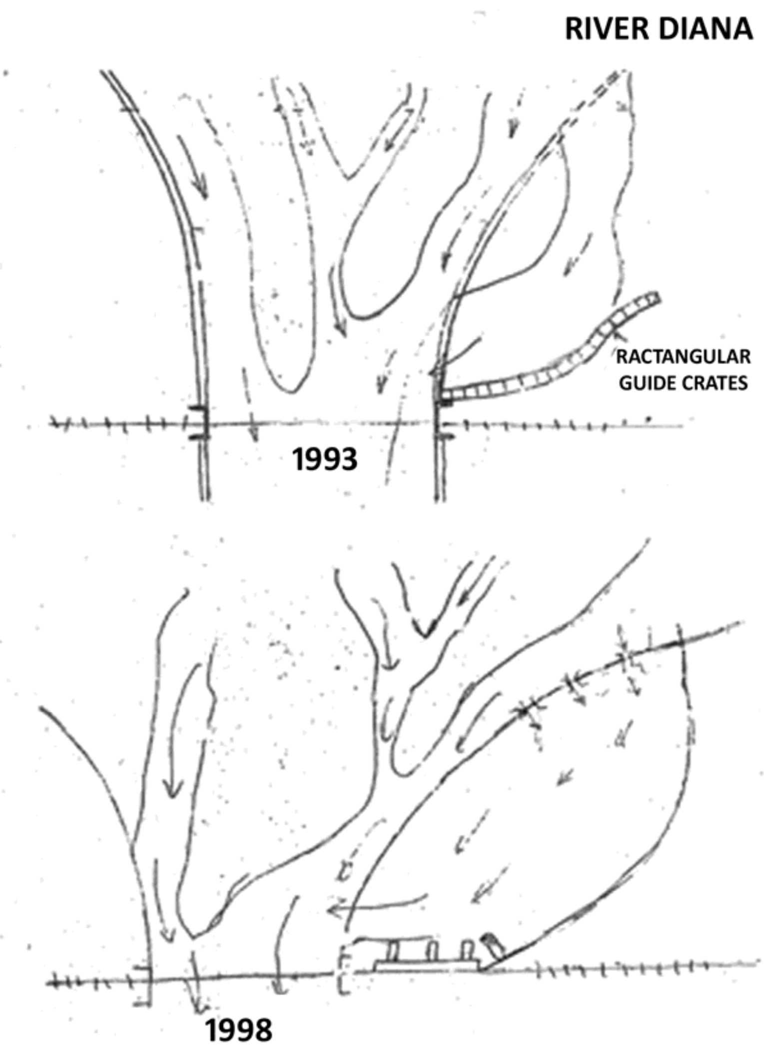


Fig. 12 : River Diana flow diagram

IV.8.6 Teesta river bridge near Moinaguri (Broad Gauge) West Bengal

Teesta is a major river in west Bengal, originating from Sikkim. A broad gauge track bridge was constructed during Assam Rail Link Project after Independence [1947]. The velocity of flow in river is very high, above 5 ft per second, due to steep bed slope. The river is contained in position by two irrigation marginal bunds which are around 3.8 km apart. The depth of flow in the river is not much. The bridge was constructed some time in 1950, having 13 spans of 47.5 m each. Approach banks cover the rest of length between the Khadirs. In 1968 there was severe flood and back waters over topped and breached the irrigation marginal bunds causing severe damage in Jalpaiguri and Domohani. While the bridge and protection works were well made, the Bell bunds needed to be increased in length to channelise flow in the funnel of the bridge. Subsequently, 7 more spans of 47.5 m were added in the bridge as constriction was quite large causing rise in water level upstream. The fury of the river is such that in monsoon water flows with loud roar. Passengers in trains keep all windows closed due to frightening roaring sound of rushing river hitting the bridge piers.

IV.9 Bridge Over Brahmaputra River at Bogibeel, River Training Works for construction of South Guide Bund (Assam) – Bridge Construction in Progress

IV.9.1 Undoubtedly, Brahmaputra is the mightiest river in India. The river flows through the Assam valley. A Rail cum Road Bridge is under construction at Bogibeel, close to Dibrugarh. While this bridge construction is a high value and difficult work, so also are the provision of protection and training works. The river tends to shift towards South, cutting bank and a large tract of land has gone under the river in succeeding decades. Approximately 2 km wide land mass has gone under the river in last 100 years. The general Khadir width is around 9 km. As would be seen in the following paragraphs despite best efforts the river could not be contained and between design stage and construction (in 10 years) bridge length had to be increased by about 250 m. The difficulties in constructing protection works have also been brought out.

IV.9.2 The bridge was to be constructed having a waterway of 4250 m The spans were 34 x 125 m +2x32.6 m , which now are to be increased by two additional spans of 125 m as protection works could not be stabilized due to river behavior.

IV.9.3 Considering the magnitude of the river, the design of guide bund had been done rigorously. The left guide bund is to be 1500 m long on upstream and 544 m on downstream side. The right guide bund is be 800 m long on upstream and 346 m long on downstream side. Top width of guide bund is 9 m. While the guide bunds channelise the river into a shorter width, the construction of guide bunds itself was a very difficult task in this massive river.[see Fig. 13]

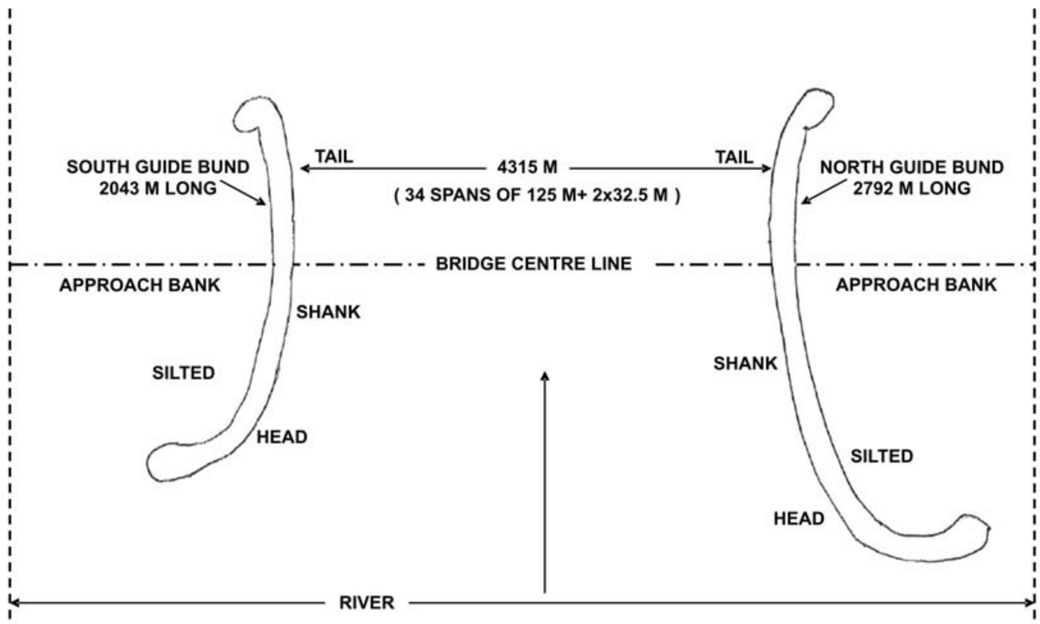


FIG. 13 : RAIL CUM ROAD BRIDGE OVER RIVER BRAHMAPUTRA AT BOGIBEEL (NEAR DIBRUGARH – ASSAM)

IV.9.4 The location and the shape of the Guide Bund were finalised based on River Model Study done at U P Irrigation Research Institute, Roorkee. As provided in the Project Report, River Training Works were required for facilitating the construction of the **South Guide Bund**. Initial works were started in 2006 itself and entire quantity of boulders, G.I. wire nettings for the Sausage Crates (to be filled with boulders and placed in position) as well as for filter materials to be used underneath the sloped boulder pitching work were collected at site. The contract for construction of the Guide Bund proper was finalized for taking up the construction from November-2008 onwards. Once the work started, it could not be held up during execution, working period (September to March) was very short and any stoppage in between was going to be disastrous as unfinished work done could be washed away. It was necessary to complete the Guide Bund work within the safe level of river, avoiding high monsoon flow.

IV.9.5 Various types of other River Training works were planned and executed from 2006 onwards to channelise river stream prior to taking up the construction of the South Guide Bund. In 2006, Bamboo porcupines and boulder crate bed bars were laid adjacent to high bank on the up stream of the Railway embankment for about 2 Km to prevent the erosion of the high banks falling in the Guide Bund mole head area and to induce the silting of the river channel crossing the Guide Bund alignment. In 2007, 2 nos. earthen spurs duly protected with slope pitching were provided at two different locations. One was on the up stream of the Railway embankment of about 600 m length and other on the downstream for about 400 m length. These were planned to divert the river flow away from the Guide Bund location and facilitate the silting in the embankment area [Fig. 14]. The river has a tendency of shifting towards South after every monsoon and the construction of these 2 spurs helped in protecting the Guide Bund location, already constructed Railway embankment and the boulder stack areas which would have otherwise come in the direct attack of the river. The River Training Works were started in the middle of August 2008 to facilitate the construction of the Guide Bund and to divert the river flow away from the Guide Bund alignment. However, the river kept on shifting towards the South Bank and the River Training Works could be carried on only upto October2008. Permeable screens, porcupines and ballies spurs were made in the river in between the Guide Bund head location and the proposed Railway alignment to divert the river channel. This diversion was necessary to facilitate the construction of Railway Embankment up to Guide Bund location.

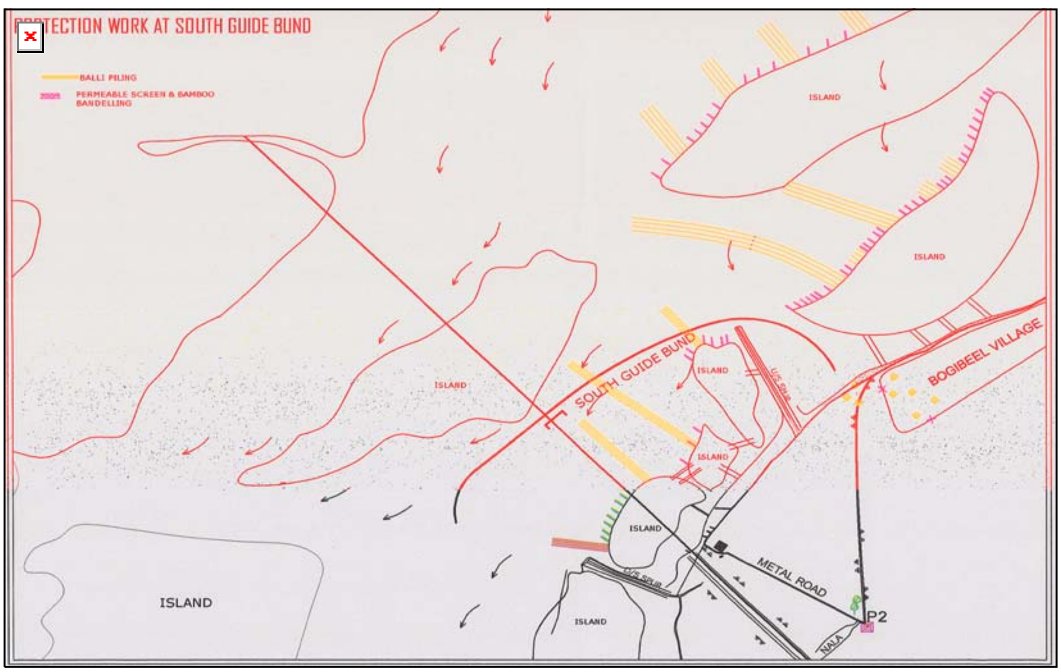


Fig. 14 : Protection Work at South Guide Bund

IV.9.6 In 2008, the South bank main river channel had shifted towards the Guide Bund alignment and with the passage of time the survey of 2004 was getting affected. As such, ballies spurs were planned and executed for inducing silting as well as shifting the river flow away from the Guide Bund alignment. These helped in diverting the current in the channel and facilitated the construction of the Guide Bund up stream of the spurs No. 1. However, due to the flash floods on 28th/29th October/2008**,** most of the ballies spurs constructed were damaged/ washed away. The Island on the up stream on the Spur No.1 which was deflecting the river channel away from the South Bank Guide Bund location, got breached in the middle, thereby attracting the main flow of the river towards Guide Bund location. Due to the shifting of the main channel after the flash flood, which shifted towards South and deepened, construction of the Guide Bund and the Embankment was not practically feasible due to very high depth of the river channel in Guide Bund alignment. Also, the island got extended towards the South after the floods and it was impossible to take up the Guide Bund and Embankment construction work in the original planned alignment by closing the main channel of River Brahmaputra, in such a short time available up to March'09.

After detailed river surveys for alternative locations for locating the Guide Bund away from the original alignment, it was decided in the month of November/2008. [Fig. 15] to shift the Guide Bund location by 250 m towards the South Bank and add two more spans in the bridge.

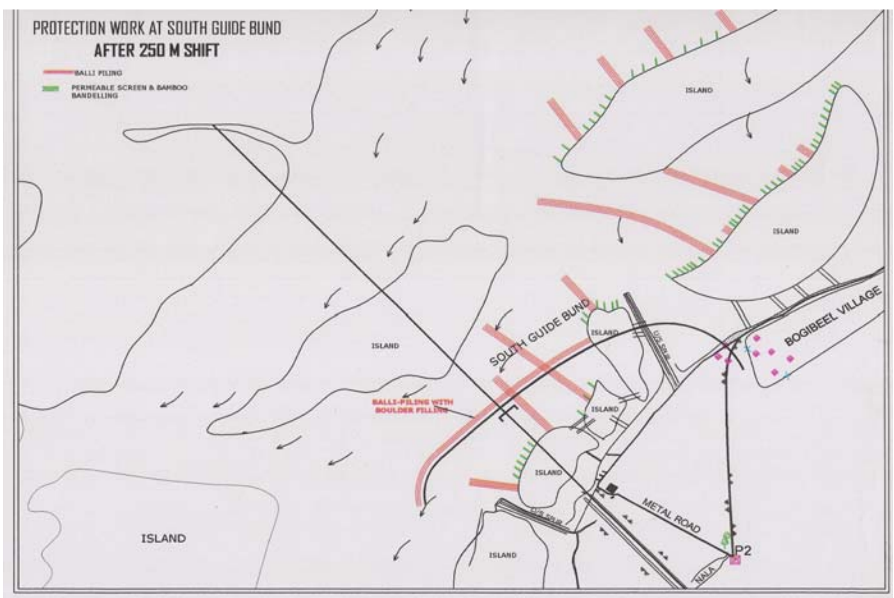


Fig. 15 : Protection Work at South Guide Bund after 250 M Shift

IV.9.7 Permeable screens were provided in many locations in between two spurs to induce silting in the Railway alignment and to reduce the current in the river channel. These permeable screens proved very effective in conjunction with ballies spurs and bamboo porcupines. The details of the permeable screens and the bamboo porcupines executed are in Figs. 16 and 17. Bamboo porcupines were placed in the river channel by loading them in boats and then lowering them in the alignment of the Guide Bund.

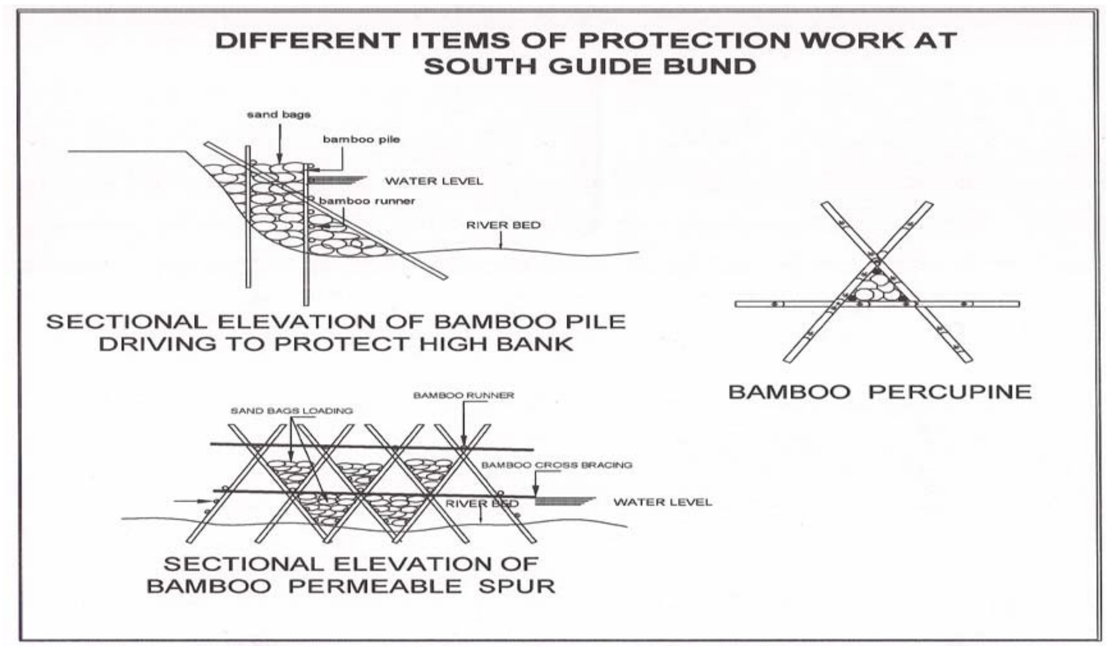


Fig. 16 : Different items of protection work at south gude bund

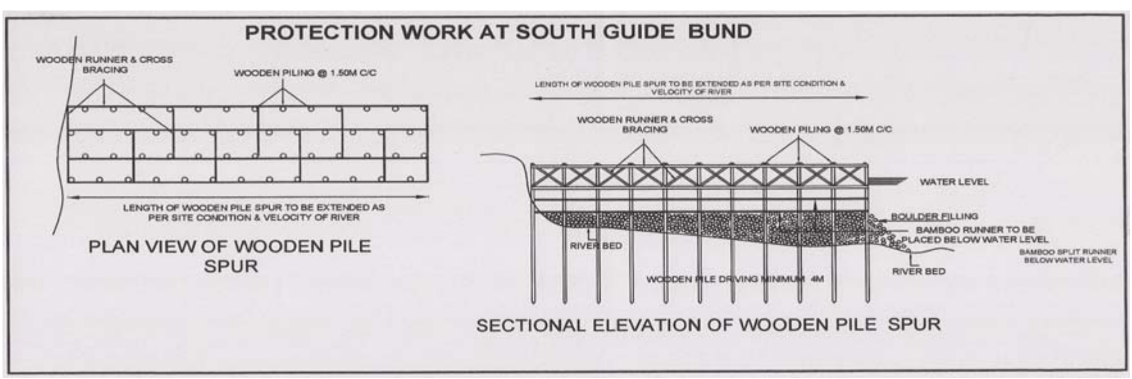


Fig. 17 : Protection work at south guide bund

IV.9.8 Pilot Channel Cutting

A channel of around 1400 m length was excavated on up-stream on left bank side, inside the river with the help of excavator by loading them on the barges [Figure 18]. The width of channel was about 30 m and it was active during the working season and helped in reducing the flow in the main channel flowing in the Guide Bund alignment by diverting the flow.

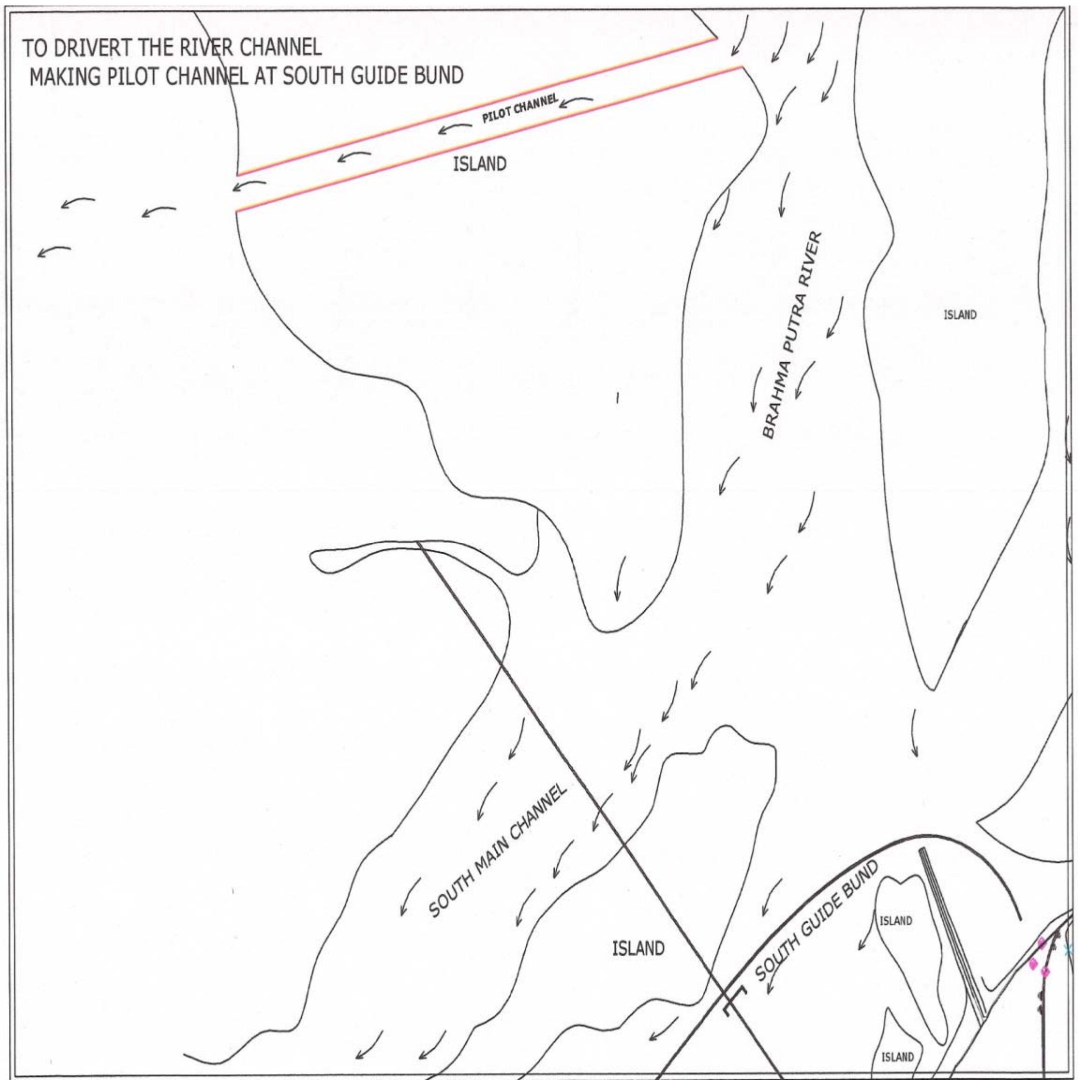


Fig. 18 : To divert the river channel making pilot chanel at south guide bund

IV.9.9 Ballies Spurs for Guide Bund Construction

Around 1500 m length of Guide Bund out of 2100 m (approximately) was falling in the active river channel. As such, wooden ballies spurs were constructed in continuation all along the outer periphery of the Guide Bund in the active channel by deploying 8 to 10 boats per day for the entire length of the Guide Bund falling in the active channel from 700 m to 2100 m from railway alignment.. Ballies were driven with the help of water pump and monkey type drop hammer. During the day, the ballies spurs were constructed as far as possible by stabilizing the boats with the help of each other suitably. The river current was 3 m per second and depth of the channel was in the range of 5 m to about 10 m. Boulder filling inside the ballies spurs was done during the night as well as day depending upon the requirement of work with the help of machine excavators to facilitate the earthwork in the follow up. In this way, the entire length of the Guide Bund falling in the active river channel was constructed from the month of December/08 to March/09. Simultaneously protection works were done for the construction of the Railway embankment up to the Guide Bund location by making ballies spurs on the up stream of the bank and filling the same with boulders. The earthwork in filling for construction of the Embankment and the Guide Bund including the apron area up to 98.8 m level mark were possible only due to the very systematic and continuous construction of ballies spurs. The alignment and locations of the ballies spurs were controlled by survey with Total Station instruments. The final alignment was marked only after the earthwork filling had been done properly duly protected with ballies and boulder filling.

IV.9.10 The quantities of different types of protection works executed for facilitating the construction of South Guide Bund inside the river to divert the river channel and to induce silting was as under:

S.No.	Type of Protection work executed	Unit	Quantity Executed
1	Bamboo Piling in river channel	RM (running meter)	25000
2	Wooden Balli Piling	RM	26000
3	Permeable Screens	Nos.	8500
4	Bamboo Bundling	RM	40000
5.	Circular Sausage Crates	RM	6550
6	Empty Cement Bags filled with earth	Nos.	205000
7	Bamboo Porcupines	Nos.	3500

IV.9.11 South Guide Bund work

The construction of Guide Bund above 98.8 m level was done after the apron area filling was completed. The laying of Crated boulders continued systematically. The labour strength increased up to 2000 and maximum progress of crate laying per day achieved was 8000 cum. The boulder pitching work on up stream slopes was started in the first week of January'09 and grouting works were taken up from February'09. The entire Guide Bund construction and protection works up to level 105.00 m (Safe level) were completed by 15.05.09. A total of 4.5 lakh Cum apron crates was laid in thickness of 3 m and 2.3 m in mole head and shark portion respectively. Grouting work was facilitated with concrete from Batching plant.

IV.9.12 The above is to indicate planning and efforts required in river protection works when siting and constructing an important bridge. As in April 2011, the South Guide Bund was complete. The North Guide Bund was also 75% complete. The North Guide Bund protections works also faced numerous challenges akin to the problems for South Guide Bund. On the North side, the Guide Bund had to be receded by 375 m and 3 more spans were added to the bridge.

BIBLIOGRAPHY

1. *River Behaviour Management and Training (Vol. 1)*, Central Board of Irrigation & Power, New Delhi, 1989.

2. Seminar Papers :

   (a) Training Gandak River by R. R. Jaruhar.

   (b) Design Features of Brahmaputra Bridge at Jogigopha by L. Singh.

   (c) River Training in Submountaineous Region to Safeguard Railway Bridges by B. K. Agarwal & Subhas Ch. Razak.

3. Bridge Over River – Brahmaputra at Bogibeel by S. C. Razak.

INDIAN NATIONAL ACADEMY OF ENGINEERING
6th Floor, Vishwakarma Bhawan, IIT Campus, Shaheed Jeet Singh Marg, New Delhi 110016

Designed and Printed at : Pratibha Printers Pvt. Ltd., New Delhi ; 9811100619