Fourth Report

INDIAN ENGINEERING HERITAGE (RAILWAYS)

Indian National Academy of Engineering

April 2015

Role of Technology in Capacity Augmentation and Railway Development

Cover Photo : FAIRY QUEEN – & Loaded Electric Train

"FAIRY QUEEN – Oldest working Steam Locomotive in the world.
It made its first journey in 1855 on East Indian Railway."

Loaded Electric Train Running under 7.45 m OHE during test trials

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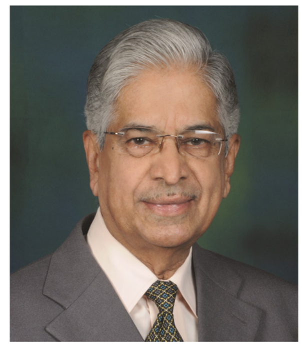
FOREWORD



The marvels of Indian engineering have roots in ancient civilizations and epitomize traditional engineering practices and techniques. The efforts of great engineers in ancient India have resulted in creating exemplary monuments, bridges, metallurgical artefacts, textiles, construction materials, irrigation systems and other engineering wonders. The need to archive the engineering heritage of India is imperative to preserve the rich knowledge and accomplishments that have been witnessed over the last few centuries. The Indian nationwide rail network, the fourth longest in the world, has witnessed many milestones and challenges in its expansion and it is vital to document these achievements for the future generation.

In this direction, Indian National Academy of Engineering (INAE) constituted Experts 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. This Expert Group has already brought out three comprehensive reports covering the history of Indian Railways since its inception and evolution over the decades as a modern railway network. The first Report on Indian Engineering Heritage (Railways) prepared by the Study Group covers History, Railway Gauge, Railway Bridges, Railway Construction Projects, Mechanical Workshops, Production units and the second Report includes use of Geotextiles; Mechanized Maintenance of Track, Coaches/Wagons and D.C./A.C. Electrification. The Third report on Indian Engineering Heritage (Railways), brought out in the year 2012, covers Rails based Urban Transport Systems, Heritage Railway Buildings, Tunneling and River Training and Bridge Protection Works.

I am pleased to note that the Study Group headed by Shri VK Agrawal, FNAE, Former Chairman Railway Board and with Dr YP Anand, FNAE, Former Chairman Railway Board and 13 Senior Retired Railway Officers from different Railway disciplines have brought out the Fourth Report on “Role of Technology in Capacity Augmentation and Railway Development”. The technological upgradation of the Railways is undoubtedly of paramount interest in its modernization. By combining ancient engineering traditions with state-of-art technology; the capacity augmentation, network expansion and modernization are achievable goals.

The efforts of the Study Group are laudable and I compliment them on the task undertaken in archiving the technical data pertaining to all facets of Railways such as Tracks, bridges, Railway stations, Buildings & tunnels, signalling & Train Control etc to name a few.

I am confident that this Fourth Report on "Indian Engineering Heritage (Railways) – Role of Technology in Capacity Augmentation and Railway Development" will be well received by the Railway Engineers and shall be a landmark document for the engineering community, not only at present, but also in the coming decades.

Dr BN Suresh
President, INAE

PREFACE

Indian National Academy of Engineering (INAE) has 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.

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

1. First Report – Indian Engineering Heritage (Railways) – 2004.
2. Second Report – Indian Engineering Heritage (Railways) – January 2008.
3. Third Report – Indian Engineering Heritage (Railways) – June 2012.

The First Report (2004) covered several areas of the historical development of technology on Indian Railways. It was however felt that areas / data needed further supplements and so it was decided to cover these and additional areas in the next Report (January 2008). The Second Report was thus planned accordingly.

The **Second Report (January 2008)** was an all comprehensive Report (including the areas covered in the First 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.

The **Third Report (June 2012)** covered 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 has now studied the **History of the Role of Technology in Capacity Augmentation and Railway Development** for the various concerned areas listed below which also includes an Introductory Chapter to give a brief overview :

1. Introduction
2. Track

3. Bridges
4. Railway Stations, Buildings & Tunnels
5. Rolling Stock – Wagons
6. Rolling Stock – Coaches
7. Electrical Multiple Units
8. Diesel Multiple Units
9. Motive Power – Steam
10. Motive Power – Diesel
11. Motive Power – Electrical
12. Railway Electrification
13. Railway Workshops
14. Signalling & Train Control
15. Telecommunications
16. Operations / Operational Practices
17. Research & Technology Development – RDSO

During this Study, **various aspects like Safety, Speeds, Environment, Information and Communication Technology (ICT), and Futuristic Trends have also been examined.** This Study is now being presented in this Fourth Report. **The Fourth Report has seventeen Chapters including the Chapter titled "Introduction"**. Railways cover practically every branch of Engineering and Technology and these Chapters try to bring out the nuances of each Discipline and its role in Capacity augmentation and Development of Indian Railways.

The INAE Railway Study Group presently consists of two INAE Fellows (Shri V. K. Agarwal as Chairman & Dr. Y. P. Anand) assisted by 13 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. Current List of Group Members 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 S. P. S. Jain	Former Member (Engg.), Railway Board
5.	Shri V. N. Mathur	Former Member (Traffic), Railway Board
6.	Shri S. C. Gupta	Former Member (Elect.), Railway Board
7.	Shri A. K. Jain	Former Addl. Member (Electrical), Railway Board
8.	Shri Chandrika Prasad	Former Addl. Member (S&T), Railway Board
9.	Shri M. M. Agarwal	Former CE, Northern Railway
10.	Shri A. K. Gupta	Former CAO, (R) DMW
11.	Shri B. K. Agarwal	Former Adv. (L&A), Railway Board
12.	Shri Kanwal Preet Singh	Former Exec. Dir. (W), Railway Board
13.	Shri Vijay Kumar Dutt	Former Addl. Member (Elect.), Railway Board
14.	Shri Kishore Pal Singh	Former MD, RITES & Former MD Tata Projects.
15.	Shri Deepak Krishan	Managing Director, IRWO & Former GM Railways.

* Fellow Indian National Academy of Engineering

(V. K. Agarwal)

April 2015 **Chairman of the Study Group**

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CHAPTER 1

INTRODUCTION

1.1.0 INDIAN ENGINEERING HERITAGE (RAILWAYS) – FOURTH REPORT

1.1.1 Indian National Academy of Engineering (INAE) has 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.

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

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Box 1

INDIAN ENGINEERING HERITAGE – Railways

Archives of Indian Engineering Heritage (Railways) Study Group

S.No.	Name	
*1.	Shri V. K. Agarwal	Former Chairman Railway Board
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1.2.0 ROLES OF TECHNOLOGY & ENGINEERING

Indian Engineering Heritage (Railways) basically is the History of Technology and its development on the Railways and has been dealt with accordingly in the present Report (Fourth) as also in the earlier Reports (First, Second & Third). One fact which needs special mention is that boundaries between Science, Technology, and Engineering are not very explicit and need elaboration / explanation. Recently, the UNESCO in its Report titled "Engineering : Issues, Challenges and Opportunities for Development (2010)", which is the first Report of its kind to be produced by any International organization, has recognized the paramount importance of the role of Engineering in Development and, inter alia, also tried to define the roles of Science, Technology, and Engineering for the purpose. This has been captured along with some other details to broadly define Science / Technology / Engineering (See Box 2) for the purpose of this Study.

Box 2

Science / Technology / Engineering

(a) **Science**

- **Science** covers the broad field of knowledge that deals with observed facts and the relationships among those facts.

- Science also differs from other types of knowledge in that scientific progress depends on new ideas expanding or replacing old ones.

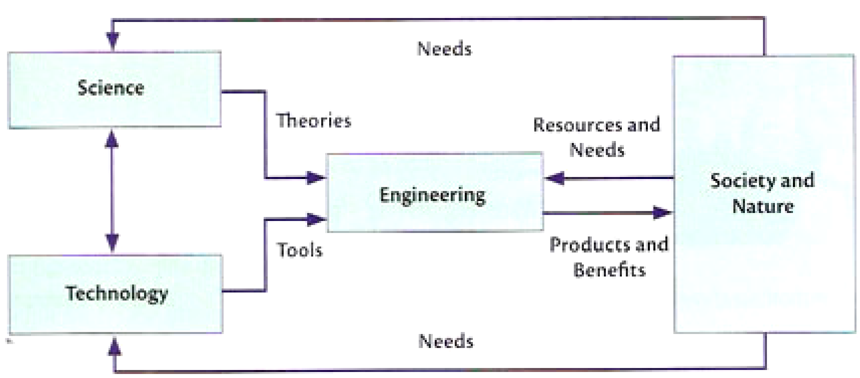
- Science has enormous influence on our lives. It provides the basis of much of modern *technology* – the tools, materials, techniques and sources of power that make our lives and work easier. The term *applied science* is sometimes used to refer to scientific research that concentrates on the development of *technology*.

(b) **Technology**

- **Technology** refers to all the ways people use their inventions and discoveries to satisfy their needs and desires.
- Technology involves the use of tools, machines, materials, techniques and sources of power to make work easier and more productive.
- **Science has contributed much to modern technology. But not all technology is based on science, nor is science necessary to all technology.**
- The word technology is sometimes used to describe a particular application of industrial technology, such as medical technology or military technology. **The engineering profession is responsible for much of today's industrial technology.**
- It has been mentioned by Dr. A. P. J. Abdul Kalam (2001) that technology includes techniques as well as the machines that may or may not be necessary to apply them. It includes ways to make chemical reactions occur, ways to breed fish, eradicate weeds, light theaters, treat patients, teach history, fight wars or even prevent them.

(c) **Engineering**

- **Engineering** is the profession that puts scientific knowledge to practical use. The word *engineering* comes from the Latin word *ingeniare*, which means to *design* or to *create*.
- **Engineers** use principles of science to design structures, machines, and products of all kinds. They look for better ways to use existing resources and often develop new materials. **Engineers have had a direct role in the creation of most of modern *technology* – the tools, materials, techniques, and power sources that make our lives easier.**
- Tony Marjoram and Yixin Zhong (UNESCO Report – 2010) diagrammatically depict the role Engineering plays (using 'Theories' from 'Science' and 'Tools' provided by 'Technology') to provide 'Products and Benefits' to 'Society and Nature' keeping in view the 'Resources and Needs'.



1.3.0 CURRENT TRANSPORT SCENARIO IN INDIA

1.3.1 The mechanized modes of transport, consisting of the transport sector in the country, comprise Railways, Highways/Roads, Coastal Shipping, Airlines, Pipelines, and Inland Water Transport. **No centralised monitoring authority/institution for regulating coordinated operation and integrated growth of different modes of transport exists in the country.** To give an example, while Railways are centrally administered as a department of the government, for the highways, infrastructure is provided by the Central and State governments, and the operation of vehicles is by private sector/owners. Some States also have State Transport Undertakings for the passenger transport.

1.3.2 The data regarding 'Originating Inter Regional Freight Traffic Growth and Changing Modal Split in India' can be seen in Table No.1. This data has been taken from the White Paper on Indian Railways, December 2009 and is based on a Study carried out by RITES for the Planning Commission. It will be seen from it that currently about 91% of the Inter Regional Freight Traffic is carried by Rail (30%) and Road (61%), and the balance by Coastal Shipping (2.3%), Pipelines (4.5%) and Inland Water Transport (2.2%), the share of Airlines being very small (0.3 million tonne). **The share of Rail in freight traffic has come down from 89% to 30% since 1950-51 and for the passenger traffic it has reduced from 69% to 15%.**

Table 1 : Freight Traffic Growth and Changing Modal Split in India

		Mode-wise Traffic in Million Tonnes with Percentage Share					
Year	**Total Originating Inter Regional Traffic (Million Tonnes)**	**Railways**	**Highways**	**Coastal Shipping**	**Airlines**	**Pipelines**	**Inland Water Transport**
1950-51	82.2	73.2 (89%)	9.0 (11%)	NA	NA	NA	NA
1978-79	283.4	184.7 (65%)	95.6 (34%)	3.1 (1%)	NA	NA	NA
1986-87	484.9	255.4 (53%)	224.0 (46%)	5.5 (1%)	NA	NA	NA
2007-08	2555.4	768.7 (30%)	1558.9 (61%)	59.1(2.3%)	0.3	113.5 (4.5%)	54.9 (2.2%)

Source : White Paper on Indian Railways, December, 2009.

1.3.3 It will be interesting to examine the pattern of **intra-regional** freight traffic carried by the Road. The inter-regional freight traffic mentioned in para 3.2 basically takes a 'District' as a 'Region' for evaluating the traffic while for the **intra-regional** traffic the movements within the Region/District are considered. The pattern of traffic for the year 2007-08 as per the Study referred to in para 3.2 is as under :

	Volume	**Average Lead**
Inter-regional freight traffic	1558 Mt	453 km
Intra-regional freight traffic	4640 Mt	15 km
	(x3)	(x1/30)

It will be seen that the volume of **Intra-Regional** freight traffic is three times the inter-regional traffic but in terms of ton-km it is about 10% only.

1.3.4 Demand for transport is directly connected to GDP growth. For a developing economy like ours, the elasticity of transport to GDP can be taken as about 1.25. GDP growth of 9% would, therefore, translate into increase in demand for transport to the tune of 11%. **The traffic is very likely to double in next 7-10 years.**

1.3.5 Our existing transport infrastructure is already under severe strain with congestions visible everywhere. Paucity of necessary resources came in the way of infrastructure development and the lower GDP growth in the earlier periods also made us complacent towards the need for such a development. However, growing economy now necessitates that the transport infrastructure develops at an accelerated pace and that too in a coordinated and integrated manner. **Development of necessary transport infrastructure is a pre-requisite to sustain the current levels of GDP growth and if timely action is not taken growth may get stifled.**

1.3.6 To compound the problem of accelerated growth of transport infrastructure, the issue of environment has assumed paramount importance in the recent years, needing cuts in emissions of greenhouse gases (GHGs). **Growth of transport infrastructure has to consciously keep in view the need for using a mode which is least polluting and hence more environment-friendly in addition to planned efforts to reduce transport demand to the extent possible.**

1.3.7 A European Study gives details of carbon dioxide (CO_2) emissions from various transport modes, both for the passenger and the freight traffic (see Table No. 2). Such emissions may even be higher for Indian conditions with less stringent fuel quality and vehicle maintenance norms. It will be seen from it that Rail is more environment-friendly with lower CO_2 emissions. On the other hand Table No.1 indicates that while the volume of freight traffic is increasing, the proportionate volume of traffic carried by Rail, which is greener and so more environment-friendly, is declining.

Table 2 : Carbon-Dioxide (CO_2) Emissions

CO_2 Emissions from Freight Transport (gms/tonne-km)

Road	158
Water Transport	31
Rail	29

CO_2 Emissions from Passenger Transport (gms/passenger-km)

Air	229
Road (Car)	175
Rail	75

Source : Soft Mobility Paper – Europe – July 2006.

1.3.8 **Transport accounts for approximately 25% of global carbon dioxide (CO_2) emissions**, and is the sector with the highest growth in emissions, and the second largest contributor overall (after electricity and heat supply sector). Railways and their energy efficiency are crucial to reducing greenhouse gas emissions. Incidentally, a shift of 3% from road to rail transport corresponds to 10% decrease in GHG emissions.

1.3.9 **Transport pricing does not tell the environmental truths because social costs are not factored in.** The social costs of transport operation chiefly encompass costs arising from accidents, atmospheric pollution, damage to the climate and to public health, noise, impairment of natural resources and the landscape, and damage to buildings. In the absence of any such authentic data for our country the data from a European Study can be taken as a broad guide (see Table No. 3) which indicates that Rail has the lowest social costs.

Table 3 : Social Costs of Various Transport Modes

(A) Average Social Costs – Freight Transport (2000) (Euros per 1000 tonne-km)

Air	271.3
Road (Light Lorries)	250.2
Road (Heavy Vehicles)	71.2
IWT	22.5
Rail	17.9

(B) Average Social Costs – Passenger Transport (2000) (Euros per 1000 passenger-km)

Road (Car)	76.0
Air	52.5
Road (Bus)	37.7
Rail	22.9

Source : Soft Mobility Paper – Europe – July 2006.

1.3.10 The approaches that need to be adopted to reduce green-house gas (GHG) emissions in the transport sector can be classified into the following groups :

- Reducing transport demand by suitable relocation of production and consumption activities; use of Information and Communication Technology

(ICT) including the use of geographic information systems (GIS) and the global positioning systems (GPS) to reduce movements or to make them more efficient;

- **Planned Shift to Non-motorised Transport (NMT)** e.g., for low lead intra-regional freight traffic (see Para 3.3) and for passenger traffic in busy metropolitan areas;
- Fuel efficiency improvements – A European Study indicated that upto 25% of fuel consumption could be saved through the use of efficient driving methods (Ecodriving);
- System efficiency improvements through traffic engineering and management measures;
- **Encouraging a shift of commuters from use of road to rail and from personalized vehicles to public mass transport;**
- **Modal shift of freight traffic towards more environment friendly modes like Rail and IWT;**
- Behavioural changes by moving towards an optimum utilization of seating space and load factor; and
- Technological and fuel changes through upgrading automobile technology and fuel quality and promoting alternative fuels.

1.3.11 The following options exist to reduce the consumption of petroleum oil, a polluting and fast depleting source :

- Industrial use of naptha, fuel oil, diesel oil and domestic use of LPG and kerosene should be replaced by natural gas. (gas availability is expected to be much better than oil and it is less polluting).
- Increased use of bio fuels.
- Encourage blending of ethanol with petrol.
- **Extend electrification of Railways.**
- **Improve Railway's freight service for a larger share in transport.**
- **Promote urban mass transport.**
- Improve fuel efficiency of motorized vehicles.
- Encourage use of hybrid vehicles.

1.4.0 INDIAN RAILWAYS : AN EFFICIENT SYSTEM BUT WITH SEVERE CAPACITY CONSTRAINTS

1.4.1 Indian Railways have done reasonably well within the constraint of resources. The Input vs Output indices shown in Table No. 4 and Select Data shown in Table No. 5 are ample testimony to this fact. The elaborate further, while the Route Kms have increased by 22% the Traffic Volume has increased by more than 1400%; Numbers of Rail Accidents have come down; and Wagon Turnaround has improved.

Table 4 : Input vs Output – Indian Railways

	1950-51	2012-13
Input Indices		
• Route Kms	100	122
• Running Track Kms	100	153
• Wagon capacity	100	325
• Coaches - Passengers	100	367
Output Indices		
• Freight Traffic – NT Kms (Rev. + Non Rev.)	100	1570
• Passenger Traffic – Pass Kms (Non-Sub)	100	1588

Source : IR Year Book 2012-13..

Table 5 : Select Data – Indian Railways

Year	Track Renewals (Kms)	Number of Accidents	Wagon Turnround (days)	Operating Ratio (Percent)
1994-95	2,763	501	9.5	82.6
1995-96	2,893	398	9.1	82.5
1996-97	2,795	381	8.5	86.2
1997-98	2,950	396	8.1	90.9
1998-99	2,967	397	8.2	93.3
1999-00	3,006	463	7.7	93.3
2000-01	3,250	473	7.5	98.3
2001-02	3,620	415	7.2	96.0
2002-03	4,776	351	7.0	92.3
2003-04	4,986	325	6.7	92.1
2004-05	5,566	234	6.4	91.0
2005-06	4,725	234	6.1	83.8
2006-07	4,686	195	5.5	78.7
2007-08	4,002	194	5.23	75.9
2008-09	3,841	177	5.19	90.5
2009-10	3,840	165	4.98	95.3
2010-11	3,465	139	4.97	94.6
2011-12	3,300	131	5.08	94.9
2012-13	3,296	120	5.10	90.2

Source : IR Year Books.

1.4.2 The argument, that capacity constraints and adequate inputs are not the IR's problem but it is basically the inefficient operation and lack of focus, does not cut much ice. Following may elucidate the point further :

- In early 1980s, problem of lack of capacity was solved in an adhoc manner by permitting running of only "rake loads" of traffic thereby making movements faster but in the process loosing high rated piecemeal traffic. Planned inputs for 'capacity generation' and 'containerisation' in time could have avoided such a situation.
- Asset rehabilitation arrears had to be wiped out through a Special Railway Safety Fund of Rs. 17,000 crore (year 2001-02 onwards) indicating inadequate investments in maintenance and upkeep of the system.
- Recently also, the capacity constraints had largely been overcome by an adhoc increase in axle loads from 20.3 tonne to 22.9 tonne. This can be broadly translated into an annual traffic increase of 90 Mt and a corresponding extra yearly income of Rs. 6,000 cr. (Sudhir Kumar & Shagun Mehrotra – 2009).

1.4.3 There is severe congestion on the Golden Quadrilateral (connecting four metro cities of Delhi, Kolkata, Chennai and Mumbai) and its two diagonals which constitute about 16% of Route Kms but carry around 60% of the IR's traffic. Large number of sections falling on these routes are having line capacity utilization exceeding 100% (see Table No. 6).

Table 6 : Line Capacity Utilisation on Golden Quadrilateral and its two Diagonals (2007-08)

Routes	**No. of Sections**	**Sections having Line Capacity Utilisation**			**Critical Sections $ (%)**
		More than 80%	More than 100%	More than 120%	
Delhi-Howrah	41	11	12	17	**70%**
Mumbai-Howrah	42	10	17	13	**71%**
Delhi-Mumbai	28	5	5	15	**71%**
Delhi-Chennai via Jhansi, Nagpur-Ballarshah	24	2	5	16	**88%**
Howrah-Chennai	17	5	6	5	**65%**
Mumbai-Chennai	25	6	5	10	**60%**
Total	**177**	**39**	**50**	**76**	**71%**

Source : White Paper on Indian Railways – Dec.2009.

Notes : 1. Sections having line capacity utilization of 100% or more have been assumed to be critical sections.

2. About 60% of IR's traffic moves on the Golden Quadrilateral and its two diagonals.
3. About two-third of the sections are showing a line capacity utilisation exceeding 100%.
4. In next 7-10 years traffic will double. Immediate action for capacity enhancement is called for.

1.5.0 EXPEDITIOUS DEVELOPMENT OF RAILWAYS ESSENTIAL FROM SOCIAL, ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

1.5.1 Transport is an essential pre-requisite for development / growth. In addition, transport by itself also accelerates growth. Integrated development of various transport modes is essential for optimum utilization of the resources. One major factor which has come to fore in recent years is the need for making the transport 'greener' that is basically reducing the Green House Gas (GHG) emissions. The transport mode selection has to keep this vital aspect also in view.

1.5.2 About 91% of the traffic in our Country is carried by Rail / Road modes. Rail is 4-6 times fuel-efficient vis-à-vis Road and **therefore reduction in the market share of Rail vis-à-vis Road is a serious concern for environment too. It may not be out of place to mention that the market share of Rail in freight traffic has gone down from 89% to 30% and for the passenger traffic from 69% to 15%, since 1950-51.**

1.5.3 Planning Commission and other recommendatory bodies like the recent National Transport Development Policy Committee (NTDPC) headed by Dr. Rakesh Mohan have all been proposing a growth in the market share of Rail to a value of around 50%.

1.5.4 **Growth of rail traffic, and that too at an accelerated pace to make up for the lost market share, is not possible only by doing some system improvements. The rail infrastructure needs major capacity expansion inputs.** The capacity expansion on Indian Railways (IR) has lagged behind due to paucity of resources. To give example, the rate of construction of New Railway lines in the pre-independence era was roughly 3 times faster than that after the Independence. The rail network has grown by about 22% while the traffic has grown by more than 1400 per cent since 1950-51.

1.5.5 The Golden Quadrilateral and its two Diagonals connecting the metro cities of Delhi, Mumbai, Chennai and Kolkata (Delhi-Kolkata; Delhi-Mumbai; Delhi-Chennai; Mumbai-Kolkata; Mumbai-Chennai; Chennai-Kolkata) constitute about 16% of the Route kms of IR but carry around 60% of traffic and are having severe capacity constraints.

1.5.6 To relieve the traffic congestion, Dedicated Freight Corridors (DFCs) are planned for the Golden Quadrilateral and its two Diagonals. Work on Delhi-Kolkata and Delhi-Mumbai Corridors is already in progress and is likely to be completed by 2017-18. **However, the speed at which the work is being done needs special inputs and efforts so that all the six DFCs are available for use, say in a period of next 10 years.**

1.5.7 Construction of these DFCs which are being built more or less parallel to the existing double line tracks will release the congestion on the existing tracks as these will then be carrying only the Passenger traffic as the Freight traffic will shift to the newly constructed DFCs. Average speeds of travel both for passenger & freight trains will also improve. **This opportunity can be taken to provide better safety for passenger trains on the existing routes by suitably upgrading them through signalling and track inputs and for some selected trains the speeds can also be enhanced to 200 kmph.**

1.5.8 It may not be out of place to mention that International Union of Railways (UIC) defines a speed of **200 kmph or more when obtained on an existing track as High Speed**. However, for the newly constructed track speeds beyond 250 kmph are defined as High Speeds but in such cases (where the new tracks are constructed for the purpose of achieving High Speeds) generally speeds of 300-350 kmph are targeted. So broadly we can have two types of High Speed Rail Systems namely :

1. **Trains running at 200 kmph or more on the existing tracks. (We can term these as Common Man's High Speed trains or Low High Speed trains.)**
2. Trains running at 300-350 kmph on newly constructed tracks. (We can term these as Conventional High Speed trains.)

1.5.9 One more issue which is intimately related to environment is to provide a mechanism so that some Road traffic could shift on to Rail and for that construction of New Railway lines in the areas where such traffic is available is essential. As has already been mentioned our New Line construction has been very slow and there is an urgent need to boost it. **While the Railway Vision document of 2009 indicated construction of New Railway lines at the rate of 2500 km per year but atleast 1000 km per year appears essential.**

1.5.10 Appreciating the need for faster growth of Rail Infrastructure, the National Transport Development Policy Committee (NTDPC) headed by Dr. Rakesh Mohan in its recent Report (2014) has proposed an increase in investment in Railways from about 0.4% of GDP in the last two decades to around 0.8% in the 12th Plan (2012-2017) and then rising to around 1.1 to 1.2 per cent of GDP in the following three Plans (2017 to 2032).

1.6.0 TECHNOLOGY – SOME POINTS TO PONDER

1.6.1 Need for Accelerated Development of Rail Capacity

1.6.1.1 For efficient and effective performance of a transport system, on a sustainable basis, following three areas need proper attention and inputs :

(i) Maintenance of existing assets – Fixed, Moving, and Others.

(ii) Expansion of the Network – As for example, New lines and additional parallel lines (Doubling; Three Lines; Quadrupling) on a Railway System, along with necessary support facilities.

(iii) Modernisation.

On the Indian Railways (IR), all the three areas have suffered primarily due to paucity of resources and policy of advantage Road vis-à-vis Rail. However, extreme concerns for Rail safety, voiced by media and public, have resulted in investments in Maintenance and Modernisation to a larger extent but the Expansion of Network has lagged far behind.

1.6.1.2 Planners have to consciously realize that booming economy will necessitate doubling of traffic in next 7 to 10 years and both the Rail and the Road, which carry about 91% of the traffic, will have to be given suitable inputs for capacity augmentation. Both the modes will have to complement/supplement each other to take on this rapidly increasing transport demand.

1.6.1.3 The congestions on roads already visible with the existing levels of traffic, cost of road service growing faster than the cost of rail especially because of sharply rising fuel costs, concerns for environment (road being much more polluting than rail etc.), will necessitate that rail not only carries the traffic on the existing pattern but improves it further. **This clearly highlights the need for accelerated capacity generation on the IR both on the existing routes (Doubling/Third Line/Quadrupling) and in the new growth areas (New Line Construction).**

1.6.1.4 Financing of various Projects/Schemes through Public Private Partnership (PPP) or other means could be considered for the IR. However, basic features of Rail/Road infrastructures needing Government support still remain and the Government of India (GOI) will need to support the accelerated pace of building of fixed infrastructure on the IR on the same pattern as is being done for Roads. Once such inputs are given to improve the capacity of the fixed infrastructure, the IR should be able to garner adequate resources for the 'moving assets' and 'other facilities'.

1.6.2 Roll-on Roll-off (RoRo) Service on the Konkan Railway

1.6.2.1 RoRo service operates on the Konkan Railway, where the road trucks are carried on rail wagons, rail freight more or less equals the fuel cost which the truck would have otherwise incurred in its road journey, and the time of travel by rail is roughly half of what it would have been by road. It is a win-win situation for the rail, truckers, and the environment. However, such a service has not picked up on other IR sections primarily because of capacity and congestion factors. Once Dedicated Freight Corridors (DFCs) are constructed, many more such services should be a practical reality.

1.6.2.2 The cost data given in Box 3 broadly indicates that while fuel cost for each net ton-km of freight carried by Road truck is Rs. 0.638, the cost of carriage by Rail is Rs. 0.50 (Based on a Study by Deutsche Bank – April 2006). If the Road truck is carried on Rail (Ro-Ro Service) it has not to spend extra money (Fuel cost = Rail Freight), wear and tear of truck is saved, door to door delivery is still possible, several road barriers enroute are avoided, etc. However, the Ro-Ro

Scheme will be attractive only when overall journey time (Loading + Rail Journey + Unloading) is also less than the time of travel by road. With the completion of the Dedicated Freight Corridor (DFC) project, free flow of freight traffic will become a practical reality and Ro-Ro trains could be planned according to fixed time schedules.

Box 3

Savings in Fuel : Rail vs Road

- Planning Commission's Integrated Energy Policy (August 2006) mentions that carriage of 3000 BTKM of freight traffic by Rail instead of by Trucks (in the year 2030) will save 50 million tonne of diesel oil. **Thus saving in the cost of diesel oil for each net ton-km (NTKM) of freight carried by rail vis-à-vis road works out to Rs. 0.60** (one ton of diesel = 1.2 kilolitres; cost of diesel Rs. 30 per litre based on 2006 prices)..

- A **Study by Deutsche Bank (7th April 2006)** indicates that cost of carriage of freight by Road per NTKM is Rs. 1.10 out of which 58% is fuel cost. On the other hand the cost of carriage by Rail is Rs. 0.50 per NTKM out of which fuel cost is 14%. This translates into the following :

  (a) Fuel cost Per NTKM-Road = Rs. 0.58x1.1 = Rs. 0.638

  (b) Fuel cost Per NTKM-Rail = Rs. 0.14x0.5 = Rs. 0.070

  (c) **Difference in Fuel costs Per NTKM = Rs. 0.568**

  This also brings out that the road transport consumes nine times more fuel in carrying one NTKM of freight vis-à-vis Rail.

- This cost data (fuel cost per NTKM for Road Rs. 0.638; cost of carriage by Rail per NTKM Rs. 0.50) further indicates **that carriage of trucks on rail wagons (similar to RO-RO service in operation on the Konkan Railway)** will not only be a financially viable option for the truckers but will also benefit the national economy by reducing the fuel consumption. **However, this can be a practical reality only when adequate rail capacity to allow free flow of traffic exists, to ensure fast movements in guaranteed time, by the Railways.**

1.6.2.3 The Ro-Ro service will have the following advantages :

(i) Win-Win situation for the Truckers and the Rail.

(ii) Saving in fuel hence environment friendly. On Swiss Railway System, road trucks are carried on rail wagons to reduce environmental pollution.

(iii) Will provide speed and reliability of Rail and flexibility of Road (at loading and unloading legs) for the freight traffic.

(iv) Will reduce congestion on existing roads.

1.6.3 High Speed Trains on Existing Rail Tracks : Common Man's High Speed Trains

1.6.3.1 According to UIC (International Union of Railways) an existing upgraded line equipped to carry speeds of 200 kmph is termed as a High Speed Line. On the other hand, for specially built new lines the speeds have to be 250 kmph or more for being qualified as High Speed Lines.

1.6.3.2 Today, High Speed trains are already in operation in 14 countries (8 countries in Europe plus Japan, China, USA, South Korea, Taiwan and Turkey) and as on 1st July 2012 there were 17,574 km of High Speed Rail (HSR) tracks in operation. In addition, construction of 9289 km and planning for 15,476 km HSR tracks were in progress in various countries (Ref.: Singh, K. P. – 2013).

1.6.3.3 On the Indian Railways (IR) currently maximum train speeds are 130-160 kmph. Train speeds above 160 kmph need grade separation (No level crossings), fencing of tracks (To avoid trespassers) and Cab-signaling (Driver to get the aspect of Signal in the locomotive itself) coupled with Automatic braking should the 'Signal' be at danger (Red aspect of Signal). These features are essential from considerations of passenger safety. At higher speeds even a collision with a cattle can derail the train. Cab-signalling coupled with Automatic braking precludes any possibility of overshooting or passing the Signal at danger by the train Driver.

1.6.3.4 Indian Railways are planning Dedicated Freight Corridors (DFCs) on the entire Golden Quadrilateral (connecting four metro cities of Delhi, Kolkata, Chennai and Mumbai) and its two Diagonals and currently work on Eastern and Western DFCs is already in progress. For the purpose two new parallel lines (Double lines) are being constructed exclusively for freight traffic thereby making the existing system a passenger corridor. All level crossings are also being eliminated as an essential pre-requisite.

1.6.3.5 Several Committees have emphasized the need for adopting measures like Cab-signalling and Automatic braking for enhancing passenger safety in the past.

There exists a good opportunity to take advantage of DFC project and usher in HSR travel (200 kmph) on the IR. This will also enhance safety of travel for all other trains which may be running at lower speeds (say 160 kmph). The High Speed Trains (200 kmph) can adopt 'tilt body' coaches to negotiate existing curves.

1.6.3.6 The HSR project can be suitably integrated with the DFC project on the Indian Railways. Inputs required will be minimal as the level crossings have already been eliminated. What will be needed is suitable fencing of tracks, provision of Cab-signalling for some selected trains and better inputs to track maintenance in addition to Special Coaches. **In this manner a HSR (200 kmph on existing lines) network on the entire Golden Quadrilateral and its two diagonals (About 11,500 km double line) can be a practical reality in a short period of time. This will improve the speed and safety of passenger travel with only lesser inputs and may even capture some of the Air passenger traffic. These trains can rightly be called Common Man's High Speed Trains in view of lower fares (vis-à-vis conventional H.S. Trains) due to lower investment and maintenance costs. A suitable HSR Blue Print has to be made and executed in a phased manner quickly.**

1.6.4 Formation of a Centralised Metro Rail Transport Authority

Metro Rail projects are not only essential to carry heavy urban traffic but also considerably reduce environmental pollution. The Integrated Energy Policy of the Planning Commission, August 2006 lays special emphasis towards development of rail-based urban transport systems in major cities to conserve fuel/energy. Construction of metro rail projects in our country has far lagged behind. Even though urban transport is a State subject but the Metro Rail projects need highly specialized knowledge and inputs. To give a boost and direction to this activity constitution of 'Centralised Metro Rail Transport Authority' appears necessary. This will ensure faster and effective coordination between the Ministry of Urban Development, Ministry of Railways, concerned State Governments, Urban Local Bodies (ULBs) and other Stake holders.

1.6.5 Assistance for R&D Inputs towards 'Carbon Sequestration and Carbon Capture' by the IR

Expanding the electrified rail network and making greater use of electric traction will help in saving precious diesel oil. This will also result in conserving foreign exchange (as most of the crude petroleum is imported) and will also enhance energy security. How far this shift from diesel traction to electric traction will impact the 'environment scene' still remains a debatable issue as most of the electricity generation in our country is Coal based (high $CO2$ emissions) and the situation is not likely to materially change in the near future. If the coal based electricity generation could be made ‘cleaner’ by developing suitable and cost effective **carbon sequestration and carbon capture** methods, it can be a win-win situation for the ‘environment’ and the IR. It may be mentioned that currently about 50% of IRs freight traffic is Coal based and the continuation of this traffic is in IR’s business interests. It will be prudent on the part of IR to support the R&D efforts in the **carbon sequestration and carbon capture** areas not only to help the ‘environment’ but also to protect its major bulk traffic viz. Coal.

1.6.6 Pointed Attention to the Aspects of Safety and Modernisation of IR

1.6.6.1 To select appropriate Technology and allied Systems keeping in focus the Social, Economic and Environmental aspects is difficult. For ‘Technology Foresight’ people with T-Shaped profiles (people with in-depth knowledge in their own domain as well as competence in a much broader spectrum of managerial, interpersonal and other skills) are needed.

1.6.6.2 The two recent Reports about IR need due consideration for implementation of the various Recommendations made therein :

(i) Report of the High Level Safety Review Committee (Headed by Anil Kakodkar) – February 2012.

(ii) Report of the Expert Group (Headed by Sam Pitroda) for Modernisation of Indian Railways – February 2012.

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CHAPTER 2

TRACK

2.1.0 HISTORICAL BACKGROUND

(i) The development of railways is basically linked with evolution of railway track and of locomotive. In 15th century stone slabs or wooden baulks were laid flush with the road surface for carriage of heavy goods, loaded on carts and drawn by animals. These were called 'Tramways'. These Tramways were extensively used in 16th Century in mines in Central Europe for carriage of coal and other minerals.

(ii) The timber baulks were replaced by iron plates in the year starting from 1767 to reduce wear and these were called 'Plateways'. These iron plates were also substituted in course of time by angle irons to give lateral support for better safety. As a further improvement, William Jessop of U.K. in 1789 replaced iron plates with cast iron beams having stone supports at ends for improved working.

(iii) In 1804, Trevithick discovered that trucks or vehicles could be propelled more easily "by the adhesion of a smooth wheel on a smooth rail" because of less friction. This perhaps, more than anything else paved the way for the use of the moving steam engine, pulling a number of coaches or wagons on plateways. The present railway track is a gradual evolution from these plateways. The rail sections were subsequently modified in different shapes as indicated diagrammatically in Fig.1 (Annexure-1).

(iv) In middle of 19th century, rails were designed as double headed (D.H.) rails and made of "I" section or Dumb-bell section. When the head was worn out during the service, the rail could be inverted and reused. The experience showed that the bottom table of the rail got dented in service by long and continuous contact with chairs and it was not possible to reuse it. This led to the development of Bull headed (B.H.) rail which had an almost similar shape but with more metal in the head to allow for greater wear and tear. This rail section had a drawback that special chairs were required for fixing it to the sleepers.

(v) A flat-footed rail, also called Vignole rail, having a cross section of inverted "T" was subsequently developed which could be fixed directly to the sleepers with the help of spikes etc. The flat-footed (F.F) rail is standardised for adoption on IR.

2.1.1 First Railway Line in India & Prevailing Track Standard

(i) Expansion of Railway Net Work: The first railway line in India was opened on 16th April 1853 for a distance of 21 miles from Bombay to Thane. Construction/additions of new railway lines continued quite expediously in India after that and inspite of very difficult working conditions & almost negligible availability of local resources, the railway network could reach a mark of 16000 kms during the period 1853-1880.

(ii) Rails & Sleepers: The rails used at that time were 90 lbs/yd for BG and 50 to 60 lbs/yd for metre gauge. The length of rails used were varying from 42 ft rails for main lines to 30 feet for branch lines.

Initially wooden sleepers of hard wood or soft wood were used in the early period as wood was the material used for making sleepers in Europe. This was possibly the most convenient and versatile type of sleeper and its versatility and utility has not decreased with the passage of time. On IR, however, in the interest to conserve forests for better ecology, the use of wooden sleepers has now been restricted inspite of its advantages. Once the wooden sleepers used were 31%, which at present is reduced to only 0.3%.

The shortage of wooden sleepers and the heavy requirements of traffic led to development of metal sleepers on the railway system sometime in the beginning of 20th century. These metal sleepers had longer life, required less maintenance and provided better lateral stability.

The metal sleepers used were broadly of two types:

(a) Steel Trough Sleepers

Once about 27% of track on Indian Railways was laid on steel sleepers; Presently only 1.5% of track on B.G is laid with S.T Sleepers. The increasing shortage of timber in the country and other economical factors were mainly responsible for the use of steel sleepers in India.

The steel trough sleeper essentially consists of a rolled steel plate of about 12 mm thickness and pressed to suitable trough shape and the rail seat canted to 1 in 20. The ends of the rolled section are flattened out in the shape of a spade to retain the ballast. The Steel Trough (ST) sleepers are basically of two types for each rail section viz.

(i) ST Sleepers with pressed-up lugs:
In this type, the lugs or jaws are pressed out of the plate itself to accommodate the foot of the rail and key. There are a lot of

maintenance problems with these pressed up lugs as they give way due to the movement of the keys as well as due to the vibrations ad impact of the moving loads.

(ii) ST Sleepers with loose jaws:

In order to obviate the above defect, another design of sleepers has been adopted. In this type, two holes are punched in the plate on either side of the plate to accommodate specially designed "Loose Jaws". The rails are held with the help of two standard keys driven either in the pressed up lugs or in the loose jaws.

Advantages of S.T Sleepers

(i) Longer life & Easy to maintain gauge and lesser maintenance problems.

(ii) Better Lateral rigidity; Very good scrap value; Free from decay and attach by vermin.

Disadvantages of S.T Sleepers

(i) Liable for corrosion & Unsuitable for track circuiting areas.

(ii) Liable to become centre bound because of slopes at two ends & Develops cracks at rail seats during service.

(b) Cast Iron Sleepers

Cast iron sleepers few years back were extensively used on Indian Railways and at that time about 42% track consisted of C.I. Sleepers, which may be either of pot type of plate type. Presently only 4% of track is laid with C.I. Sleeper.

Design features of CI Pot Sleepers

These consist of two hollow bowls or pots of circular of elliptical shape, placed inverted on the ballast section. The two pots are connected by a tie bar with the help of cotters ad gibs and slight adjustment of gauge ± 3 mm (1/8") is done by changing their positions. The rails is placed on the top of pot in a rail seat provided with a cant of 1 in 20 and is held in position with the help of a key. The pot sleeper suffers from the disadvantage that it cannot be used on sharper curves on B.G. Most of the fittings are hidden and their inspection and maintenance is quite difficult. These type of sleepers has become obsolete now and are not being procured by the Indian Railways any more.

CST-9 Sleeper

This is the standard sleeper and was once most extensively used on the Indian Railways. It is called CST-9 (Central Standard Trial-9) because it is the 9^{th} of the series produced by Central Standard Office. The sleeper is a combination of pot, plate and box sleeper. It consists of two triangular inverted pots on either side of the rail seat, a central plate with a projected keel and a box on the top of the plate. The two C.I. plates are connected by a tie bar with the help of 4 cotters. The rails are held to the sleeper by two way key provided at each rail seat on the gauge face side. Gauge is adjusted to a value of ± 5mm (3 1/6") by altering the relative positions of 4 cotters.

The rail seat of CST-9 sleeper is 115 mm (4 1/2") wide along the rail length and this narrow bearing tends to reduce the rocking of the sleeper under the wave motion of the rail. The sleeper provides bearing area approximately equal to the effective bearing area of standard B.G wooden sleeper i.e. 5 ft. (4545 sq. cm.) for both the plates. The CST-9 plates are available with reverse jaws (T-443 type) also to serve as an anti-sabotage measure, when a few of these are provide in each rail length. Normally, 3 reverse jaw CST-9 sleepers are provided per rail to serve anti-sabotage purpose. The weight of a CST-9 sleeper assembly along with fastenings for BG is 102 kg and for MG is 58 kg.

Limitation of CST-9 Sleepers

CST-9 sleeper was once one of the popular sleepers on IR., but it has certain serious limitation.

(i) The sleeper is not suitable for modern track because of not having a flat bottom.

(ii) The sleeper is not suitable for being tamped by Modern Track machine.

(iii) The sleeper has only limited longitudinal and lateral strength to hold L.W.R. particularly in the breathing length.

(iv) Due to less metal under the rail seat, the shocks and vibrations are directly transmitted to the ballast, resulting in (loose packing) poor retention of packing and hence increased frequency of attention.

(iii) Concrete Sleepers: In the year 1877, Mr. Monnier, a French gardener and inventor of reinforced concrete, suggested that cement concrete could be used for making sleepers for the railway track. Monnier designed a concrete sleeper and obtained a patent of it, but this did not work successfully. The design was further developed and Railways of Austria and Italy produced first concrete sleeper with promising design around the turn of the nineteenth century. This was closely followed by other European Railways where large scale trials of concrete sleepers were made due to economic considerations. Much progress, however could not be achieved till 2nd world war, when the wooden sleeper practically disappeared from the European market and the prices shot up. Almost at the same time as a result of extensive research carried out by French and other European Railways, modern track was born. Heavier rail sections and long welded rails came into existence. The necessity for a heavier and better type of sleeper which could fit in the modern track was felt. These conditions gave a spurt to development of concrete sleepers and the countries like France, Germany and Britain went for development of these concrete sleepers to perfection.

Different concepts of Development

The development of concrete sleepers, that took place on various railway systems, was mainly based on the following different concepts:

(i) R.C.C. or pre-stressed sleepers similar in shape and size to wooden sleepers.

(ii) Block type R.C.C. sleepers connected by steel tie bar.

(iii) Pre-stressed concrete blocks and a steel or an articulated concrete tie bar.

(iv) Pre-stressed (pre-tensioned or post tensioned) type of concrete sleepers.

These four concepts of design form the basis of development of present day concrete sleepers.

Out of these the type (iv) of concrete sleepers i.e. pre-stressed concrete sleepers are being used mostly on IR.

The main advantage/disadvantage of concrete sleepers are:

Advantage

(i) Concrete sleepers, being heavy, lend strength and stability to track and are specially suited to L.W.R. due to the great resistance they offer to the buckling of track.

(ii) Concrete sleepers with elastic fastenings provide a track which can maintain better gauge, cross level and alignment. It retains packing also very well.

(iii) The concrete sleepers, because of their flat bottom, are best suited, for modern methods of track maintenance like mechanical maintenance, which have their own advantages.

Disadvantages

(i) Handling and laying of concrete sleepers is difficult due to their being heavy. Mechanical methods have to be normally adopted for handling which involve considerable initial expenditure.

(ii) There is no scrap value for the concrete sleepers.

Types of Concrete Sleepers

Various types of concrete sleepers (pre-stressed pre-tension concrete sleepers, pre-stressed, post tension concrete sleepers and two block concrete sleepers) are being manufactured on Indian Railways. Details of these sleepers are given in the tabulated statement given below:

Gauge	Type of Sleeper	Rail Section	Standard Drg. No.	Sleeper design No.
BG	Mono block Mono block Mono block Mono block	60 Kg.UIC 52 Kg. 60 Kg/52 Kg. 90 R/75 R	RDSO/T-2496 RDSO-T-2495 RDSO/T-3602 RDSO/T-2521	PDS-14 PDS_12 Post tension type RCS-6
MG	Mono block Twin block Twin block	90 R 75 R/60R 75 R/50 R	RDSO/T-2503 RDSO/T-3518 RDSO/T-153	PCS-17 PCS-12 PCS-11

2.1.2 Importance of Track

Track constitutes the basic infrastructure of a railway system and bears the brunt of ever increasing faster & heavier traffic. There has been progressive upgrading of track which has enabled the railway to carry traffic with increased axle load & higher speeds and finally resulting in capacity augmentation of IR.

2.2.0 DEVELOPMENT OF RAILWAY NETWORK & TRAFFIC CARRIED

The details of railway network from 1853 upto 1950-51 are given in Table 2.1

Table 2.1 : Development of Railway network & traffic carried from 1853 to 1951-52

Year	Kms Open	Capital at charge (Rs. Lacs)	Passenger carried	Tonne Carried	Tonne carried per km.
1853	32.18	38	--	--	--
1861	2553.48	3400	--	--	--
1871	8164.06	9001	19283	3542	0.43
1881	15861.52	14081	54764	13214	0.83
1891	27808.34	22106	122855	26159	0.94
1901	40809.06	33917	194749	43392	1.06
1911	52837.95	45007	389863	71268	1.35
1921-22	59961	64797	569684	90142	1.50
1931-32	68886.11	87634	505836	74575	1.08
1936-37	69392.95	88013	--	--	--
1937-38	66091.28	84568	--	--	--
1941-42	65127.49	84806	623072	96997	1.49
1946-47	65203.12	63927	--	--	--
1947-48	54681.86	74220	--	--	--
1951-52	54897.47	83818	1232073	98025	1.78

Note: As the records for early stages of railway are not available in detail, it is not proposed to analyse the same. The records of route kms & track kms for subsequent years from 1950-51 to 2011-12 are available in detail & there are given in Table 2.2

Table 2.2 : Development of Railways network & traffic carried from 1950-51 to 2012-13

Year 1	Route Kms 2	Running Track Kms. 3	Average speed Goods train 4	Gross million Tonne Kms per route kms 5	Gross million Tonne Kms per running track kms 6	Passenger Kms per route km 7	Passenger Kms per track km. 8
1950-51	53596	59315	17.4	5.24	4.29	1.77	1.45
1960-61	56247	63602	16.1	8.32	6.59	2.03	1.61
1970-71	59790	71669	17.9	10.38	7.49	2.88	2.07
1980-81	61240	75860	19.7	12.55	8.84	5.15	3.63
1990-91	62367	78607	22.7	18.13	12.67	7.12	4.98
2000-01	63028	81865	24.1	21.95	15.55	9.49	6.73
2007-08	63273	85158	25.4	28.03	19.74	14.63	10.31
2010-11	64460	87040	25.6	31.90	22.73	17.36	12.37
2011-12	64600	89801	25.0	33.50	23.17	18.30	12.65
2012-13	65436	89236	25.5	34.20	25.77	18.90	13.86

Note: From Table 2.2 it will be seen that there has been significant improvement in capacity augmentation of IR as could be judged from the analysis given in the following para.

(I) **Freight Traffic output:** The gross tons kms per route kms have increased from 5.24 (1950-51) to 34.20 (2012-13) (553% increase) in spite of increase in Route kms from 53596 (1950-51) to 65436 (2012-13) (22.1 % increase)

The gross tons kms per Running Track Kms have progressively increased from 4.29 (1950-51) to 25.77 kms (2012-13) (501% increase) inspite of Running Track kms having increased only from 59315 kms to 89236 kms (51% increase)

The average speed of freight trains have progressively increased from 17.4 kmph (1950-51) to 25.5 km per hour (2012-13) (50.4% increase)

(II) **Passenger Traffic Output:** Passenger kms per Running Track km for B.G have increased from 1.45 (1950-51) to 13.86 (2012-13) (814 % increase) inspite of running track kms have increased by only 50.4%.

All these improvements in Traffic capacity augmentation have been possible because of many factors, but one of them being the role of track and its improvement & modernization as given in subsequent paras.

2.3.0 TRACK MODERNISATION

This capacity augmentation has been possible because of upgradation and modernization of various constituents of track. The details of these items are given briefly in subsequent paras.

2.3.1 Rails : Rail is an important component of track which provides a continuous and level surface to movement of trains. The rails carry out the function of transmitting the load to a larger area of formation through sleepers & ballast. Important developments of rails are:

(i) Better Quality of Rails: Heavier, higher UTS & more wear resistant rails are being used progressively on IR starting from 75 lbs and 90 lbs sections to the present day rails of 52 kg/60 kg and 90 UTS rails, (instead of 72 UTS rails) which can take higher axle load at faster speeds & require lesser maintenance. Infact efforts are also being made to provide 65 kg per metre heavier rail on Dedicated Freight Corridor etc so that heavier axle loads can be carried.

Harder rails and sometimes even head hardened rails were also used so as to allow heavier and faster trains to more.

(ii) Longer Rails: Earlier rails used were single rails of 13m long, giving lot of maintenance problems. Instead longer rail upto 65 meters are now being rolled. Efforts are also being made to roll 130 m long rails.

(iii) **Welded Rails:** Rails are now being welded by Flash Butt Welding technique up to 130 meter or even longer rails. The concept of long welded rails have helped in reducing maintenance efforts & also in capacity augmentation of IR.

At present B.G main line IR have about 86.5% of route length as long welded rails & 91.5% of B.G rail system is having 52kg/60 kg rails having UTS of 90 or more.

Modernisation of railways track consisting of better quality of rails including heavier rails and long welded rails and concrete sleepers have helped immensely to increase the traffic output on I.R.

(iv) **Reduction in Number of rail fractures:** In order to provide long welded rails it was necessary to weld the rails. Most of the welding was done by modern method of 'Flash Welding Technique' and only at actual field site planned Thermit welding was done. Due to temperature variations and also due to various field problems, there were earlier lots of rail fractures mostly in Thermit welded cases, causing interruption to rail traffic. However, in the present time using modern technology, standardising the system of welding and with proper monitoring, the number of rail fractures have progressively reduced. This has resulted in lesser interruption to traffic.

The steps which helped in reducing number of rail fractures were briefly as follows:

(i) **Longer Rails:** Manufacturing and using longer rails of 65 metres or even 130 metres.

(ii) **Flash Butt welding Techniques:** Getting the rails welded mostly by Flash Butt welding technique to get higher quality of rails. At some locations, even mobile flash welding plants have been organized.

(iii) **Improving quality of Thermit welds:** This was done by

(a) Adopting new technique of SKV welding* which in turn reduced the time of welding. The result was that the 'block period' was reduced & there were improvement in the quality of welds.

*Note: * S.K.V. is the short form of German Phrase "Schweiss Verfahren mit Kur vorwarming" This when translated into English read as "The Short Preheat Welding method" The* *technique therefore is also termed as SPW (short preheat welding) and carries the same sense as SKV.*

(b) Better monitoring of Thermit welding process by proper training of welders and stream lining as well as standardizing the Thermit welding process to get better quality of welds.

(c) Adopting latest techniques like use of 'Welding Recorders', use of one-s hot crucible' use of 'Anuto Thimble' and some other techniques.

The reduction in number of rail fractures have resulted in lesser interruption to traffic, which finally helped in better line capacity of Railways.

Note: *UTS means 'Ultimate Tensile Strength'. It is an indication of bending strength of rails as well as its hardness. Higher the UTS, rail is able to carry higher loads within permissible bending stresses and has higher hardness to have better wear-resistant quality of rails*

2.3.2 Formation

Formation supports the entire track structure & have important role in stability of track.

(i) Formation design & its consolidation: Old practical way for making formation was to dump the borrow pit material at the prescribed site & allow it to consolidate for few rainy season. Instead formation now is well designed, it is well laid in layers and progressively consolidated with the help of sheep foot roller or other mechanical measures at optimum moisture content. This helps in providing more stable formation.

(ii) Blanket & Blanketing materials: Presently formation are provided with blanketing material of suitable design which help in giving better stability to track & is very helpful whenever the soil conditions are difficult.

(iii) Soil stabilization by Geotextile method: This method of stabilization of soil is used in stabilizing the track. The result is that modern well designed and well laid formation gives better stability to track & helps in improving the traffic output.

2.3.3 Sleepers & fastenings

Sleepers carry an important role as they transmit the wheel load from the rails to ballast.

(i) Better Quality of Sleepers: Earlier sleepers used were mostly wooden sleepers, CI Pot sleepers, CST-9 & trough sleepers. Wooden sleepers, though quite versatile were weak in strength & also had poor life span. On account of the above reason the maintenance efforts to maintain these sleepers were quite big; There used to frequent replacement of wooden sleepers and also the strength of the track to bear heavy and fast traffic was very limited. The wooden sleepers were having mostly dog spikes, which used to get loose. This was affecting adversely the movement of trains. Instead now concrete sleepers which are heavier & stronger sleepers are being used progressively, which have very less maintenance & also have long service life.

Concrete sleepers are economical & technically more suitable for carrying high speed & heavy density traffic. These can be maintained by heavy track machines, have longer life & lesser maintenance efforts. At present 97.3% of main line BG track is covered with concrete sleepers.

(ii) **Increase of Sleeper Density:** Sleeper density is number of sleepers per rail length or number of sleepers per km. Depending upon the sleeper density, the spacing of sleepers is fixed. The spacing is kept uniform throughout the rail length but is made closer near the joints because of the weakness of the joints and the impact of the moving loads on it. There is, however, limitation to the close spacing of the sleepers as enough space is required between the sleepers for working the beaters to pack the joint sleepers.

In order to cater for higher speeds & heavier loads, the sleeper density increased which gives more stability to track by improves the capacity of track to take their extra stresses. For this Sleeper density which was earlier only 1340 sleepers per km has now been increased to 1540 or even 1660 to meet the requirement of modern traffic.

(iii) **Elastic fastenings:** To bind the rails with sleepers earlier rigid fastenings like dog spikes & screw spikes etc. were used which give a rigid track and require a special attention. Instead today modern elastic fastenings like elastic rail clip, HM fastening & new elastic 'G clip fastenings' are being used. These fastenings give better quality to track & are able to cope with excessive vibration & stresses due to heavier & faster traffic.

(iv) **Rubber pad:** Instead of conventional 4.5 mm thick rubber pad, modern 6 mm thick grooved rubber pad & lately composite grooved rubber sole plate for 60 kg are being utilized, which help giving more elasticity to track.

The result is that improved quality of sleepers and elastic fastenings have enabled better track standards, which in turn help in better output of traffic.

Note: *The rubber pads are normally provided on concrete sleepers to add elasticity of the track & also to ensure that concrete sleeper are not damaged.*

2.3.4 Ballast

Ballast is an important constituent of track & helps in distributing the load from sleeper to formation & provides drainage as well as stability to track.

Following have been main developments which enabled the betterment of ballast quality.

(i) **Better quality of ballast** Earlier sand ballast, Jhama brick ballast (over burnt bricks ballast) & sometimes even coal ash ballast were used in quite large stretches of railway track of course at few locations stone ballast was also used, but these were no standard specification for stone ballast. At present ballast used is of stronger material from hard rock's such as igneous rocks & proper grading and proper size of ballast are laid down as per standard specification.

(ii) **Better ballast cushion:** Ballast cushion which was earlier only 150 mm to 200 mm has been increased now from 250 mm to 300 mm to give more elasticity and stability to track.

(iii) **Deep screening of ballast:** Lot of emphasis is laid on deep screening of ballast to provide good drainage to track. Earlier this was done manually & now it is being done by modern ballast cleaning track machines. This helps in earlier restoration of track at higher speed.

(iv) **Crib and Shoulder consolidation:** In order to give more stability to track, crib & shoulder of ballast are packed by modern track machines. This helps in restoring the track to normal speed more expediously after deep screening etc.

2.3.5 Turnouts

Turnouts consisting of points & crossing help the vehicles to more from one line to another line.

The main developments to turnouts are:

(i) **Smoother entry/exit turnouts:** Earlier conventionally 1 in 8.5 & 1 in 12 turnouts were being used even for passenger trains, limiting the speed of train to about 10 to 15 kmph. Presently modern high speed 1 in 16 or 1 in 20 turnouts are being used with flatter angle of entry & exit.

(ii) **Better structure of turnouts:** Also the structure of turnouts have been made more robust with thick web switches & CMS crossing etc., due to which the maintenance efforts are less & give more stability to track.

These aspects have improved the speed of turnouts up to 30 kmph or more.

2.3.6 Track maintenance & track renewal

Track maintenance is an important issue to keep the track safe with good health.

Earlier track was being maintained manually using 'Beater packing' system. Instead now track is being maintained mechanically with the help of heavy on track machines as given below:

(i) **Heavy Track machines:** Track is being maintained by Heavy track machines giving better quality of track & more retentively of packing to track. Track machines are being progressively improved. Earlier Plasser 06-16 universal tamping machines were used which can only tamp 2 sleepers at a time. Presently Dynamic Tamping express 09-4x is being utilised, which can tamp 4 sleepers at a time. To maintain the track to better standard different track machines are being used for different purposes as given below:

- **(a)** **Points & Crossing tamping machines** for tamping of points & crossing.
- **(b)** **Ballast cleaning machines (RM-80)** for cleaning of ballast & for regulating ballast on track.
- **(c)** **Crib & Shoulder consolidating maintenance** for crib & shoulder consolidation for better stability of track & restoring normal speed at a faster speed.
- **(d)** **Dynamic track stabilizer** for stabilization of ballast bed in order to provide stable track.

(ii) **Track Renewal:** Earlier track renewal was done manually with the help of manual gangs. Conventionally about 20 gangs using about 400 labour used to renew track & general progress was very slow, quality of track renewed was also not very good. Now-a- day modern track machines are being used which can renew the track at faster speed needing lesser traffic block & restoring track to normal speed at faster rate. Track renewal normally is done as follows:

- **(a)** **Track renewal by using PQRS equipment** with pre-fabricated panels.
- **(b)** **Switch relaying machines** for renewal of points & crossing.

(c) **Track relaying trains for** complete renewal of track; carrying out automatically all the works of track renewal by different units of Track Relaying Train.

Note: *(i) Earlier about 21 days were required to restore the track to normal speed while carrying out manual maintenance. Now with the help of mechanized maintenance, the speed of track is restored to normal in 7 days period.*

(ii) All these methods of track maintenance & track renewal have helped in improving quality of track, reducing track maintenance efforts & improving though output of traffic.

2.3.7 Gauge Conversion Projects

Gauge conversion projects; which converted MG/NG to B.G sections were executed by IR in order to enhance traffic output. From 1993 onward, the Gauge conversion projects have been taken vigorously and by 2012-13, 19100 kms have been converted from MG/NG to B.G.

Due to gauge conversion as well construction of additional new lines, the BG route kms have been progressively increasing. The result is that in 60 years, the BG route kms have almost doubled, though the total route kms have only increased by about 22% as could be seen from table below:

Table 2.3 : Route Kms of I.R. from 1951-2013

Year	BG	MG	NG	Total
31.03.1951	25258	24185	4300	53743
31.03.1983	32624	24514	4247	61385
31.03.1994	37824	20653	3985	62462
31.03.1996	40620	18501	3794	62915
31.03.2000	44383	15013	3363	62759
31.03.2004	46806	13290	3124	63221
31.03.2007	49819	10621	2886	63326
31.03.2009	52808	8473	2734	64015
31.03.2010	54257	7180	2537	63974
31.03.2012	56956	6347	2297	64600
31.03.2013	57140	5999	2297	65436

The overall result is that Gauge conversion has played an important role in enhancing/augmenting traffic capacity on I.R.

2.4.0 TRACK MONITORING SYSTEM

Earlier track used to be inspected/monitored by manual method & these were no method of assessing the quality of track maintenance objectively.

Presently track inspection is done not only by manual effort but also by mechanical methods. At present, the assessment of track maintenance efforts is being judged objectively using sophisticated modern track monitoring system as given below:

2.4.1 Track Recording cars: These are track recording cars which can be attached to a train & Car monitor the quality of track with the help of various gadgets & factors attached to the car. These cars can objectively assess the quality of track by measuring vertical & lateral profiles with the help of sophisticated gadgets.

2.4.2 Portable accelerometers: This is a handy instrument used for measuring vertical & lateral acceleration. This helps in assessing the quality of track.

2.4.3 Track Management System: TMS, which has recently developed by I.R. is a computerized tool for planning, implementation and monitoring the track maintenance works. It prioritises maintenance inputs based on track condition thereby ensuring need based maintenance.

Track Management System is a central server based web enabled software programme which integrates various track structure data, inspection data, work data, etc. to assist Railway Engineers in ascertaining the correct level of maintenance and renewal inputs to be made at requisite location with the objective to maximize benefit of inputs given to track.

Information being provided by TMS plays vital roles in track maintenance. It specifies where renewals are required and it initiates and controls the activities required for maintaining track in satisfactory condition. It is felt that TMS will have a profound impact on optimum utilization of scarce track maintenance resources and improving the general efficiency of engineering department. TMS will also help in planning of deployment of costly track machines for maintenance and renewals.

TMS is very useful software for the P. Way Supervisors and Engineers. This will very helpful in planning & maintenance of track record keeping, doing away with various registers. Inventory controls, alerts for attention to track. Track supervisors will have more time for better maintenance of track.

TMS has already been implemented or is under process of implantation on 6 Divisions of Indian Railways. In next few years TMS is likely to be introduced on the entire Indian Railways. With the introduction of TMS Indian Railways will be one of the modern Railway System where entire track management system will be need based and cost effective, using the modern software technology.

Track Management System is likely to streamline Track maintenance system, which is likely to help in improving quality of track, which in turn will result in better output of railway.

2.5.0 SAFETY ASPECTS

Modern track consisting of heavier rails with higher UTS & long welded rails, concrete sleepers, and elastic fastening has provided a very stable infrastructure giving safe and comfortable rail travel. Modern track machines have helped in better maintenance of track with proper track geometry in order to ensure better safety and stability to the track. Track recording cars and other methods of Track monitoring have helped immensely to plan the track maintenance programme systematically in order to ensure better track maintenance, which will finally help immensely in giving better safety, faster and rail travel. This is turn will improve the capacity of I.R.

2.5.1 Role of Railway track in improving the environment/safety: Railway transport is supposed to be more environment friendly compared to road transport as can be seen from the following facts:

(i) The movement of steel wheels on steel rails in the railway system has the basic advantage of low rolling resistance, (which is almost 20% compared to road transport) which reduces energy requirements and haulage costs.

(ii) Rail transport is more efficient than road transport in terms of land use.

(iii) Railways is an energy-efficient mode of transport, particularly for freight traffic, and can use different forms of energy. It also causes relatively less environmental pollution than road transport.

In addition, the following further factors have helped in improving the environment.

Provision of Long welded rails: The provision of long welded rails instead of single rail with fish plated joints have definably improved the environment because of lesser noise. Similarly provision of elastic fastening & better ballast cushion has also helped in making rail travel smoother & less noisy.

The railway track has this helped a lot in improving environment conditions which eventually leads to the better safety conditions on Railways.

2.6.0 PRESENT POSITION & FUTURISTIC TREND ABOUT TRACK DEVELOPMENT

Indian Railway are progressing ahead in a big way in modernisation of Railway Track and its maintenance practices in order to move the traffic at higher speed & cope up with heavier axle load with an ultimate objective to improve traffic output of the railway system.

Heavier rail section consisting of 60kg/90 UTS rails are being used replacing old 90 lbs/yd & 52 kg/metre rails of 72 UTS strength. Long welded rails are being used replacing the earlier fish plated joints having single rail or 3 rail length panels. Similarly, concrete sleepers are being progressively used replacing earlier wooden, steel & CST-9 sleepers and providing elastic fastening instead of rigid conventional fitting.

As on 31.03.2013, on BG main lines of IR, about 87.6% of the length is covered by long welded rails, 98.3% with PSC sleepers and 92.7% with 52kg/60 kg 90 or higher UTS rails.

2.6.1 Futuristic Trends: As far as future position is concerned IR are planning ahead in big way for expansion of railway network, multiplication of many lines, as well to improve speed & axle load as outlined in Railway Vision 2020.

Similarly Indian Railways are planning Dedicated Freight Corridor for separate carriage of freight trains with higher speeds & higher axle loads & improvement in various other track parameters.

Details of all these futuristic items of activities particularly concerning track are discussed in subsequent paras.

(i) Dedicated Freight Corridors: Dedicated Freight Corridors (DFCs) have been planned for the entire Golden Quadrilateral and its two diagonals by laying new parallel double lines exclusively for freight traffic thereby making the existing system a passenger corridor. The approximate length of six DFCs (Four sides of the quadrilateral plus two diagonals) will be 11,500 kms of double line (23,000 kms of rail track)

Axle Loads: The existing axle loads on the IR system are 20.3 t and have recently been enhanced on some selected routes to 22.9 t. The DFCs are being designed to take axle loads of 30 tons and for the present 25 tons axle load wagons are proposed to be run for which Feeder Routes (About 30,000 kms; axle load 22 tons are also being upgraded to enable carriage of 25 tons axle load wagons.

Higher axle load will require better track standards consisting of heavy rails of 60 kg or even heavier rails, 110 UTS, higher sleeper density of 1540 to 1660 No of PSC sleepers per km, more ballast cushion of 300 mm & such other better track standards.

Higher Speeds: It is proposed to have maximum speed of 100 kmph for freight train. This will require flatter gradient of 1 in 400, smoother curves of 1 to 2 degrees, stronger bridges, No level crossings & such other improvement in track conditions.

Various technical specifications are given briefly in Table 2.4.

Table : 2.4 : Standard of Construction & Other parameters of DFC

1.	Gauge	1676 mm
2.	Rails	60 kg 110 UTS-20 Rail panel (260m) to be handled by mechanical track laying equipments.
3.	Sleeper	PSC 1660 Nos. per km density for main line & 1540 Nos per kms density for loop line.
4.	Points & Crossings	60 Kg rail with, 1 in 12 curved switches and CMS crossings on PSC sleepers and thick web switches.
5.	Ballast	300 mm cushion (Machine crushed) with present RDSO specification.
6.	LWR/CWR/ Welding	* 20 rail panels are to be converted into LWR.CWRs with mobile flashbutt Welding/gas pressure welding * SKV* welding should be avoided strictly. All in situ welds to be joggle fishplated.
7.	Gradient	* Flat Territory Mid section-1 in 400 or flatter (Compensated) Yards-1 in 200 * Semi Ghat Territory mid section-1 in 200 compensated or Yards 1 in 1200 * In the block section at a convenient location gradient of 1 in 1200 to be provided for future crossing station.
8.	Curvature	* Flat Territory Maximum Curvature-One Degree * Semi Ghat Territory maximum curvature-2 degree

9.	Formation	* Top width of embankment-7.5 m with 2 : 1 side slope * Track Centre-5.3 m * Complete embankment should invariably be provided with turfing.
10.	Cutting	* Cutting width including drains-11.0 mtrs. Side slopes to be designed depending on earth material. * Erosion, Boulder fall, Earth slips blocking the drain etc. to be totally avoided.
11.	Bridges	* Ballasted deck bridges with RCC slab/RCC Box/PSC slab/PSC Box girder. * To ensure high quality concrete, use only Ready Mix concrete. Mobile ready Mix plants can be planned which can be shifted at suitable interval. * Use only high grade concrete with suitably designed admixtures to create economical structures.
12.	Road crossings/ level Crossing	* As far as possible, there shall be no level crossing. * Complete length to be fenced on both sides
13.	Maximum speeds	100 kmph (Freight train)
14.	Type of traffic &Axle load	* 25 tonne double stack container movement with 15000 tonne trailing loads: 30 tonne for bridges.

*Note: * S.K.V. is the short form of German Phrase "Schweiss Verfahren mit Kur vorwarming" This when translated into English read as "The Short Preheat Welding method" The technique therefore is also termed as SPW (short preheat welding) and carries the same sense as SKV.*

In order to meet these high standards of DFC, which includes 100 kmph speed for freight trains, 25 to 30 ton axle load; better track standards have to be adopted. Railway track will play a important role in construction of DFC, which in turn is bound to increase the line capacity and traffic output of IR.

(ii) Expansion of Railway Network: Indian Railways plan to expand its route network at the rate of 2500 kms, per annum. By 2020, 25000 kms of new line are proposed to added and almost the entire network (barring the hill and heritage railways) would be in Broad Gauge. More than 30,000 kms of route would be of double/multiple lines. Electrification of 14,000 kms of routes would take the total length of electrified route to 33,000 kms. This would include all inter-metro links and the other busy corridors.

(iii) Multiplication of lines: Indian Railways are likely to have in near future more than 6000 kms quadrupled lines with segregation of passenger and freight services into separate double-line corridors. This shall include Delhi-Kolkata, Delhi-Mumbai, Kolkata-Mumbai and Delhi Chennai routes. All these routes would have separate dedicated freight corridors and high speed passenger corridors.

It may be brought out that while expanding the railway network, carrying out multiplication of lines, providing higher track standards like 60 kg or even heavier rails and higher sleeper density, smoother curves, flatter gradients are proposed to be provided, which is turn will help in improving capacity of railways.

(iv) High Speed Trains: As per railway budget 2014-15, Indian Railways plan to undertake following projects:

(A) High Speed Corridors:

a. Bullet train proposed on identified Mumbai-Ahemdabad sector.
b. Setting up of Diamond Quadrilateral Network of High Speed Rail connecting major metros and growth centers of the country.

Higher track standard will be required for making the high speed corridors which in turn will help in faster running of trains, which finally will improve capacity of IR.

(B) High Speed on Existing tracks:

It may be brought out bullet trains would require completely new infrastructure, higher speed for existing trains will be achieved by upgrading the present network. Hence, an effort will be made to increase the speed of trains to 160-200 kmph in select sectors so as to significantly reduce travel time between major cities.

The identified sectors are:

(i) Delhi-Agra (ii) Delhi-Chandigarh (iii) Delhi-Kanpur (iv) Nagpur-Bilaspur

(v) Mysore-Bengaluru-Chennai (vi) Mumbai-Goa (vii) Mumbai-Ahmedabad

(viii) Chennai-Hyderabad and (ix) Nagpur-Secunderabad.

For enabling the railway system to have higher speeds, railway track should be fit for these high speeds and accordingly track has to be upgraded and modernized.

(v) Improvement in Railway Safety

Indian Railway corporate safety plan (2003-2013) had laid down an objective to reach the accident level on I.R. as 0.13 per million train km. This has since been achieved as in the year 2012-13, this figure is 0.11 accidents per million track km.

In Railway vision 2020, a target of 'Zero accidents for IR' has been laid. In order to achieve that target, IR will have to make efforts in all directions. In this connection, improved track structure, modernization of track, monitoring devices, track management system will play a key-role to improve the safety standards of IR.

Elimination of Unmanned Level Crossing

Indian Railways have 30348 Level Crossings, out of which 11563 are unmanned. Each unmanned level crossing is being examined in detail and depending on the site condition action will be taken to eliminate it by suitable modality. Multi-pronged approach is proposed to be adopted eliminating Unmanned Level Crossings.

Automatic Door closing of trains: Pilot project is proposed on Automatic door closing of trains in mainline and sub-urban coaches. The pilot project will give an idea about its suitability for trains to improve safety & further action will be taken after its test-checking.

(vi) Improvement in Goods train services

(a) Higher axle loads: up to 25 to 30 metric tonnes for Dedicated Freight Corridor as well as for feeder routes. This will require improved track standards.

(b) Higher speeds upto 100 kmph for goods train: This will require smoother curves, flatter grades & such other improved track parameters.

The higher axle load & higher speed of goods trains & a separate corridor for freight traffic is bound to increase the line capacity of IR in a big way.

All these details have been given in the para **'Dedicated Freight Corridor'**.

2.7.0 SUMMARY

Summarising, Track has played an important role in improving the through-put of railways by developing modern track with high quality maintenance standards which can take the burden of running faster & heavier trains The important aspects of track which have helped Indian railway to improve the traffic capacity are as follows:

(i) Track Modernization and Better Track Structure: Heavier Track structure consisting of 60 kg or heavier rails and rails welded to long welded rails, concrete sleepers with sleeper density of 1540 to 1660 sleepers per km or more and elastic fastening have been provided. Stronger rails of 110 UTS which are also harder rails with more wear resistant qualities have also been used. This has helped in improving the speed of the trains as well as enabling the railway to run heavier trains.

More stable formation, hard and clean ballast, cushion of 25 mm to 30 mm have helped not only in providing trouble free track, but also reduce traffic interruptions & provide track with lesser speed restriction in order to enable more trains to run.

All these aspects of track have helped in increasing the axle load, speed up the trains which in turn have helped in capacity augmentation of IR.

(ii) Mechanised Track maintenance & proper track monitoring: Better Track Maintenance & systematic monitoring of track has provided trouble free track with least interruptions to traffic and also improving the speed of train, which finally will improve capacity of IR.

(iii) Improving track parameters: In order to cater for higher speeds, various track parameters, which effect the speed have been improved. This includes smoother curves, flatter gradients, Minimum number of level crossing, flatter turnouts etc.

(iv) Gauge Conversion Projects: The innovative effort of converting MG/NG to B.G. at fast pace and so far doing about 19000 Kms of gauge conversion project have helped in enhancing traffic capacity of the railways network.

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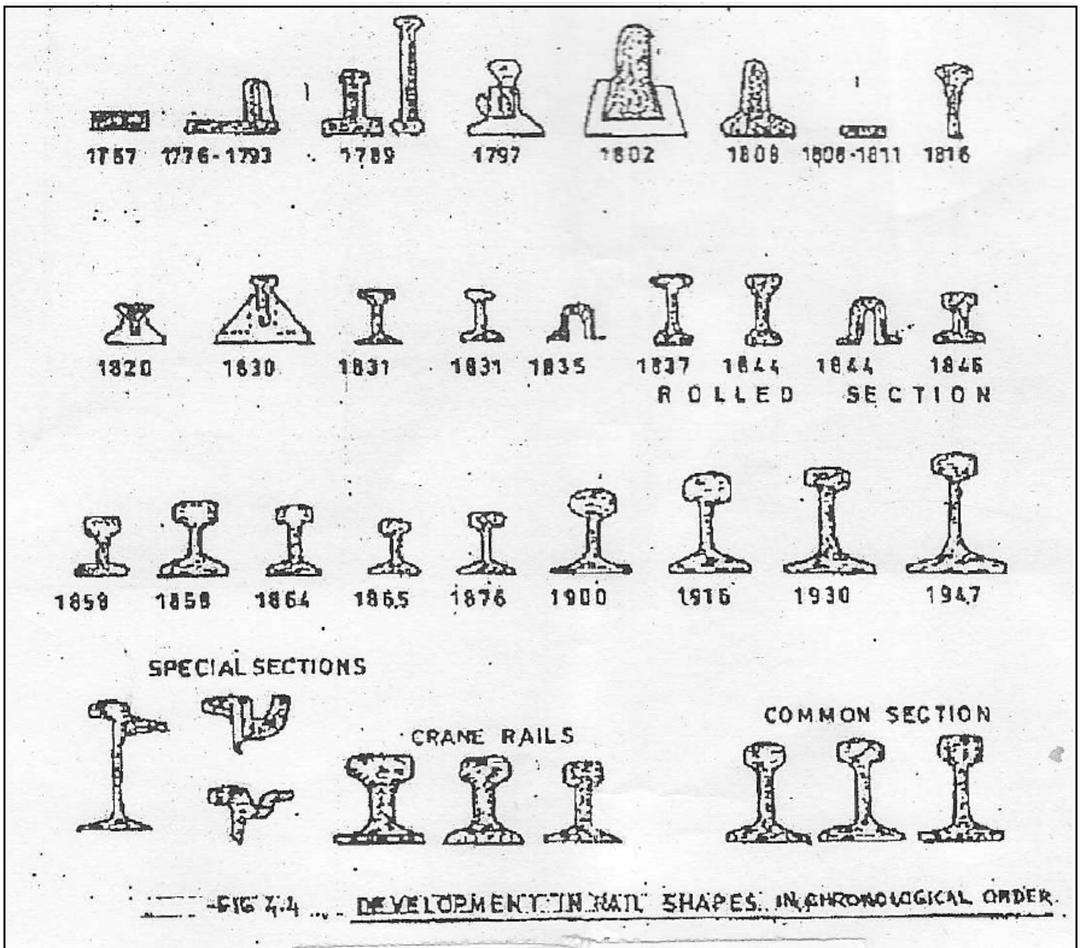


Fig. 1: Development of Rail Section

CHAPTER 3

BRIDGES

3.1.0 INTRODUCTION

3.1.1 Bridges are an integral part of railways and are provided to negotiate obstacles such as water streams, deep gorges, low ground or cross over other railway line or a road. History of bridges is not new. Railway bridges were constructed when new railway lines were laid in early part of the 19th century in England, however, the road bridges were already in existence though in nascent form. Construction of railway bridges needed a different approach and superior technology as there were intrinsic differences between them and road bridges. The railway bridges needed to carry much heavier loads and the effect of speed on them was much more severe than in their counterparts in roads. Railway bridges also demanded a close and systematic attention during their service period as failure would have resulted into catastrophic results vis-à-vis roads. This required a very different approach in designing, construction and maintenance of railway bridges.

3.1.1.1 As on 01-04-2012, there were a total of 133873 bridges on Indian Railways of which 725 were important ones. Detail break up is given in Box 1.

Box 1

Bridge Statistics on Indian Railways.

(as on 01-04-2012)

A. As per size of the bridge:

Important bridges (a bridge having total length of opening of 300 meter or more/ cross section of 1000 sq meter or more and such bridges as decided by the Chief Bridge Engineer)	725
Major bridges (a bridge having a single span of 12.2 meter or more / total length of opening 18.3 m or more)	10833
Minor bridges (other than above)	122315
Total	133873

B. As per type of super structure:

Triangulated Girders	749
RSJ/Plate Girders	12017
Composite (steel plus concrete)	164
PSC/RCC Girders	2389
PSC/RCC slabs	40161
RCC Box culverts	16577
Arch bridges	19403
Other types	42413
Total	133873

Notes : RSJ = Rolled Steel Joists PSC = Pre Stressed Concrete

RCC = Reinforced Cement Concrete

3.1.2 Planning and Construction of railway lines in India followed closely the opening of the first passenger railway in England between Darlington and Stockton in the year 1825. However, nature of rivers in India was very much different than those in England and posed serious problems in bridging them. A large number of rivers remained un-bridged for a long time. The nature of river flow caught attention of several British Engineers who were working in this field in India. Some famous Engineers included J R Bell, Sr Francis J E Spring, G Lacey and Inglis. Gerald Lacey was working in the Irrigation Department of Punjab and conducted extensive studies on the flow characteristics of rivers in alluvium plains. Guide lines evolved by him for scour and river width in regime conditions are still being used to design substructures of railway bridges in India.

3.2.0 EARLY CHALLENGES

3.2.1 Britishers faced major challenges in construction of bridges as the rivers here were very much different in behaviour, especially in the sandy plains of northern and eastern India. The climatic conditions varied considerably and so did the flow through the rivers. The volume of water registered seasonal variations of magnitude unknown in other parts of the world. The varying character of the river-bed soil further aggravated the problem. Most rivers passed through alluvial soil devoid of rocks. To quote Charles Greaves, one of the early Engineers visiting India in 1852:

"*The whole of the Bengal plain is nothing but a sea of mud; there is hardly a stone as big as coconut or a hill as high as a house. It is wonder having regard to the softness or looseness of the soil that Calcutta remained where it was."*

3.2.2 Early Railway Engineers in India had to innovate and devise special methods for constructing bridges to overcome the problems presented by the terrain and non-availability of proven materials of European origin at the work-site. Large bridges were, and continue to be, a major problem. The rivers of northern India are fed mainly by the Himalayan snow and discharge their waters into the Bay of Bengal in the vicinity of Kolkata (Calcutta). In doing so, they traverse hundreds of kilometers of almost flat land largely composed of silt deposited over the centuries. The other source of water feeding these rivers is the monsoon rain, falling between the months of June and September each year. During the dry period, the rivers shrink to a sluggish, steady flow in the course of which silt is deposited on the bed. When the monsoon rains come, the flow increases to a flood and the river bed having been raised by silt deposit during the dry period, rises correspondingly with each monsoon. The inevitable happens; the rivers overtop their high banks, be they natural or man-made, and find a new route across the flat land. When the floods subside, the river may have shifted from its original route and gouged a new channel. James Meadows Rendel, the great Consulting Engineer, associated with Railways in India from its very inception commented in 1854:

"There are engineering difficulties to contend with in India, which people at home cannot possibly conceive. Yet I am bound to say that the works executed by East Indian Railways (EIR) are equal to any of the kind done in this country; several large bridges have been built over river streams and rivers near Hooghly, and on exceedingly treacherous, sinking and shifting ground. Yet no failures have happened nor have any major accidents taken place, although since the planning of railway, heavier flood have risen in Bengal than have been witnessed since the days of Clive."

3.2.3 Difficulties in bridging the major rivers could favour a particular track alignment and sometimes even the terminus. A bridge over river Hooghly was the most difficult engineering problem faced by railway men of that era. Mr. Simms, the Consulting Engineer to the Government of India, sent out by the Court of Directors of East India Company in early 1850 finally decided to place the terminus for the EIR line on the right bank at Howrah, although he had previously, in May 1846, submitted a recommendation of a contrary tenor. In April 1850, he wrote:

"In May 1846, I expressed myself in favour of bringing the railway into the heart of the town; and it is therefore due to myself now to state that when that report was penned, there appeared to be every probability of an abundance of money to carry out the whole of the railway project from Calcutta to Delhi, with bridges spanning the great rivers, the Yamuna, Sone and the Hooghly; and therefore in so magnificent a project, the extra outlay (large as it would necessarily be) to make so great a work quite complete by bringing the railway into the heart of the town, would, under such circumstances, be quite unworthy of consideration in comparison with the whole cost of the undertaking".

3.2.4 Rowland Mcdonald Stephenson, the promoter of East Indian Railway Company had to compromise on the decision of choosing a terminus for his railway, thus Howrah was chosen instead of Calcutta. The bridge over Hooghly is an interesting story. An organisation calling itself `Steam Ferry Bridge Association of Calcutta' initiated building a Floating Bridge across the river. All the material including two floating bridges were delivered at Calcutta in 1842, but because of a dispute with Bengal Marine Board, the project had to be abandoned. A different design of `Floating Bridge' more in the shape of a pontoon bridge was however constructed a few years later by Sir Bradford Leslie. The roadway, 30 ft (12.2m) wide and 2000 ft (610m) long was supported on twenty-six flat bottomed iron pontoons, each 80 ft (24m) long by 26 ft (7.92m) wide, placed 50 ft (15.24m) apart and moored by heavy chains to a cable carried across the river from bank to bank. On each side of the river two of the pontoons were movable, giving a 155 ft wide opening for the passage of the ships. At each end of the roadway was a 110 ft long platform, one end resting on the shore, the other on a pontoon. By this means, the 22 ft rise and fall of the tide could be accommodated. This system continued for 30 long years and all the material meant for Calcutta moved from Howrah through the `Floating Bridge'. A connection to Calcutta by rail was established 40km (24 miles) northwest of Calcutta, giving East Indian Railway a direct link, via the Eastern Bengal Railway. This Bridge, the Jubilee Bridge named after the Golden Jubilee of Queen Victoria was formally opened by the Viceroy on 21st February 1887.

3.2.5 On the western front, Colonel J.P. Kennedy, promoter of Bombay Baroda and Central India Railway (BB&CI) suggested a line connecting Bombay with the territories of Northern Konkan, Surat, Bharuch, Gujarat, Khandesh, Rajasthan, Malwa, Sind, Punjab and the north-west provinces. Opponents of this proposal suggested that there were two grave impediments viz.

(1) It would be very difficult to cross the broad estuaries close to the sea and the spurs coming down from the Sahyadri range, and

(2) There were near impassable river streams in Tapti Valley.

Kennedy replied (excerpts from his report of 1854) thus:

"It is far from my intention to undervalue the obstacle that rivers and nullahs are likely to pose to Indian railway construction; all that I maintain is, that the rivers and nullahs in these districts are like the rivers and nullahs in other districts of India, and that the engineer who is not prepared to deal with such obstacles had better turn his back upon India altogether. They are assuredly the chief subject requiring fore-thought and caution in the execution of public works in this country, and upon the mode in which we deal with them will depend the broad questions of whether our railway operations shall succeed or fail; whether the results from them shall be a profit or loss or whether their execution shall be rapid or slow. So strongly did I feel the importance of this subject and the danger of adopting in India any of the costly and dilatory principles which have caused so much ruin and delay elsewhere, that I ventured to recommend, formerly, in my official reports to Government, the temporary omission of bridges altogether on the larger class of Indian rivers, rather than damage the character of Indian railway investments by risking the interests of the shareholders for the construction of those great masonry viaducts of former days. Our more recent practice, however, and the improvements and experience of the last few years, in our iron structures of this class, fully justify me in saying that no such inconvenience to our traffic, as a temporary omission of the larger bridges, will be now required, if we can obtain iron at a reasonable rate, and that point the investigations made by this company have placed beyond the shadow of a doubt; still, however, the bridging of rivers will be vital point in Indian railway construction."

On getting iron at reasonable price, Kennedy suggested;

"If we construct our viaducts, rails, etc., of native iron of our own manufacture, we may calculate on executing our railroad at an average rate of £4011 per mile. That if we adopt the same principle of construction, but purchase our iron in the English or other market, we may calculate on expending £ 7053 per mile; and if we use brickwork or masonry viaducts, with English iron rails, our outlay would be £8769 per mile. Hence, then, the very first preparation that I should earnestly recommend to enable us to secure the most successful result in our future railway operations would be, the immediate establishment by our company of a native iron foundry."

From the foregoing, it will be evident that bridges played a major role in deciding the alignment of many rail lines in India.

3.3.0 OTHER ISSUES

3.3.1 Training of Rivers

Rivers in India change drastically in rainy season. They change their course over a period of time depending upon the topography and terrain and the rainfall pattern. Railway Engineers mastered the art of training the rivers, which changed course sometimes by miles. Never before in the history of railways, the engineers had come across such problems. However, their ingenuity, dedication and hard work provided the solutions.

3.3.2 Foundations of the bridges

The foundations of many of these large structures presented difficulties and problems peculiar to India. The usual method of founding the abutment and piers of large bridges in the sandy beds, extending often to unknown depths of great rivers, could not be followed due to sub-soil conditions of the foundation bed. In most of the early constructions, well foundation was adopted by sinking cylinders or wells of brickwork either singly or in groups on which the pier sub-structure was built. **This system though novel to civil engineers in other parts of the world, was being practiced in India for centuries in a systematic way.** Nearly all the ancient bridges of upper India were formed by this method. Recognizing the suitability of this method, the practice of well sinking foundation was further developed by the Americans and they became the masters of pneumatic caisson. Near coastal areas for clayey strata, he system of 'screw piles' with cast iron outer shell filled with sand was successfully used as bridge foundation system.

3.3.3 Use of Local Materials and Craftsmanship

Looking to the advantages of local materials like stones, etc. the masonry structure was used in a big way for construction of piers and abutments of the bridges. For superstructure, Indian Engineers preferred massive use of 'early' mild steel, particularly for large bridges as these were the only materials capable of producing the required long spans.

Extract from Col. J.P. Kennedy's writing in 1854 highlights the use of iron superstructure and screw-piles made by local smiths of Surat.

"*Examination of the Tapti and Narbada justifies me in recommending that these rivers should be bridged by an iron superstructure, supported on iron-piers. The bridging of these two rivers will be the most serious operations we shall have to encounter in executing our works. We have had some screw-piles made by the ordinary smiths in Surat, to try their capacity, and the result of this, and* *other operations of a like tendency, has been very satisfactory, showing that, we may calculate upon good service from the native mechanics of India."*

3.3.4 Architecture of the bridges

The railway bridges gave rise to a new architecture based on engineering and science rather than empirical knowledge. Bridges are the most spectacular of all railway engineering works. In size, materials and position they made an unparalleled impact on landscape. Some of the bridges may remind us of such earlier works as the Roman aqueducts, but on the whole they represent a new architectural form unconnected with local traditions, though a few architects tried to merge the local art prominently at the bridge approaches.

3.3.5 Innovation

Early bridge engineers were highly innovative. They developed techniques to face the difficulties and challenges squarely. Some of them documented their experiences for the benefit of their brethren. Amongst the earliest technical papers published in India, bridges and river training thereof had lion's share. Briefs of some of these articles published from 1866 to 1876 give a glimpse of this rich literature:

- 1866; Geo. Broderick of East Indian Railway; 18 pages and 1 photograph describe the construction of Tonse Bridge near Allahabad consisting of lattice girders each of 150 feet span and piers on 12 wells.
- 1870; Edward W. Stoney of Madras Railway; describes construction of Pennair Bridge, 1680 ft long, 24 spans of 64 ft each, and superstructure made of wrought iron plate girders.
- 1870; Imrie Bell of Delhi Railway; describes the Yamuna Bridge at Sirsawa near Ambala and the innovation - use of `sand pump' in sinking of wells, sinking 6 ft in 8 hours.
- 1870; Alexander Robert Terry of Great Indian Peninsula Railway; restoration of the Mhow Ke Mullee Viaduct on Bhore Ghat line washed away in a violent storm in 1867 and construction of a new viaduct from 1868 to 1870.
- 1872; George Woodbridge of Oudh and Rohilkhand Railway; a memorandum of a hand dredger for sinking wells, invented and patented by W. Bull, Resident Engineer of ORR.

- 1873; R.T. Ives, Engineer of Public Works Department, Punjab; describes his patented excavator used on the Beas Bridge Works on the Sind, Punjab and Delhi Railway.
- 1874; W. Bull of Oudh and Rohilkhand Railway; describes his very simple fixed clay cutter.
- 1874; Edward Byrne, M.I.C.E; an analysis of factors causing disasters on some of the well-known bridges in India.
- 1874; C.H.G. Jenkinson of Rajputana State Railway; an analysis of Warren, Whipple Murphy and other types of trusses for bridges and their suitability for meter gauge lines.
- 1874; W.H. Pitt of P.W.D., Bombay, suggests his design for a dredger for deep well digging.
- 1876; author not mentioned; the floods of 1871 damaged a number of piers of Yamuna Bridge, Sutlej Bridge and Beas Bridge, the author gives some river training works undertaken on these rivers.

These are only a few samples to show the enthusiasm of Railway Engineers of that time on river training and bridge works, something novel for them on the Indian soil. Bridges were the most spectacular of railway engineering and architecture on Indian Railways a century ago and it continues to be so at the close of this millennium. To illustrate this statement, an example:

The bridge over river Sone near Arrah had a chequered history. Construction was started in 1856, disrupted during the risings of 1857 and was completed in 1862. The opening ceremony was performed by Lord Elgin, the Viceroy, who paid tribute to the achievement with these words: 'this magnificent bridge was exceeded in magnitude by only one bridge in the world'. It was indeed a triumph for the pioneer bridge builders in India. It remained the longest bridge in the Indian subcontinent, till it was eclipsed by the Upper Sone Bridge in the twentieth century. The bridge was designed by James Meadows Rendel, the consultants and the distinguished architect Sir Matthew Digby Wyatt, both associated with EIR. The total length of the bridge is 4726 ft, made up of 28 decked wrought iron spans, each 150 ft long, or 162 ft from centre to centre of piers, which are each 12 ft thick, carried on three brick wells of 18 ft diameter, sunk to a depth of 32 ft below low-water into a stiff bed of yellow clay. Re-produced below is the beautiful account of this bridge written by Captain Davidson in 1868:

"The Sone River, rising in the elevated districts of Central India, traverses the plains of South Bihar, and discharges itself into the Ganges, near Patna, after

draining an area of nearly 23,000 square miles. Its extreme discharge in floods is said to be about 1.75 million cubic ft per second. ……..During the season of floods, the depth of water carried averages barely 20 ft, and it seldom exceeds 30 ft in the deepest parts. …….After careful examination of this formidable obstacle to the railway, a narrow point not far from the natural direction of the line was selected. Here the river was only about 4000 ft in width; and the banks were high and composed of clay, a bed of clay was also found by borings to underlie the sand across the whole width of the bed. It was at first proposed to construct a bridge of brick arches; but after some discussions, it was finally decided to adopt brick foundation-wells, with piers of similar material to support a superstructure of wrought-iron girders, each of 150 ft span, carrying the rails on the top, and having an ordinary roadway below. The foundation of the first pier sunk in the year 1856 was composed of a group of twelve brick wells, each 10 ft in diameter, laid close together in two rows of five, with additional wells at either end for the cutwaters. Initial work on the bridge was well in hand, when in July 1857, the native regiments at Danapur mutinied, and marching towards the west, overran the works. …

Work at the bridge site was of course suspended, and could not be resumed until November 1858, when operations had practically to be commenced de novo. The design for the pier foundations was now modified, and in place of the cluster of small 10-feet wells originally intended, the piers were founded on three wells, each 18 ft in diameter, built on very strong wrought-iron curbs, having vertical iron rods attached to them connected with horizontal rings of iron built at intervals into the brickwork. The foundation-wells were sunk into the riverbed to an average depth of 32 ft below low water, entering into a bed of stiff clay, and by the year 1860 construction work on all the piers was in full progress. As soon as the piers were completed, the girders were rapidly erected by the aid of a timber staging; and the bridge was virtually finished by the end of the year 1861, its final completion being unfortunately delayed by the loss of certain portions of the iron work in transit, so that it was not ready for traffic until the end of 1862. Lord Elgin, Viceroy and Governor-General, soon afterwards, in February 1863, officially opened the section of main line as far as Mughalsarai. The initial cost of constructing the Sone Bridge, which was completed for a double line of rails including protective works is given as 33 lakh of rupees."

3.4.0 BRIDGE LOADINGS

3.4.1 Railway bridges are designed to carry much heavier loads than their counter parts in highways. The railways bridges have to take much larger tractive and braking forces which are longitudinal forces in nature and come into action only at the time of ‘starting’ the train and ‘braking’. Though construction of railway bridges started in the early 1850s, there were no written guide lines, elaborating the forces to be taken in to account for design which first appeared only in the year 1892 in the form of 'Bridge Rules'. The design forces adopted were are indicated below:

Bridge loading of 1892

Gauge	**Year**	**Axle load**	**Remarks**
Broad gauge	1875	7.5 tons	Light
Broad gauge	1882	17.0 tons	heavy
Broad gauge	1886	14 tons	

Note: Trailing loads and longitudinal forces (tractive and braking forces) were not indicated.

From the above, it is seen that design axle load was reduced from 17 tons to 14 tons. The exact reason for this is not known but it may be for the reasons of economy in construction.

3.4.2 After the introduction of Bridge Rules in 1892, the bridge loadings were revised in the year 1903 when the axle load was increased to 18 tons (18.32 metric tonnes) and a trailing load (TLD) of 1.2 ton per foot was specified. In the first Bridge Standard Committee – Committee of Engineers to formulate various design standards- meeting held in the year 1925, there is a mention of standard 'B' loading of 1892. The 1903 loading has been defined as B+65%. It is quite possible that the loading specified in 1903 was 1.65 times of that specified in 1892. The standard 'B' loading of 1903 was not found adequate for carrying heavier loads and very soon the standards were revised upwards by 25% in the year 1908. The axle load was specified as 22.5 tons and the trailing load was also increased to 1.5 ton per foot (5 tonnes per meter). The longitudinal forces were still not specified. There is mention of BB&CI (Bombay Baroda and Central India) standard of 1916 in the 5th Bridge Standard Committee meeting minutes at page 25. This loading indicates two engines with 22.8 tons on each coupled axle followed by trailing load of 1.8 ton per foot.

3.4.3 Bridge Loading of 1926

The bridge loadings were thoroughly revised in the year 1926. The loading standards were indicated under three classes namely BGBL (Broad gauge branch lines), BGML (Broad gauge main lines) and HM (Heavy Mineral loadings). Details of loadings for each class are indicated below:

Bridge Loading of 1926

Class of loading	Axle load	Trailing load	Tractive forces	Braking forces
BGBL	17 tons (17.3 Tonnes)	1.5 ton per foot (5 Tonnes per meter)	25% of loads on coupled wheels of loco	20% of braked axle loads of loco plus 10% of other braked axles.
BGML	22.5 Tons (22.9 Tonnes)	2.3 T per foot (7.67 Tonnes per meter)	Same as above(Max TF 36.8 Tons for two locos	Same as above
HM	28 Tons (28.5 Tonnes)	Same as above	Same as above	Same as above

The loadings of 1926 continued for a very long time except that the HM loading was abolished in 1964.

3.4.4 RBGML loading of 1975

With the introduction of diesel and electric locomotives in 1960s, the existing bridges started facing a very different type of problem. The new locos were light in vertical loading but had much higher values of traction forces-longitudinal in nature. The bridges designed for BGML loadings had adverse effect on the substructure (the lower part of a bridge comprising abutments, piers and their foundations) while the effect on the superstructure (comprising girders and slabs) was less severe. In due appreciation of the facts, the Bridge Standard Committee, in its extra ordinary held in November 1966, recommended to revise the loading tables and also recommended that all new designs for girder spans and substructure be checked for BGML loading as well as for the revised loading for diesel and electric locos. However, these recommendations were not accepted by the Railway Board. The Railway Board directed that the loading standards for future should be evolved by the Research Designs Standards Organisation (RDSO) taking care to ensure that the heaviest locomotives with the largest trailing load were provided for. Board also desired to review the provisions for dynamic augmentation (impact forces due to speed) in view of the new types of diesel and electric locomotives which were more silent in working and created less impact forces. The Bridge Standard Committee in its extra ordinary meeting held in April 1974, discussed the new loading which was designated as RBGML 1975. The new standard of loading was lighter in vertical loads but considered higher longitudinal forces in the form of traction forces. The details of this loading are given below:

RBGML 1975 Loading

Maximum axle load of locomotive	22.5 tonnes	
Trailing load	7.67 tonnes per meter	With a maximum axle load of 22.9 tonnes
Max tractive effort (TE)	75 tonnes	For two locomotives
Braking force (BF)	20% of train load	

Note: Maximum span up to which TE remains more than BF is 44 meters

3.4.5 MBG loading of 1987

As the time passed and traffic increased on Indian Railways, the RBGML 1975 loading was also not found adequate for certain routes carrying iron ore and other minerals for which the bridge loading standards were further revised and a new hypothetical loading, known as MBG-1987 was evolved. This loading was adopted to construct bridges on specific routes only. Details of MBG-1987 loading are given below:

MBG-1987 Loading

Maximum axle load of locomotive	25 tonnes	
Trailing load	8.25 tonnes per meter	
Max tractive effort (TE)	100 tonnes	For two locomotives
Braking force per loco axle (BF)	25% of the axle load	
Braking force of train load	13.4% of train load	

Note: Maximum span up to which TE remains more than BF is 55 meters.

3.4.6 Gauge Conversion (GC) loading

Large scale conversion of Meter gauge track to Broad gauge was undertaken in 1990s which needed heavy strengthening of existing bridges when checked for the RBGML -1975 standard of loading. To get over the problem, a new light type of loading was considered known as Gauge Conversion (GC) Loading. This loading was meant for a very limited purpose, for strengthening of existing bridges on Meter gauge routes sanctioned for Broad gauge conversion. Details of this loading are given below:

Gauge Conversion (GC) Loading

Vertical load	**One WDM2 loco or two WDM2 locos followed by BOXN wagons, trailing load of 7.59 tonnes per meter**
Tractive Effort	60.9 tonnes for two locos

3.4.7 HM loading of 1995

The loading standards were upgraded further in the year 1995 to take care of future heavy axle load locomotives and heavy haul operations. The tractive effort of locomotives went up to 135 tonnes (for three locos). This loading was known as HM-1995, details of which are given below:

HM Loading -1995

Locomotive combination	**Single/ double**	**Three locos**	**Four locos**
Axle load	30 t	30 t	30 t
Tractive Effort (TE)	60 t per loco	45 t per loco	30.45 t per loco
Max TE	120 t	135 t	121.8 t
Braking Force	25 t per loco	25 t per loco	22 t per loco

Note: Maximum span up to which TE remains more than Braking force is 75 meters

3.4.8 25 Tonne loading of 2008

In the meantime another series of high power locomotives were introduced on the Indian Railways. The HM of 1995 loading did not satisfy the characteristics of newly introduced high power locomotives which were lighter in vertical loads compared to HM-1995 loading but had much higher values of longitudinal traction forces. The loading was therefore once again revised where vertical loads were reduced and the longitudinal forces were increased.

Details of this loading which was designated as 25 tonne loading of 2008, are given below

25 t loading of 2008

Axle load	25 tonnes
Maximum TE for single loco	84 tonnes
Maximum TE for two locos	126 tonnes
Trailing load	9.33 tonnes per meter
Braking force per loco	25% of axle load
Braking force of train load	13.4 % of train load

Note: Maximum span up to which TE remains more than Braking force is 75 meters

3.4.9 Dedicated Freight Corridor (DFC) loading of 2008

Keeping in view the ever increasing goods traffic and need to have better average speeds of goods trains, the Government of India sanctioned work of two dedicated freight corridors from north to west and the other one to east. These dedicated routes are under construction at present and are supposed to carry large volume of goods traffic. For design of bridges on these routes, a new heavy bridge loading was evolved. This was to be used only for the specific routes. Details of this loading are given below:

DFC loading of 2008

Axle load	**32.5 tonnes**
Maxm TE for single loco	84 tonnes
Maxm TE for double locos	126 tonnes
Trailing load	12.13 tonnes per meter
Braking force per loco	25% of axle loads
Braking force for train load	13.4% of train load

Note: Maximum span up to which the TE remains more than Braking force is 65 meters.

3.4.10 Summary of loading standards

Loading	Axle loads	Trailing loads
Br rules of 1892	7.5 Tons (1875) 17.0 Tons (1882) 14.0 Tons (1886)	Not mentioned
1903	18.0 Tons	1.2 T per ft
1908	22.5 Tons	1.5 T per ft
1926	17.0 Tons BGBL 22.5 Tons BGML 28.0 Tons HM Tractive Effort (TE) 25% of coupled wheels of locomotive	1.5 T per ft 2.3 T per ft 2.3 T per ft
1975 RBGML	22.5 tonnes, TE 75 tonnes, Braking Force (BF) 20% of train load	7.67 t per meter
1987 MBG	25.0 tonnes TE 100 tonnes, BF 25% of axle load of locomotives +13.4% of train load	8.25 t per meter
1995 HM	30.0 tonnes, TE 60 t per loco for single and double locomotives, 135 for three locos and 121.8 t for four locos BF 25/22 t per loco	12 t per meter
2008 (25t)	25 tonnes, TE 84 t for single loco , 126 t for double locos BF 25% of axle load of locos, + 13.4% of train load	9.33 t per meter
2008 (DFC)	32.5 tonnes, TE 84 t for single loco, 126 t for double locos BF 25% of axle load + 13.4% of train load	12.13 t per meter

3.5.0 CONSTRUCTION MATERIALS

3.5.1 During the early part of construction of railways in India, the material science was not so developed. Wood, stone and bricks in lime-surkhai mortar were the materials used extensively in bridge construction. Use of timber was limited as beams in small span bridges only. Sal ballies were used as pile foundation, mainly in temporary restoration works.

3.5.2 Stone was used extensively in foundations, abutment and piers and also in arch rings. Stone was also used as slab for small spans. Choice of bricks or stone was largely dependent on economics of availability of the material locally. However, in large span arch bridges, stone was invariably used for arch rings. In the northern and eastern parts of the country, use of soft stone has been observed. However, in the southern and western parts, we find generally hard stone such as basalt and granite. In the coastal part of the country, use of laterite stone has been found on wide scale. Because the laterite stone has softer part, it was found to loose strength over a period of time due to leaching. Such bridges built in laterite stone are being gradually replaced.

3.5.3 During the middle of nineteenth century, iron came up very fast as construction material used in a wide variety of structures including bridges. In earlier bridges we find extensive use of wrought iron, both in plate girders and also in triangulated open web girders. As the time passed, steel replaced the wrought iron. But the manufacturing process of steel was not that perfect till the end of nineteenth century, resulting in failures of girders prematurely. It was observed that in the early steel girders, fatigue cracks used to develop well before the life of the girders. This was analysed and it was found that the cracks were due to high local concentration of sulphur and phosphorus although the average quantities of these impurities was well within permissible limits. As a policy, Indian Railways decided to replace all such girders which were built prior to the year 1905 by modern type of steel / concrete spans. Recently, use of high tensile steel of weldable quality in main structural members of the girders including welded joints has made it possible to use longer spans going up to 125 meters.

3.5.4 Reinforced Cement Concrete (RCC) was another material which found greater favour with Railway Engineers in construction of bridges in the early part of the twentieth century. However, to begin with, only small size bridge slabs were cast both pre-cast and in-situ. Use of plain RCC in larger spans was not found feasible due to its poor strength in tension and therefore requiring very heavy sections. A revolutionary and path breaking achievement was witnessed in Concrete technology in the year 1928 when Eugene Freyssinet, a French engineer introduced Prestressed Concrete which was ideally suited for construction of long span bridges. However, initially the use of PRC girders was restricted to smaller spans. The first PRC girders were used in three bridges with spans ranging from 12.8 meters and 19.2 meters in the year 1949 near Siliguri, on Assam Rail Link.

3.6.0 TYPES OF BRIDGES AND METHODS OF CONSTRUCTION

3.6.1 **Super Structure**

3.6.1.1 In the initial years of the history of Railways in India, not much problems were faced in the construction of bridges. Spans were limited so was the choice of construction materials. For very small spans, especially for small irrigation channels, open top and pipe bridges were adopted. Use of earthen pipe was abundant in pipe bridges. For medium sized openings, arch bridge was the preferred choice as the technology of construction of arches was already available and used widely in construction of buildings and aqueducts. For design of arch rings, thumb rules were adopted as no proper analytical methods were available. Arch bridges have been provided from 1 meter (3 feet) to 18 meters (60 feet). While for smaller arches, good quality brick masonry was used, for larger spans, locally available stone was the preferred material of construction. Bridge no 13 on Tundla- Agra section of North Central Railway is one of the arch bridges where arch span has been provided with 27.43 meters (90 feet) opening, probably the largest arch span in the country. Bridge no 208 on Howrah-Burdwan main line section of the Eastern Railway is the longest arch bridge in the country. This bridge has got 254 spans of arches, each with opening of 3.6 meters (12 feet), totaling 954.9 meters (3133 feet).

3.6.2 With the wide use of wrought iron in construction, larger spans were possible to bridge bigger steams and rivers. Plate girders with spans ranging from 3.6 meters (12 feet) to 30 meters (100 feet) were provided for smaller streams to larger rivers. However, for larger rivers with erodable rivers bed material (sand and silt) deeper foundations were needed to take care of the scour at high floods. For spanning such major rivers, plate girders were not found to be economical due to their restricted spans. For such rivers, open web triangulated girders were adopted where spans were going up to 60 meters (200 feet). Examples are Yamuna bridge near Allahabad and Delhi. For such larger spans, girders were fabricated in pieces and transported to the site as such. Erection of girders was done, span by span, using very elementary methods. Supports were provided at each nodal point for laying the bottom chord first. Camber jacks were used to provide necessary camber in the girders at the nodal points. After that verticals and diagonals were fixed followed by the top chord which required use of slings. This operation was possible in dry riverbed conditions only, limiting the time for erection. In some cases where complete dry conditions were not available, water channel used to be diverted for completing the work in those stretches.

Girder erection in dry river bed using supports at nodal points

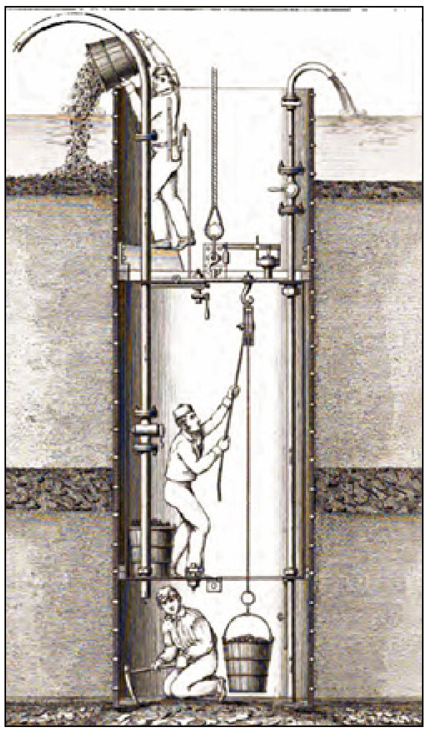
3.6.3 For very large rivers, where water used to flow through out the year, a different method of erection was followed. Girders were erected on the approaches and pulled longitudinally to bridge the gap. This required fixing of a launching nose, a cantilever service girder in front of the main girder. In case of multi spans, other girders were connected in series one after the other Special arrangements were required for sliding the girders, using double headed rails and steel balls. This method could not be used for very wide rivers due to limitation of pulling force required.

3.6.4 For very wide rivers, balanced cantilever launching was used. This required starting the work from piers, and members added in either direction equally maintaining the balance. The girders acted as cantilever till they met with the other part in the middle of the span. This method required a very high level of precision in fabrication and in erection work at site. The final camber in the girders depended purely on the degree of precision. A number of major rivers were bridged and are being bridged even presently following balanced cantilever erection method.

3.6.5 In tidal rivers, advantage is taken of the rise of water level during high tides. Girders are assembled / cast completely on the approaches and loaded on the floating barges. The barge is brought to the final position and made to wait for high tide. As the water level rises during high tide, the barge also gets lifted along with the girder. Thereafter the barge is shifted laterally to bring the girder in final alignment of the central line of the bridge. As the water level recedes, the girder finds itself supported on the bearings. This method requires a very detailed and thorough planning and swift action during high tides, as the time available may be limited. Construction of Thane creek bridge has been done using this method.

3.7.0 FOUNDATIONS

3.7.1 Early bridges were provided with ‘open type’ foundations for small depths where scour was not a problem. In cases where deeper foundations were needed on consideration of scour during high floods, ’well foundations’ were provided.



The technology of construction of wells was already developed in the country. For ease of sinking the wells, a steel cutting edge was fixed at the bottom. The cutting edge is first placed on a dry patch in the river bed, where the pier is to be constructed. The, masonry is added on to this for about 3 to 6 meters in height at a time. Sinking is then done by scooping (dredging) the earth from inside the well. As the earth is dredged out, the well sinks under its own weight. There are many types of dredgers but usually ‘Bell’s dredgers’ are mostly used. Vertical load is also kept on the top of the well when the rate of sinking is less than the desired level. The cycle of adding masonry and sinking continues till the bottom of the well reaches the designed level.

During the sinking process, wells may go out of plumb, which is corrected by manipulating the dredging sideways or using other specialized methods such as water jetting etc. For water jetting, steel pipes are pre-embedded in the steining of the well.

In the earlier bridges, wells have been constructed in good brick masonry. Quality of the bricks used was so good that even today, after more than 100 to 120 years; the foundations of such bridges are giving good service (examples- Yamuna bridge near Delhi and Allhabad, Malviya bridge near Varanasi/Kashi). With the advent of reinforced concrete, the modern bridges are now being provided with concrete wells.

3.7.2 **Well sinking with caissons**: In cases where it is not possible to find a dry patch in the river bed, use of caissons is made for the sinking. Caissons are steel structures which can float in water. They have a cutting edge at the bottom and side plates to cast concrete for steining wall. The caissons are floated to the final position in deep water and placed on the river bed by adding weight at the top. Height of the wall of caissons is such that it projects above the water level.

3.7.3 **Pneumatic well sinking:** In situations where it is difficult to dredge earth from inside of the well using dredgers due to presence of hard strata of clay or rock, the excavation is done by drilling or blasting. This requires lowering of water level by pressurised air. This is known as pneumatic sinking. A closed chamber from the top and open at the bottom is pressurised which lowers the water level and provides a dry space for drilling or blasting operations. Workers have to work in pressurised environment for which they have to pass through pressure chambers while going down and also coming out. Also the working hours for the workers under pressure have to be limited. Second Godavari bridge is a good example of use of pneumatic sinking.

3.7.4 **Pile foundations:** Pile foundations have also been provided in railway bridges. However, due to slenderness of piles, these are not suitable type of foundations in rivers where bed material is liable to scour during high floods. Pile foundations are generally provided in restoration of traffic where temporary bridges are constructed in flowing-water conditions. However, in such cases piles are adequately protected by dumping stone boulders.

Bored Pile on a dry patch

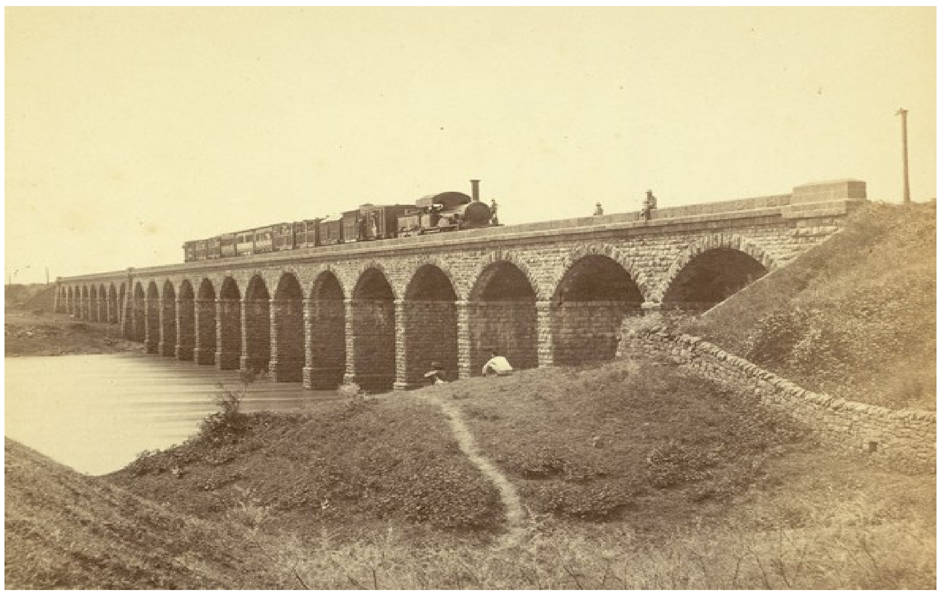
Pile driving in river

Pile foundations have been used widely in recent times in viaducts where flowing water is not a problem. Examples of use of piles in permanent bridges are Zuari bridge, Mandovi bridge near Goa on Konkan Railway and Vembanad rail bridge in Kochi.

3.8.0 IMPORTANT BRIDGES ON INDIAN RAILWAYS

3.8.1 Dapoorie Bridge

This bridge is located between Dapori and Khadki near Pune on Central Railway and was constructed in the year 1895. This bridge is situated across river Mula and has 21 spans of 7.42 meters (25 feet) The bridge has two clusters of arches, having 14 and 7 spans as can be seen from the photograph of the bridge.



A file photo of the Dapoorie bridge

3.8.2 Br no 541 (multiple tiers Arches) at Km 64/ 15-16 on Kalka Simla narrow gauge line

The bridge was constructed in the year 1898 along with the construction of the Kalka Simla narrow gauge line to facilitate transfer of huge number of staff of the Government to Simla which was the Summer Capital of India. It is a multi tier (4 tiers) battery of arches. Total height of the rail level above the bed is about 23 M. One of the important features of the bridge is that it carries track on a reverse curve of 48 degrees (36.4 meter radius). The arrangement of spans in four tiers was a great ingenuity which took care of the problem of slenderness of piers. The construction was done in stone using locally available material. There are several bridges on Kalka- Simla route using this unique technique where the number of tiers depended on the width and depth of the gorge to be bridged.

Technical details

Total length – 52. 9 M

Spans:

Tier 1: 1x0.52 M + 4x 2.90 M + 1x0.75 M

Tier 2: 2x2.74 M + 3x 2.9 M

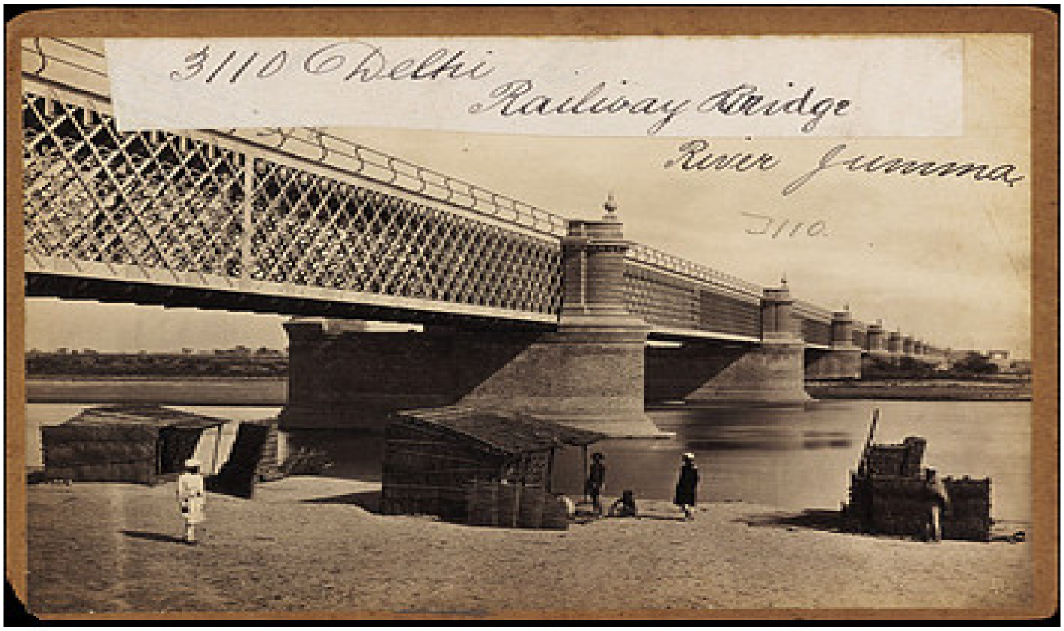
Tier 3: 1x 0.75 M + 2x 1.00 M + 1x 3.05 M + 4x 3. 25 M + 2x 3.40 M

Tier 4: 1x 1.25 M + 2x 1.29 M + 1x 3.70 M + 5x 3.65 M + 4x 3.8 M

Total no of spans = 34 spans in 4 tiers

3.8.3 Yamuna Bridge No 249 (old Yamuna bridge) near Delhi station

The old Yamuna Bridge was constructed in the year 1866 by the East India Railway at a cost of £16,16,335. It has a total length of 2,640 feet and consisted of 12 spans steel open web lattice type girders of 200 feet span each. With the completion of this bridge, two principal cities of the country, Kolkata and Delhi, were connected by the Railways. In 1913, the bridge was converted into a double line bridge by adding down line girders, 12 spans of 200 feet each and 2 end spans of 40 feet. It is a double deck bridge with railway tracks on the upper deck and road on the lower deck. Foundations of the bridge are with brick wells which are resting mostly on the rock of shallow depth. Originally, the girders of the bridge were of early steel which were replaced in 1933. Shallow foundation of the bridge posed repeated problems in the past requiring temporary closure of the bridge for traffic. The bridge is being replaced by a new one close to the existing alignment on the downstream side.

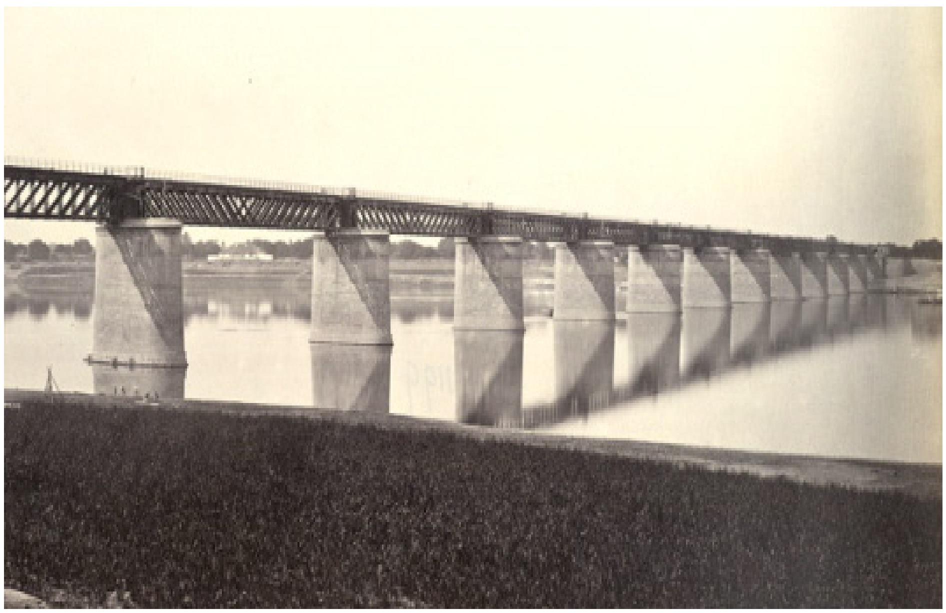


A rare photograph of the Yamuna Bridge at Delhi

Bridge at high flood

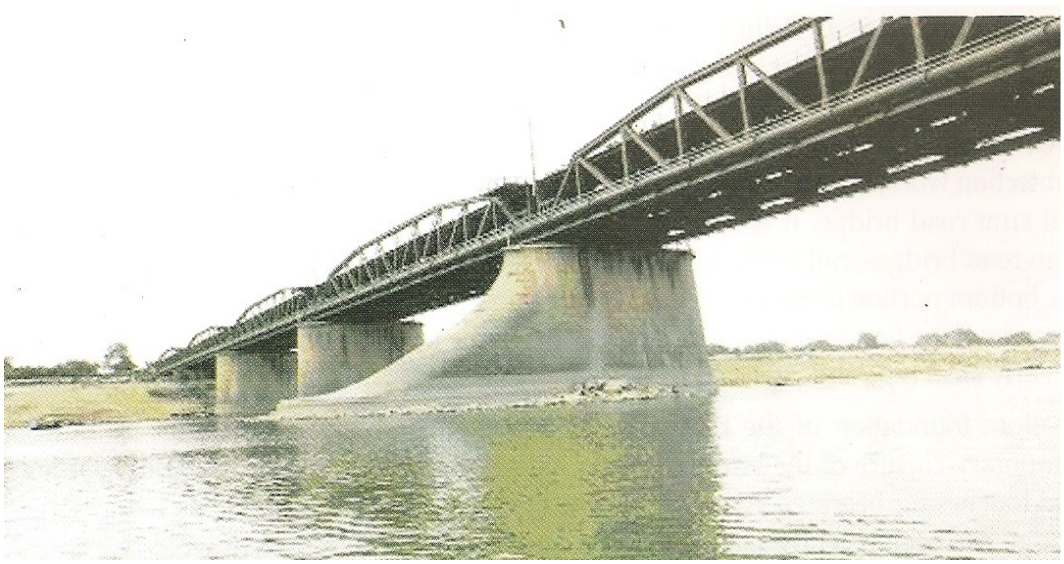
3.8.4 Yamuna bridge no 30, Allahabad

This bridge is located on Mughalsarai- Allahabad section of North Central Railway (NCR). Location of this bridge was decided in 1855 but actual work started only in the year 1859. The first train on this bridge ran on 15th July, 1865. The bridge is having 14 spans of 61 meters (200 ft), triangulated girders and two spans of 8.8 meters plate girders plus one arch span of 9.18 meters. Originally the bridge was constructed with lattice type girders for single line track. At the time of regirdering, it was made a double decker with railway track on the upper level. Maximum discharge at the bridge is estimated as 43000 cumecs (15 lakh cusecs) with maximum velocity of 3.5 m per second.



An old photograph of Yamuna Bridge Allahabad

Yamuna Bridge, Allahabad (at present)



Yamuna bridge, Allahabad Pier no 13 from Mughalsarai end has a unique shape

Sub structure of the bridge is on brick masonry wells with lime mortar having depth varying from 12 m to 27 meters. By August, 1862 all the wells were almost completed except well for pier no 13 (from Mughalsarai end). It gave trouble and a coffer dam had to be built for rectification. The water was lowered 3 m below the low water level, the well was cut down and flooring of large ashlar stone was laid. On this an arch of stone masonry was sprung, 16.5 meters diameter, over which the pier was constructed. About 2.5 million cubic feet of masonry and brick work was used in the construction of the bridge.

3.8.5 Rajendra Setu (Mokama Bridge)

The bridge is situated across river Ganga near Mokama It is a rail cum road bridge. Prior to construction of this bridge, between the Malviya bridge at Varanasi and Harding bridge at Sara, now in Bangladesh , there was no bridge over the river Ganga. Necessity of one bridge at suitable location near Patna was felt since 1907. After formation of East Pakistan (now Bangladesh), in the year 1947 rail traffic to Assam which earlier went via Harding bridge , was disrupted. This necessitated construction of a new bridge near Mokama. The bridge was sanctioned in the year 1953 and construction was completed in the year 1959. In honour of the first President of India Dr Rajendra Prasad, the bridge was named as Rajendra Setu.

This was the first important bridge constructed by railway engineers after independence. It has been playing a vital role in socio economic development of the country especially of Bihar state. The bridge caters to a catchment area of 750000 square kilometers. The bridge has 14 spans of 119 meters along with 4 spans of 31 meters, 2 on either side. On north side, a guide bund of 1600 meters on upstream and 300 meters on down stream side were constructed. Bridge is having double D well foundations of 16mx9.5 m size.

Super structure of the bridge is for a single line broad gauge railway track on the lower deck and two lanes for road traffic on the intermediate deck. The girders are double decker Warren type with depth of 18 meters.

The girders of this bridge were designed by Freeman Fox and Partners of London. Fabrication of steel work was assigned to M/S BBJ of Kolkata. Main members of the girders are fabricated with high tensile steel. Total weight of steel used in superstructure was 13287 tonnes, out of which 6819 tonnes were of high tensile quality.

3.8.6 Pamban Bridge

This bridge connects the Rameshwaram island to the main land. The bridge popularly known as "Pamban viaduct" (Bridge No. 346) was constructed between August 1911 and December 1913. It was opened for traffic in February 1914.

Prior to the construction of this viaduct, traffic between India and Sri Lanka was conducted through Tuticorin. With the completion of this bridge, a ferry service was started between Dhanushkodi and Thalaimannar in Sri Lanka.

Pamban rail bridge –in closed position

Pamban bridge –in open position to pass a vessel

The construction of the bridge was carried out under the direction of Mr. J.J. Lewis, an Englishman who was the Chief Engineer, and Mr H.P.O. Shaughnessy Executive Engineer of Southern Railway. The bridge is 2.057 km long with 145 spans of 12.2 m girders and a two leaved, rolling lift bridge, also known as 'bascule' type bridge which is of 60.9 m in length. It was known as Scherzer rolling lift bridge named after Scherzer Company of Chicago who designed it. The depth below the bridge is 3.65 m and the navigation channel is known as the Pamban Pass.

Devastating cyclone of 22nd December 1964 washed away 124 spans of the bridge, leaving behind 19 spans on Mandapam end and the main Scherzer span. Restoration work commenced almost immediately and with vigorous efforts, by pooling all resources of the railways, it was possible to completely re-girder and restore traffic within a short period by 1st March 1965 that is in less than 90 days. The railway line to Dhanushkodi was also damaged during the cyclone. For the passage of the vessels, the Scherzer span of the bridge is lifted. The entire operation which is done manually, takes nearly 40 to 50 minutes. Originally the bridge was carrying a single meter gauge track. However with the conversion of the route to broad gauge, the bridge was also modified to carry broad gauge track in the year 2007.

3.8.7 Second Godavari Bridge

The second Godavari bridge, a rail-cum road bridge, was constructed when the track was doubled between Kovvur and Rajahmumndry. Prior to this bridge , there was only one single line bridge called Havlock Bridge, constructed in the year 1897 by F. T. G. Walton under the guidance of Sir Arthur Cotton.

The bridge has a total length of 2.74 kilometers with 27 spans of 91.4 metres and 7 spans of 45.72 metres including 6 spans of 45.72 metres. Rajahmundry end of the bridge is located on a 6° to avoide the built up area in that reach. At one point of time this bridge was considered to be one of the longest bridge on Indian Railways. The bridge was constructed by Bharat Bhari Udyog Nagam Ltd and completed in the year 1972 at a cost of Rs 63 crore.

3.8.8 Godavari Bow and String Arch Bridge

The bridge also called the Kovvur-Rajahmundry Bridge, is the third railway bridge on the river Godavari at Rajahmundry. The arch bridge, made of bow-string girder arches in reinforced concrete was built between 1991 and 1997 at a cost of 72 crores of rupees. It was commissioned for passenger traffic in March 1997. The bridge is said to be one of the longest span PSC arch bridges in Asia and is considered an outstanding example of expertise of the Indian Railways.

The bridge, built by the Hindustan Construction Company, was designed by M/S Bureau BBR, Switzerland and checked by M/S Leonard Andrea and Partners of Germany.

The bridge is built across Godavari River as it enters into the deltaic reach before entering into the sea. At the location of the bridge, the river flows in a width of about 3 kilometres, split in two channels with an island formation in between. The bridge is located in a cyclonic area where the wind speed could touch 200 kilometres per hour.

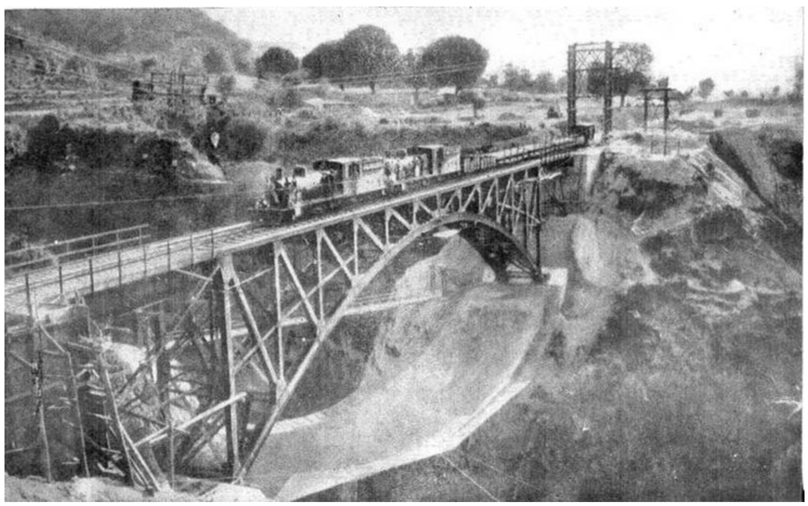
Initially when it was decided to build the bridge to replace the first Godavari Bridge, the planning was to provide girders made of steel. The issue was reviewed and it was decided to examine the possibility of evolving a prestressed concrete (PSC) bridge with a 97.55 metres span. Of the three firms who were shortlisted to submit offers, two firms opted for the concrete bridge option and one for the steel bridge option. The offers received from the three firms were examined and the design offered by M/s. Hindustan Construction Company Ltd was accepted. The Godavari Arch Bridge is of the bow-string girder type bridge comprising prestressed RCC twin arches of 800 millimetres width with depth of arch ring varying from 1,700 millimetres at the springing to 1,150 millimetres at the crown. The arches are connected laterally with RCC struts. There are 28 identical spans of arches, of 97.552 metres span from centre to centre. The arches are of parabolic profile built in reinforced concrete of M 45 grade . The girders were desiged for MBG loading of 1975. The projected speed for the trains is 160 km per hour.

The deck of the bridge which is in the shape of box girder were cast in M 42 grade concrete. Each girder was prestressed with 16 longitudinal cables to a force of 2950 kN each. The BBRV system of prestressing was used for the permanent stressing of girder as well as temporary prestressing during construction. The slab was provided with 24 lateral cables which were also prestressed. The design of the girder accounted for loading conditions of full span train load, half span train load, one third span train load and so forth with due accounting of temperature variation of ±10 °C . Each span of the bridge has 24 hangers, 12 on either side. Each girder is supported on four pot bearings of 1050 tonnes capacity. Three sets of bearings were imported from Switzerland, while the balance bearings were made by M/s. BBR (India) Ltd.

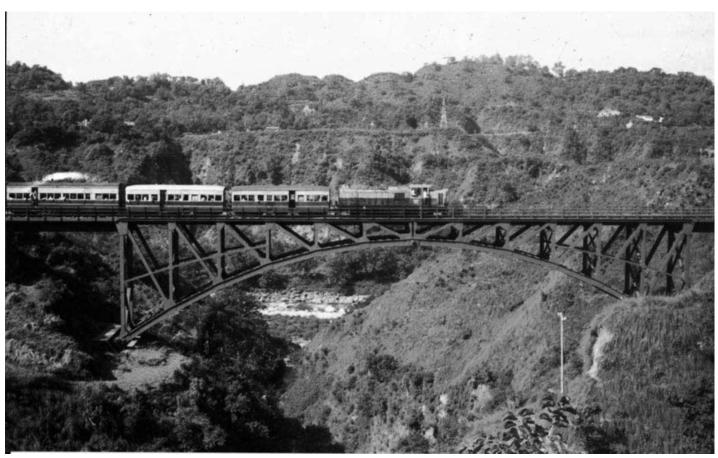
3.8.9 Steel Arch Bridge no 549 across Reond Nallah (KVR)

The steel arch bridge no 549 on Kangra Valley Railway of Northern Railway is an engineering feat, considering the time when the bridge was erected. The steel arch, sited in a spectacular position, bridges a deep precipitous nullah with almost vertical sides rising to about 60 meters above the nullah bed and spans over an opening of 80 meters. The arch is a three pinned spandrel braced type, only one of its kind in the country, 54.86 meters centre to centre of bearings and is approached by 12.2 meter girders on either end. The arch having 9.44 meters rise (crown height) was designed for a single line meter gauge loading. Keeping economy in view, the floor system was designed for only a narrow gauge(760mm) track. The arch was fabricated by Braithwaite & Company at their Mulund Works in Mumbai. The weight of the girder is 230 tons, together with erection towers, anchors for the cable-ways and general erection gears.

The cable way, was erected on towers 12.5 m above rail level and positioned 120 meters apart. A traveller suspended from the cable and carrying the tackle, worked by crab winches, handled three tonne pieces at one time. The bearings of the skew backpins from which the two halves of the arch were built up, were founded on massive concrete blocks. The setting of these bearings required very careful adjustment. Before concreting in, the heavy castings were mounted on a frame work of mild steel which permitted location of the pins to the nearest 0.4 mm accuracy.



The arch girder of the bridge under test train

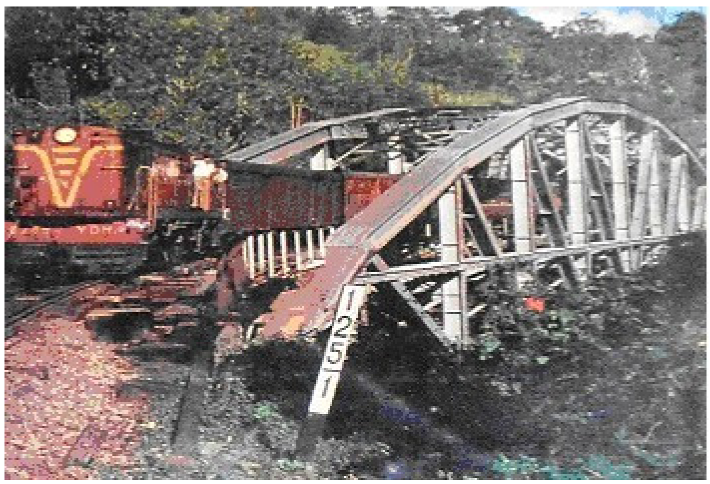


Diesel loco headed train passing over the bridge

The erection work on the bridge started on December 10, 1927 and was completed in six weeks. The perfect fabrication and erection of steel members of the arch is a tribute to the Railway Engineers of that time.

3.8.10 Dhanuk Steel Arch Bridge on Lumding – Badarpur section of N F Railway

This steel arch bridge is located on Lumding Badarpur hill section of North East Frontier Railway. It has main arch girder of 106 m span. Originally the bridge was having 2 spans of 12.32 m+1 span of 30.5 m+ 5 spans of 12.2 m span on 10 degree curve alignment.



A goods train passing through the bridge

The piers that carried 5 spans of 12.2 m spans and the northern end of 30.5 m span were built on a spur which projected in to the valley crossed by the bridge. During the rainy season of 1915, the spur moved towards the bed of the stream, more or less diagonal to the alignment of the bridge. All the piers on the spur were displaced by about 2 meters and wre leaning heavily to one side . A 106 meter span arch girder was built to replace shorter girders due to uncertainity of obtaining stable foundations for shorter spans. The design and working drawings of the girder were provided by consulting Engineer M/S Randel, Palmer and Triton of England. Erection of the girder was completed in 1920-21.

3.8.11 Jubilee Bridge

Jubilee Bridge no 8 is an important bridge between Naihati and Bandel on Eastern Railway. The bridge was opened on 16 February 1887 at a cost of Rupees 39 lakh, in the fiftieth (jubilee) year of the reign of Queen Victoria hence named as Jubilee Bridge.

The bridge has three spans , two end spans of 164.6 meters and one central span of 36.7 meters. The middle arh girder is having cantilever ends on both sides. Total length of the middle girder is 109.9 meters including two cantilevers of 36.6 meters each which project both sides beyond the piers. On either end of the main bridge, there are viaducts of length 999.13 meters and 134.42 meters respectively constructed as masonary arch spans, having a total 141 spans, varying fom 3 to 15 meters.

The Bridge was designed by Sir Bradford Leslie, Chief Engineer in India, and Alexander Meadows Rendel. The construction work started in 1882 and completed in 1887 under the charge of Lt Col Arthur John Barry, Chief Engineer in charge of construction. Fabrication of girders was done by Hawks Crawshay of Gateshead in England and James Goodwin of Motherwell in Scotland. The size of caissons used was 22.1 m x7.6 m. A serious accident took place on 26th April, 1884 to caisson no 1 due to extra orinary tidal waves. The caisson was torn away and carried for a distance of one kilometer away upsteam and grounded on the west side of the channel. However during another tide, which was even stronger, the caisson structure was brought back to its original position.

The bridge is currently planned to be phased out and a new rail bridge is being built adjacent to it to be named as Sampreeti Bridge. The Jubilee Bridge is unique in its type and as it's one of the oldest rail bridges in India.

3.8.12 Saraighat Bridge over Brhmaputra river

Saraighat Bridge is the first rail-cum-road bridge constructed over the Brahmaputra River near Guwahati. The site of the bridge was selected as the banks were relatively stable and the river width was also minimum.

Construction of the bridge started in January 1958 by the Hindustan Construction Company and was opened to goods traffic in Oct, 1962 and opened for passenger traffic on 7 June 1963. The estimated cost of the bridge was Rs.10.65 crore. The idea of construction of a bridge over the river Brahmaputra was first mooted in 1910 and the thought gathered momentum during the Second World War. But there were doubts over the stability of the Railway line between Bongaigaon and Amingaon following devastating floods in 1942-43.

The girders of the bridge are designed for two meter gauge tracks or single broad gauge track. However, presently it carries one broad gauge track and a meter gauge track located in the middle of the broad gauge track. The bridge carries 7.2 meters wide road on the intermediate deck Double warren type girders with high tensile steel main members along with sub-verticals having 18.3 meters depth (equivalent to the height of a six storey building) have been provided. The bridge has ten spans of 122.95 meters span and two approach spans of 33.2 meters length. Total length of the bridge is 1492 meters. Total weight of the girders is 11115 tonnes. Foundations of the bridge are with double D type cement concrete wells of 16.31 x9.75 m size with steining thickness of 1.52 meters. A 12.2 meters clearance is kept from the normal high flood level to ensure free navigation under the bridge.

3.8.13 Naranarayan setu near Jogighopa

This bridge is located on the new line on the south bank of the river Brahmputra connecting New Bongaigaon- Jogighopa to Guwahati. The bridge was completed in April 1998 and was the second railway bridge on the mighty river Brahmputra. The bridge consists of 17 main spans of 125 meters, one span of 94.6 meters and two spans of 32.6 meters. The bridge is a rail cum road bridge with road on the upper deck and provision for two railway tracks on the lower deck. Main members of the girders are of high tensile steel while secondary members are of mild steel. Girder erection was done by cantilever erection mehod, starting from the abutment. As the bridge is situated in high seismic activity area, special arrangements have been made on each end cross girder to prevent dislodgement of the main girder during intensive seismic activity. Bearings of the girders have been designed with meticulas care considering forces and movements at the support for maximum forces including seismic forces. Design of the truss and the floor system is based on space frame analysis using computer programme.

Naranarayan setu across Brhmaputra river near Jogighopa-under construction

Naranarayan Setu-view of completed bridge

The bridge used a total of 18640 tonnes of high tensile steel and 10345 tonnes of mild steel. The piers are resting on concrete well foundations of double D shape of size 17m x 11m. Total length of the bridge is 2.284 km. Length of guide bund on the north side is 850 meters and on the south side 478 meters. The bridge is designed for a maximum discharge of 90400 cumecs (32 lakh cusecs).

3.8.14 Malviya Bridge near Varanasi

Malviya bridge, originally known as Dufferin bridge, number 11 on the Mughalsarai- Varanasi route of Northern Railway is one of the important bridges over river Ganga. This was the first bridge of its type constructed in the Indian Sub- continent by the Engineers of Oudh and Rohilkhand Railway (ORR) in the year 1885. The bridge has seven spans of 111.5 meters each and nine spans of 35 meters each. Originally the bridge was constructed as a single line bridge with rail and road at the same level. The bridge was originally named after Lord Dufferin, who inaugurated it on 16th December, 1887. In his inaugural speech he mentioned "*I imagine, I am right in saying that nowhere in India has a more difficult engineering task been performed than that whose triumphant accomplishment, we celebrate to-day. Now in connection with it can I resist the temptation of offering my humble admiration and my best congratulations to those eminent gentlemen whose knowledge of their* *profession, whose practical skill and whose fertility of resources have enabled them to triumph over every impediment and to master and enthrall the gigantic forces of nature with which they were contending*."

Work of regirdering of the bridge was sanctioned in the year 1939 for Rupees 78 lakh. Design work was assigned to M/S Raendell, Palmer and Tritton and fabrication of girders was given to M/S Braithwaite, Burn and Jessop Construction Company. Erection of the girder was handled by M/S Sham Singh and Company. The regirdered bridge was opened in 1947 with road deck at the upper level. After re-girdering, the bridge was renamed as Malviya bridge in honour of Pandit Madan Mohan Malviya, founder of the Benaras Hindu University (BHU) of Varanasi. The bridge is also known as Rajghat bridge.

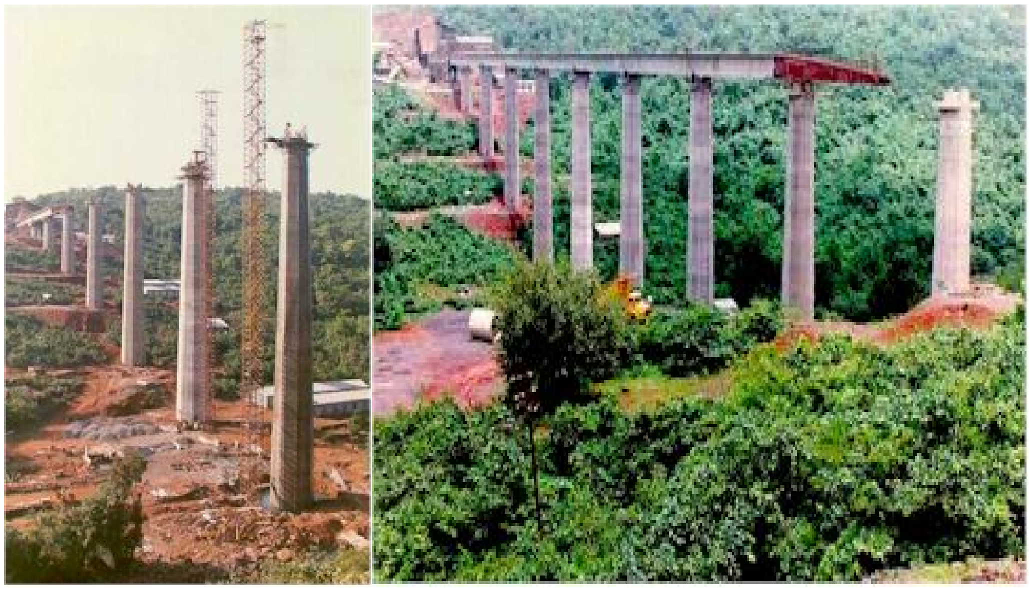
The bridge is having well foundations in brick masonry with depth ranging from 19 m (63 feet) to 67 m (220 feet) below the rail level. Both the abutments and the first three piers at the Kashi end are founded in clay while the remaining piers are on sand. Piers no 1,2 and 3 were provided with shallow well foundations as the construction engineers considered that the clay bed would be in-erodible . During the construction of the bridge, the overlying 9m (30 feet) layer of sand was completely washed away exposing the clay layer. In order to stablise the foundations, an island of kankar blocks pitching was done around each pier and repairs to these were carried out year after year. During the high flood of 1948, pitching around pier no 3 was completely washed away and was partially damaged around pier no 2. In the year 1950, further protection was provided around piers no 2 and 3 in the form of girdles comprising heavy cement concrete blocks of 2.44mx1.52mx0.6m (8x5x2 feet) weighing 4 to 5 tonnes each inter connected by steel chains. Since then the bridge has not posed any serious problem.

At the bridge site, the Ganga is flowing in a curve. On the upstream side of the bridge, famous Kashi Ghats of pucca structure are there up to 4-5 kilometers. For such an important bridge of mighty extent and even river flowing in a curve, no river protection works have been provided, however the bridge is performing quite well. The bridge has passed a discharge of 15.3 lakh cusecs for the highest recorded flood.

3.8.15 Panvalnadi Bridge On Konkan Railway

The 424m long railway bridge for single line of broad gauge track, constructed in the year 1994 is located near Ratnagiri of Konkan Railway. The bridge superstructure is a single-cell continuous prestressed concrete box girder with nine intermediate 40m spans and two end spans of 30m each. The substructure consists of hollow octagonal reinforced concrete piers resting on open foundations.

The tallest of the piers is about 64m above bed level. This makes Panval Nadi Viaduct the second tallest bridge in Asia. Construction of the prestressed box girder was the first use of the incremental launching technique in India. The bridge was cast in 20m segments at one of the approaches under a covered casting yard. The first segment was provided with a 30m long steel launching nose to reduce the stress in the box girder during launching. The piers were cast by slip form.



Bridge during construction phase

The bridge is anchored for longitudinal forces at the abutment on the Mangalore end while the expansion joint is on the opposite Ratnagiri end abutment. In 1995, this bridge received the Most Outstanding Concrete Structure in India Award from the American Concrete Institute (Maharashtra India Chapter) and also an award from the Indian Institute of Bridge Engineers.

3.8.16 Vembanad Rail Bridge at Kochi

Presently, this is the longest railway bridge in the country with a total length of 4.62 km. The bridge cuts across an island over the Vembanad lake. The bridge connects Edapally to Vallarpadam and is a part of the nearly nine km railway link built for Vallarpadam International Container Transhipment Terminal (ICTT). The bridge has 132 Pre-stressed Concrete Girders , 99 of 40 meters span and remaining 33 of 20 meters span. The piers are resting on piles of depths ranging between 45 to 55 meters. The bridge consumed 11,700 tonnes of reinforcement steel, 58000 tonnes of cement and 73500 cum of stone aggregates and involved earth work of 154308 cum.

View of completed bridge

The bridge has been constructed by M/S Afcons Infra Ltd through Rail Vikas Nigam Ltd (a PSU of Indian Railways), Construction of the bridge started in June 2007 and completed in March, 2010. The cost of the completed bridge along with track and other facilities has come to Rupees 350 crore.

3.8.17 Bridges over Zuari and Mandovi Rivers of Konkan Railway

Zuari (30x22.80m PSC+7x53.50m PSC Box+2x124.20m Steel G+1x10m RCC Slab*)* and Mandovi (*22x22.80 PSC-G +1x124.20 Steel G+6x53.50 PSC Box)* are the two most important rail bridges in Konkan Railway in Goa State. The construction of these bridges was quite intricate as foundations presented complex problems due to absence of rock strata and requirement of adequate navigational clearance. The two rivers flow in flat land with wide, shallow, estuarine creeks within the tidal zones. The rise of water at the highest tide was around three meters above the low water level. Scour was not a problem, as the high velocities were not generated due to absence of floods.

Keeping in mind the navigational requirement, two spans of 124.2m each, through steel girders with vertical clearance of 13.7m were adopted for the Zuari River. For the Mandovi main channel, it was decided to adopt one span of 124.2m, with 12m vertical clearance over the Navigational Channel. For other than navigational spans, it was decided to adopt 53.5m PRC box girders. All piers supporting the 124.2m steel girder spans and 53.4m PRC box girders were founded on wells while other girders on piles, 1.2m /1 meter diameter (four for each pier).

The weight of each girder was 665 tonnes and was fabricated in Central Railway workshops at Manmad. The manual metal arc, submerged arc and CO2 welding processes were adopted for fabrication. The operation of launching 124m girders by a unique method of using a floating crane was by far the most ingenious and extremely cost-effective.

Zuari Bridge

The piers of the Mandovi and Zuari bridges consists of two cylindrical RCC, solid piers, 2.5m diameter for 124.2m span, 2m diameter for 53.5m span and 1.5m diameter for 22.8m span. Reinforced concrete pneumatic caissons were used for well sinking due to several advantages associated .The Construction of bridges over Mandovi and Zuari were undertaken by AFCONS. Work on these bridges started in October 1992. and completed in December'95.

Mandovi Bridge

Well and Piling in progress

Launching of steel girders in progress

3.9.0 SOME IMPORTANT RAILWAY MEGA BRIDGES UNDER CONSTRUCTION

3.9.1 Bogibeel rail cum road bridge near Dibrugarh

The Bogibeel rail cum road bridge is being constructed across the River Brahmaputra in the Dibrugarh district, in the state of Assam in northeast India. When completed, the 4.94 km bridge will be the longest river bridges in the country. The work on the project began in 2002. The project is now scheduled to be completed by the end of 2015. The estimated cost of the project is Rupees 3378 crore. The bridge is located 17 km downstream of the town of Dibrugarh. It will connect Dibrugarh in the south to Lakhimpur in the north of the river. The rail-road bridge is the fourth being built on the river, the others being Saraighat, Kalia-Bhomara (only road bridge) and Naranarayan Setu at Jogighopa - all of them in Assam.

Bogibeel bridge- well foundations under construction

The Bogibeel Bridge is the longest structure being built on the River Brahmaputra. The bridge is a double-deck bridge with a two-line railway track on the lower deck and a three-lane road on the upper deck. It has 39 spans of 125 m and 2 spans of 32.75 meters, one on each end. The girders are having steel floor system for railway tracks and composite with concrete deck for road. Total quantity of steel consumed in girders is going to be approximately 68000 tonnes. Design of the bridge is another landmark in the history of railways bridges. The composite truss bridge is unique and different from the conventional bridges built in India. It is a complete welded steel truss with composite reinforced road deck. First time, all the joints are going to be welded joints. The design of the composite welded girders has been done by M/s Ramboll of Denmark through RITES and the proof checking done by M/s Anwikar Consultant of Germany. The girders shall be launched by incremental launching method. Some of the design provisions have been taken from the international bridge codes. The bridge is supported on 42 piers resting on well foundations of double D shape of 16.2m x 10.5m size. The piers are twin circular hollow piers of 5.5m OD x 3.5m ID. A navigation clearance of 100m width and 10 m height has been provided under the girders.

The bridge has guide bunds of 2792 meters length in the north and of 2043 meters length in the south. Flood dykes have been provided for 9 km on the upstream side and for 7 km on the downstream side.

The rail project comprises laying of 74 km of railway line, including the rail links on the south and north banks of the river. The rail line will be linked to Chowalkhowa, 5.83 km from Dibrugarh, on the south bank and between Sisi Borgaon and Sirpani on the north bank

3.9.2 Chenab steel Arch bridge on Jammu-Baramula-Srinagar new rail line

This bridge is under construction on Kashmir new line project and is situated across the river Chenab near village Salal. The main span of the bridge is in the form of steel arch of span 465 meters. The rail level will be 359 meters above the river bed. The approaches are on a viaduct of steel girders resting on concrete piers. When completed, this bridge will have the longest single arch span in the world.

Artist view of the bridge

The bridge will consume 25000 tonnes of structural steel in the superstructure. The concrete work will use 4000 tonnes of reinforcement steel and 43000 cum of concrete with 6 lakh cum of excavation in rock for foundations. The bridge has been designed for heavy wind forces due to being at a height. To finalise the design, model of the bridge was tested in a wind tunnel in Denmark. The bridge has been designed for blast forces also. A comprehensive scheme for monitoring the health of the bridge during service has been conceptualised.

3.9.3 Rail cum Road Bridge across river Ganga at Patna

A new rail cum road bridge is under construction across river Ganga connecting Patna to Hazipur. The bridge was sanctioned in the rail budget of 1997-98 as a rail bridge. However, in the year 2006, road was also added. Sanctioned cost along with road portion was Rupees 1389 crore, railway's share being Rupees 835 crore. Revised cost (up to second revision) of the bridge stood at Rupees 2921 crore, Railway's share being Rupees 1681 crore.

The bridge consists of 36 spans of 123 meters long and 2 spans of 64 meters, making a total of 4.56 km, When completed, it is going to be the second longest main line railway bridge in the country. Foundations comprise double D wells of size 18 x 9.5 m going up to depth of 51.5 meters. The piers are twin circular hollow piers with outer and inner diameters as 5.5 m and 3.9 m respectively. The girders are Warren type welded steel truss with railway track at the bottom deck and road at intermediate level, depth of girders being 18.5m. All components of the girders are welded with riveted joints. The bridge has been designed for MBG loading for railway.

Ganga Bridge under construction at Patna

3.9.4 Rail cum road bridge across river Ganga at Munger

The rail cum road bridge across river Ganga at Munger was sanctioned along with the railway bridge at Patna. The sanctioned cost of the bridge was Rupees 921 crore which has now increased to Rupees 2363 crore, railway share being Rupees 1247 crore and road share Rupees 1116 crore. Up to January, 2012, a sum of Rupees 613 has already been spent. The bridge has 29 girders of 125 meters span and 2 girders of 32.6 meters span.

Munger rail cum road bridge- sub structure under construction

The foundations of the bridge consist of double D wells of 18 x 11 m size and going up to depth of 55.5 meters. Piers are of twin circular hollow cylindrical shape, with outer and inner diameters as 5.3 m and 3.3 m respectively. The girders are Warren type welded steel truss with railway track at bottom level and road at intermediate level. Depth of girders is 18.5 meters. The designed loading for railway is 25 tonnes standard. All the components of the girders are welded with riveted joints.

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CHAPTER 4

RAILWAY STATIONS, BUILDINGS & TUNNELS

4.1 RAILWAY STATIONS AND PASSENGER AMENITIES

4.1.1 The railways in India commenced operations in 1853, i.e. about 160 years ago and most of the busy stations in major cities came up about 100 years back. During this period most of the area around the stations has seen heavy settlement and commercial activity and the stations been surrounded by high density construction leaving little space for future expansion. While architecturally most of the important station buildings were well designed, and the spaces were also adequate for handling future traffic loads, the existing facilities provided for booking, waiting, ingress and egress of passengers, toilets, over bridges and sub-ways have been terribly over stressed by the quantum jump in the number of passengers and trains handled at these stations. This has led to heavy congestion at the stations with consequent inconvenience to the users.

4.1.2 As a result, additional handling capacity at most of the existing stations had to be created using technological innovations and planning. These measures were aimed to achieve the following objectives:

- Optimize passenger comfort, satisfaction and safety
- Minimize congestion
- Be resilient to surges in patronage and train service disruption and
- Provide opportunities for additional trading or railway activities where possible and appropriate in overall support of the railway services

4.1.3 This has been possible by optimizing sizing and relative arrangement of waiting, operational and circulation spaces, and station facilities with:

- safe, effective and convenient access to train services
- relevant facilities
- safe, effective and convenient operation and management of the station
- clear circulation routes with minimum travel distances
- freedom from obstructions

4.1.4 Indian Railways have also used other new technologies and remodelling of station spaces and facilities to increase the handling capacity of the stations to optimize the activities as described below:

- Provision of escalators to reduce congestion on foot over bridges and with proper approaches to reduce clearance times at escalator landings and staircases off a platform
- clearance times at revenue protection barriers by increasing the number of entry and exit gates with clear passages
- Waiting times at ticket vending machines and ticket windows by computerization and increasing the number of vending machines and ticket windows.
- Improving signage and reducing dwell times in accessing, reading and understanding passenger information
- interchange times to access other modes of transport
- journey times from entrance to platforms
- journey times between interchanging trains

4.1.5 All the different performance criteria together have helped produce sufficient space to allow free flow of passengers through public areas and to give reasonable comfort in waiting areas. This has also provided an optimal balance between convenience, safety and other demands.

4.1.6 The other improvements at stations on Indian Railways to enable them to handle much more traffic effectively, economically, and efficiently, using technological developments and state of the art planning and design concepts include provision of wider foot over bridges with escalators and lifts, mechanized handling of parcels using forklifts, and golf carts for elderly and disabled passengers, computerized ticketing, facilities for passengers such as better and larger waiting rooms, food courts and restaurants, internet cafes as well as relocation of entrances and exists to place them optimally relative to pedestrian flows and physical constraints. This has enabled the stations to cope up and handle additional trains and passengers. However most of these works have been done in piece meal manner and the stations are still over crowded, with inadequate amenities and lacking in the requirements of modern day travellers. Further, it is necessary to assess the implications of emergency and perturbed situations, such as train service delays

4.1.7 An important aspect is to consider how an area may operate in future years with forecasted movements and assess significant timetable changes and to how the movement of people needs to be managed and determining where way finding/ directional signs or other methods to direct people are required.

4.1.8 Summarizing, the technological / engineering developments which have helped the Railways to increase the capacity of stations to handle more traffic in terms of trains as well as passengers are as under :

- Improvement in circulating areas and parking facilities
- Provision of more booking windows and computerized ticketing machines- both manned and self-operated ticket vending machines speeding up the booking process
- Streamlining of entry and exit passages clear of all obstructions
- Improved security checking with X-Ray machines
- Mechanized loading, handling, and movement within station areas of parcels and booked luggage
- Provision of wider foot over bridges with escalators and lifts to enable speedier and more comfortable entry and egress from platforms.
- Provision of better waiting areas, with more seating and snack bars, book stalls etc.
- Provision of internet cafes and entertainment for waiting passengers
- Mechanized cleaning of platforms and washing of tracks on ballast less track in platform locations
- Flatter turnouts and improved signalling enabling trains to arrive/depart on the platforms without needless speed restrictions and slowing down

4.1.9 Most of these improvements have come about in a piece meal manner and the facilities are disjointed and not integrated leading to sub optimal use of the same. To overcome this deficiency, Indian Railways are now planning for remodelling a large number of important stations with integrated facilities as per state of the art to bring them to world class standards and an SPV called IRSDC with equity participation of IRCON and RLDA has been set up for this purpose.

4.2 RAILWAY BUILDINGS

4.2.1 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.

4.2.2 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.

4.2.3 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.

4.2.4 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, 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.

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 constructed of brick and stone are finished with a cladding of light buff coloured Coorla stone with dressings, cornices and mouldings etc. in Porbandar and Seoni stones 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

4.2.5 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.

4.2.6 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.

4.2.7 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.

4.2.8 The Headquarters of other Company Railways were more or less constructed as conventional functional buildings. After regrouping, the Central and Western Railways occupied the above buildings in Mumbai while Southern Railway and South Eastern had their own landmark buildings.

4.2.9 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.

4.2.10 The Headquarters of Eastern Railway at Fairlie Place, Kolkata are in an old brick and stone building which 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.

4.2.11 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.

4.2.12 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. 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.

4.2.13 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:

4.2.14 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.

4.2.15 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.

4.2.16 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.

4.2.17 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.

4.2.18 The Railway stations on the quaint but Historic Hill Railways must not escape mention. The small yet impressive buildings at Shimla, Barog, Palampur, Wellington and Ooty, Ghoom and Darjeeling would merit mention.

4.2.19 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.

4.2.20 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

4.2.21 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.

4.2.22 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.

4.2.23 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.

4.2.24 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 Pavilions. Lucknow Railway station (Charbagh) and BNR Head Quarter Buildings are examples of this style of architecture.

4.2.25 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.

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

4.3 RAILWAY TUNNELS / TUNNELLING

4.3.1 Tunnelling 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 19th 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.

4.3.2 Railway Tunnels

4.3.2.1 Railway tunnelling 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 kilometres of track to skirt hills depending on the contours. This could be avoided by tunnelling which directly reduced the length of the alignment as it avoided first elevating to the saddle, following the contours and then coming 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.

4.3.2.2 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.

4.3.3 Broad Gauge Railway Tunnels on Main Line Sections of Indian Railways (IR)

4.3.3.1 These railway tunnels were constructed in the 19th and early 20th 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.

4.3.3.2 The first tunnelling 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.

4.3.3.3 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

4.3.3.4 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.

4.3.3.5 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**.

4.3.3.6 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.

4.3.3.7 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.

4.3.3.8 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.

4.3.3.9 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 totalling 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 tunnelled 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

4.3.3.10 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.

4.3.3.11 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 tunnelling length of 10.3 km.

4.3.3.12 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.

4.3.4 Tunnels on Narrow Gauge (NG) Hill Railways

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

4.3.5 Kalka – Shimla Railway

4.3.5.1 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 kilometre line, built on a 2'6" (762 mm) gauge, was opened for traffic on November 9, 1903.

4.3.5.2 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. The 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.

4.3.5.3 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 its 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.

4.3.5.4 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.

4.3.5.5 Technology and Procedures adopted for tunnelling 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) height 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.

4.3.6 The Kangra Valley Railway

4.3.6.1 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.

4.3.7 The Nilgiri Mountain Railway

4.3.7.1 This 46 Km meter 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.

4.3.8 The Neral – Matheran Toy Train

4.3.8.1 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.

4.3.9 Darjeeling Himalayan Railway

4.3.9.1 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 kilometres 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.

4.3.10 Long BG tunnels in India - Konkan Railway and Railway lines in Jammu Kashmir.

4.3.10.1 Konkan Railway

4.3.10.2 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. 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 tunnelling 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.

4.3.10.3 Geologically, the entire Konkan region falls into two zones. In the first zone from Roha to Kankawali, soils consist of dark coloured volcanic lava flow and laterite. These soils are mainly basaltic and tunnelling 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 tunnelling media was extremely soft and innumerable difficulties were encountered making such tunnelling very expensive and time – consuming.

4.3.10.4 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 behaviour when mixed with varying quantities of water could not be judged resulting in unforeseen problems

4.3.10.5 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.

4.3.10.6 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 tunnelling. 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 Tunnelling 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.

4.3.10.7 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.

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

4.3.11 Jammu – Udhampur Rail Link

4.3.11.1 The section has 20 tunnels with a total length of 10.59 Km. Nine of these tunnels were constructed with conventional method of tunnelling 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.

4.3.12 Udhampur – Katra Section of Udhampur-Srinagar-Baramulla (USB) Project

4.3.12.1 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 shaped and have been provided with conventional lining. The method of tunnelling 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.

4.3.13 Katra – Qazigund Section of Udhampur-Srinagar-Baramulla (USB) Project

4.3.13.1 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

4.3.13.2 Also recently completed is the longest Railway tunnel constructed in India. The 11-kilometre-long "Pir Panjal" tunnel between Banihal and Qazigund in Jammu and Kashmir has been commissioned and opened to traffic in 2014, is part of the 340-km-long railway project in Jammu and Kashmir, which will link the Valley with the rest of the country.

The tunnel is an engineering marvel, it has been 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.

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.

This tunnel has many firsts to its credit such as the extensive use of road header (a tunnelling machine) and the adoption of the New Austrian Tunnelling Method (NATM) on a large scale anywhere in the country. In the New Austrian Tunnelling 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.

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.

4.3.14 Metro Railway Tunnels

4.3.14.1 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.

4.3.15 The rationale on going under-ground in metros

4.3.15.1 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. 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.

4.3.15.2 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.

4.3.15.3 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.

4.3.15.4 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.

4.3.16 Kolkata Metro

4.3.16.1 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 tunnelling was done mainly by cut and cover except in small stretches where shield tunnelling was done. However where the metro alignment passed under residential building or a canal the "driven shield tunnelling method" was adopted. 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.

4.3.16.2 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 construction is in progress underneath.
- Shield tunnelling using compressed air and airlocks.
- Ballast-less 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.

4.3.16.3 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 tunnelling 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 labour 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 tunnelling operation has been tried before; it was in fact a new technology for the project.

4.3.16.4 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).

4.3.16.5 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).

4.3.17 Delhi Metro

4.3.17.1 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.

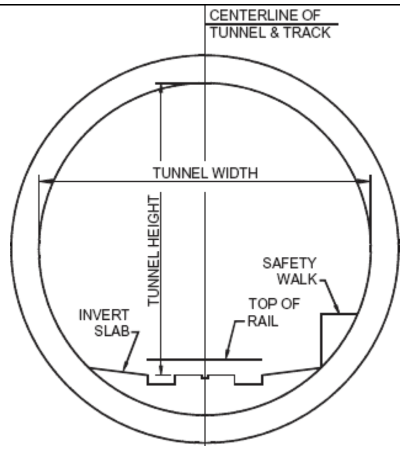
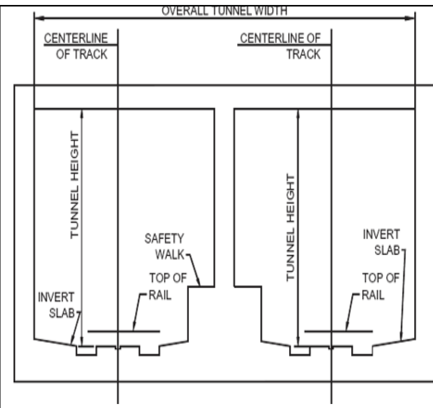
4.3.17.2 The construction of the Delhi metro was sanctioned in September 1996 and the first leg was completed and commissioned in 2002. Delhi Metro now has a total of 31 underground stations with a total length of the underground corridor which is presently 48.06 kilometres.

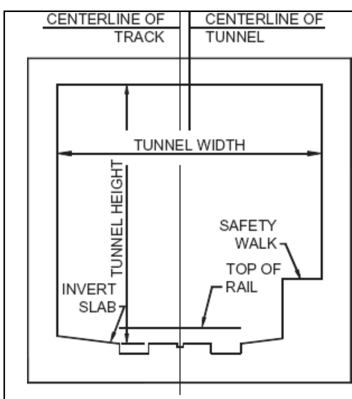
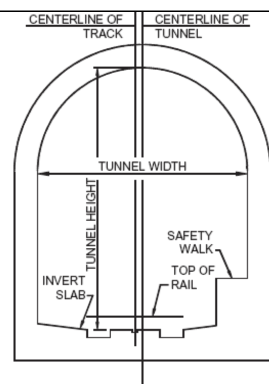
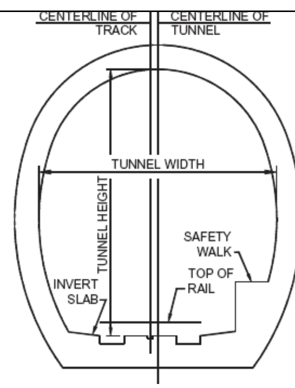
4.3.17.3 In Phase 3, being taken up now there will be 28 underground stations and under-ground corridors of 41.044 kilometres. The decision to construct more underground corridors was taken this time to ensure that the construction work causes minimum inconvenience to the people. By constructing so many 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.

4.3.17.4 Tunnelling 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 tunnelling 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 tunnelling in soft soil. NATM was used for Chawari Bazar station where space was a major constraint.

4.3.18 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**

4.3.18.1 Tunnel cross sections have to essentially satisfy the clearance requirement laid down in the Schedule of Dimensions of Indian Railways. Beyond the Fixed 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.

4.3.19 Use of different technologies for tunnelling in different situations

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

4.3.19.1 Cut & Cover

4.3.19.1.1 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 tunnelling 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.

4.3.19.2 Shield Tunnelling

In soft soil and where deep tunnels are excavated, a tunnelling shield is normally adopted. In early shield tunnelling, the shield functioned as a way to protect labourers 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.

4.3.19.3 Tunnelling 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 tunnelled. 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 tunnelling. 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.

4.3.19.4 Use of Tunnel Boring Machines (TBM)

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 tunnelling with TBMs is much more efficient and results in a shorter project completion time.

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.

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.

4.3.19.5 New Austrian Tunnelling 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.

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CHAPTER 5

ROLLING STOCK – WAGONS

5.1.0 PRE-INDEPENDENCE

5.1.1 Railways had appointed a British firm, M/s Rendol, Palmer and Tritton as consulting engineers to obtain designs of wagons for Railways from this firm besides other areas of consultancy provided by them.

5.1.2 As the Railways in India prior to independence were company managed, there was need for co-ordination and standardization in technical matters. Central Standards Office (CSO) was therefore set up in 1930 for the purpose of preparing specifications, standards, tender documents etc.

5.2.0 POST-INDEPENDENCE

5.2.1 In 1952, Railway Testing and Research Centre (RTRC) was set up for undertaking applied research, providing basic design criteria, producing new designs, validating new concepts of designs, testing prototypes for their performance characteristics and to eliminate bottlenecks in the full utilization of the existing assets.

5.2.2 Soon thereafter, it became possible to dispense with the foreign consultancy and the contract with M/s Rendol, Palmer & Tritton was terminated in 1955. In 1957, CSO and RTRC were merged into a single organization called Research, Designs and Standards Organisation (RDSO). Ever since, Indian Railways have acquired high capability to undertake designs of wagons, not only for Indian Railways requirements, but also for use of private and public sector undertakings within the country under consultancy terms. Designs of wagons have been also been evolved by RDSO for manufacture in India for export to foreign countries.

5.2.3 Broad Gauge Wagons Designed By CSO/RDSO

(i) TPR - 4 - Wheeled Petrol Tank Wagon

This revised version of TP was designed by CSO in 1951. The capacity of the barrel was slightly increased and the pump & piping arrangement for suction discharge of petrol was modified to top filling and bottom discharge arrangement.

(ii) TOH - 4 - Wheeled Heavy Oil Tank Wagon

This wagon was designed in 1956 for transporting commodities like fuel oil, furnace oil, creosote, pitch etc. which become more viscous in cold weather. The design provides for steam heating of the contents. No master valve is provided and the diameter of the bottom discharge pipe is bigger than TPR/TORX wagons.

(iii) BOX- Bogie Open Wagon

The first major design undertaken by RDSO in 1957-58 was broad gauge Bogie Open Wagon type BOX. This design was developed for the bulk movement of commodities, especially coal, and incorporates special features, which were not provided in the older design, viz. higher axle load of 20.3t. as against 16.3t, roller bearing in place of plain bearings, high capacity semi-automatic centre buffer coupler, improved suspension system with a speed potential of 100 km/h, use of weld-fabricated techniques in the construction of bogies and wagon body and improved braking system incorporating clasp brakes and provision of slack adjuster and empty load box.

(iv) BVM-4-Wheeled Goods Brake van Match Truck

This modified version of BVG was designed in 1958 with provision of transition centre buffer coupling to make it suitable to be used as a match truck between the older wagon stock with screw coupling and side buffers and new stock with centre buffer coupling.

(v) BWT/A - Bogie Well Wagon

This modified version of BWT was designed in 1958-59. Wooden floor was removed & track guides were provided. The floor height of the well was maintained as that of BWT by making the girder deeper.

(vi) BRH-Bogie Rail Wagon Heavy

This wagon was designed in 1960 with 20.3t axle load and plate fabricated bogie of BOX type for transportation of rails and heavy steel sections.

(vii) BWX/A - Bogie Well Wagon

This modified version of BWX was designed in 1960-61. The well length was increased from 3.96 meters in BWX to 5.94 meters by raising the height of the floor of the well to meet the special requirement of defence movement.

(viii) BOI- Bogie Open Gondola Wagon

This open wagon was designed in 1961, especially for the movement of high density items like iron and manganese ore. The height of the body was reduced thereby increasing the payload by about 30%. Both AVB equipped and air-brake equipped versions of BOI wagons have been built for KK line of Southern Eastern Railway.

(ix) TPGL, TPGLR- 4-Wheeled LPG Tank Wagons

This wagon was designed in 1962 for transportation of LPG at a pressure of up to 15 bar. The designed axle load was 16.31. It used standard IRS suspension. The design incorporates an insulated barrel fabricated from cryogenic steel with filling and discharge arrangements at the top. Revised version of this wagon, known as TPGLR, was developed in 1974 without insulation on the barrel and with a higher carrying capacity.

(x) BCX- Bogie Covered Wagon

This design was evolved in 1963 for bulk movement of commodities requiring protection from rain etc. This design includes all the special features of BOX wagon and in addition has provision of swing-cum-flap doors.

(xi) BHS- Bogie Well Hole wagon

Designed in 1965, this well hole wagon provides for a clear hole of 6250 x 2440 mm in between two girders. With 92t pay load, this wagon was specially designed for transport of transformers manufactured by M/ s. Bharat Heavy Electricals Ltd.

(xii) BOY- Heavy Duty Bogie Open Gondola Wagon

A successor to BOI wagon, this was especially designed in 1967 for transportation of minerals/ ore in closed circuit. With an axle load of 22.9t and payload of 71t, the wagon tare weight was 20t. This design included all improved features of welded construction and sub-systems. The design permits full utilisation of track loading density and is suitable for haulage of a gross trailing load of up to 4500t in the existing loop length. The wagon is provided with modern high-speed cast steel bogies with speed potential of 100 kmph and air brakes.

(xiii) BWZ- Bogie Special Well Wagon

This 182t capacity special purpose heavy duty well wagon was designed in 1968 for transport of turbo-generator stators from BHEL/Hardwar. This all welded design incorporates four 6-wheeled 22.91 axle load bogies coupled together through intermediate bridges.

(xiv) CRT (4-wheeled covered wagon)

The utility of an improved design of 4-wheeler wagon was established from the commercial consideration. Hence, a new design of covered wagon type CRT was developed in 1971. This design incorporates improvements over the conventional 4-wheeler wagon by increasing the axle load from 16.3t to 20.3t, increased volumetric capacity, strengthened body structure, use of light-weight centre buffer coupler and roller bearings and increase in the payload by about 26%.

(xv) BVZT (4-wheeied goods brake van)

Improved design of brake van type BVZT was designed in 1973 to meet requirements of higher speed of goods trains. This incorporates softer suspension with longer links and was designed to have a speed potential of 100 Km/h. The design also provided for better facilities and environment for the Train Guard.

(xvi) BOXN (New bogie open wagon)

For meeting the increased demand for bulk movement of commodities like coal during the Corporate Plan period, a new design of bogie open wagon was evolved in 1976. This design is a radical improvement over the earlier BOX wagon in terms of payload capacity, efficiency, reliability and ease of maintenance. The design uses cast steel bogies. By striking a judicious balance of various constraints and requirements, it was possible to obtain the maximum utilisation of track loading density and the design is also suitable for running trains with gross trailing of 4500t. Now BOXN wagon fitted with Casnub 22HS bogie has been designated as BOXNHS wagon, which is suitable for 100 km/h operation.

Boxn HS Wagon

(xvii) BOBS Mk.-II (Bogie Hopper Wagon special)

This hopper wagon with provision of side discharge is a modification to the older BOBS design. The design was completed in 1976. It uses 22.9t axle load cast steel snubbed bogies.

(xviii) BOGIE HOPPER WAGON FOR BALLAST - BOBY

This hopper wagon was designed in 1977 to meet the transportation requirements of ballast for the railway's track maintenance. The wagon has a special feature for regulating discharge of ballast in between and/ or outside the track and thereby eliminating manual re-distribution.

(xix) BCN. BCNA Covered Wagons

BCN wagon similar to BCX Mk.-II type wagons, was designed in the year 1984.Casnub 22 NLB type bogie and air brakes were fitted. BCNA wagon was designed in the year 1990 by reducing the length of the wagon and increasing the width and height to achieve similar volumetric capacity. This new design resulted in 7.5% increase in throughput. BCNA wagon fitted with Casnub 22 HS bogie has been redesignated as BCNAHS fit for operation at 100 km/h.

(xx) BFNS type Wagon

BFNS wagon, suitable for 100 km/h operation was designed in the year 1998 for transporting HR/CR coils, plates etc. The design incorporates Casnub 22 HS bogies, non-transition CBC and air brake.

(xxi) BOXNHA Wagon

A landmark thrust towards higher axle loads in IR was made in 1998 with the design of BOXNHA wagon with higher axle load of 22.1t & with a view to increase throughput per train by 11%. The design incorporates Cast Steel IRF108 HS bogie, non-transition CBC and air brake. However, axle load has since been reduced to 20.32t for regular operation at 100 km/h speed until track upgradation works are completed.

(xxii) BVZI Brake Van

BVZI brake van was designed in the year 2000. The design incorporates fitment of ICF type bogie, non-transition CBC and air brake. This brake van is fit for operation at 100 km/h & has better ride comfort.

The above designs show that IR has the capability to meet all its needs of wagon stock.The details of major achievements in Wagon design between 2006-2007 & 2012-2013 are given in a nut-shell below.

Recent Achievements in Wagon Design

S.No.	Year	Area	Title	Description	Likely Benefit	Status
A.	**Design and Development of New Design Wagons**					
1.	2008-09	Pay to tare ratio increased	Design & Development of 22.9 t A/L Open Wagon type BOXNHL	First prototype BOXNHL wagon was manufactured and tested.	Rake throughput increase of 22% over rake of BOXN (CC)	Implemented
2.	2008-09	Pay to tare ratio increased	Design & Development of 22.9 t A/L Covered Wagon type BCNHL	BCNHL is the first all stainless steel covered wagon of 22.9 t axle load.	Rake throughput increase of 4.7 – 39% for different commodities.	Implemented.
3.	2010-11	Pay to tare ratio for Cement and Fly-ash	Design of Fly-ash / Cement wagon type BCFC	The rake of this RDSO designed wagon will provide additional carrying capacity for cement and	Rake throughput increased for Cement and for Fly-ash.	Implemented.

				for Fly-ash in comparison with present cement wagon design.		
4.	2011-12	25 T container wagon	Design of 25t axle load Container Wagon BLC25	Oscillation trials with the track friendly Bogie done.	Wagon floor height suitable for Double Stack Containers	Oscillation Trails.
5.	2011-12	Pay to tare ratio	Design of 25 t A/L Coal Wagon type BOXN25	25 t Wagon suitable for fitment with 25/32.5t track friendly bogie	Throughput increase over BOXN.	Oscillation trials
6.	2011-12 onwards	Higher throughput	Design of frameless wagon for petroleum products	A frameless wagon for carrying petroleum products (BTFLN) has been developed leading to an increase in Rake throughput.	Reduced cost with higher throughput.	Under implementation.
7.	2013-14	Higher throughput	Design & development of high pay to tare ratio 25T Gondola wagon.	Development of cost effective 25T Gondola wagon for existing and DFC networks.	Reduced cost with higher throughput.	Under implementation.
B.	**Modification of existing Wagons/Components**					
1.	2006-07	Double stack container service	Introduction of Double Stack Container Services on IR	Double stack container operation has been done.	100% increase in rake throughput of container wagons.	Implemented.
2.	2007-08	Throughput increase.	Modifications of Wagons to	Four types of wagons :	Rake throughput	Implemented

			operate at 25t axle load	BOBSN, BOXN, BOY & BOBRN have been permitted with conditions.	increased.	
3.	2009-10	Higher axle load Double stack Container	Double stack Container Flats made fit for 100 kmph with 22T Axle load	Design is modified for double stack container operation resulting in decrease in the turn-around time.	Increased speed of 100 kmph in loaded condition (from existing 75 kmph)	Implemented
C.	**Other Works**					
1.	2008-10	Faster turn-around	Increase in Speed of Existing Wagons	Speed of various wagons in loaded condition increased at CC+6+2t loading.	Higher throughput	Implemented

5.3.0 ONGOING PROJECTS / ACTIVITIES

1. Design and development of 25t & 32.5 t axle load improved pay to tare ratio of wagons.
2. Development of Track Friendly Bogie for 32.5/25t axle load wagons.
3. Introduction of Bogie Mounted Brake System on IR.
4. Design and development of 22.9t axle load BTPN wagon.
5. Development of tank wagon for residual furnace oil and Low Sulphur heavy stock wagon type BTOH.
6. Upgradation of Casnub bogie for increasing the speed of existing wagons in loaded condition
7. Design and development of dedicated fly-ash & clinker wagon with RITES.

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CHAPTER 6

ROLLING STOCK – COACHES

6.1.0 Prior to 1955, only wooden bodied coaches were manufactured in Railway Workshops. In 1955, the Integral Coach Factory was set up at Perambur, Madras (now Chennai) to manufacture steel bodied coaches in collaboration with M/s Schlieren of Switzerland.

6.1.1 These coaches had integral coach shell construction which ensures increased safety for passengers in the event of an accident. The coaches had fabricated bogies with laminated springs in secondary & coil springs in primary suspension and a speed potential of 96 kmph. Since then the steel body integral coach shell became the standard coach design on IR and even the new coach factory at Kapurthala adopted this design.

6.1.2 Major modifications were subsequently carried out to the original Schlieren design to make them suitable for Indian operating conditions. Some of these were:

(i) Corrosion Control – Low alloy steel IRSM-41 was adopted to minimize corrosion. Thickness of structural was optimized to achieve weight reduction. Floor construction was changed through use of 2mm PVC floor laid with adhesive over 12mm compreg (compressed ply) boards. Stainless steel & FRP lavatory inlays and epoxy resin bonded floor were adopted to eliminate water seepage in lavatories. Use of ferritic stainless steel / austenitic steel in critical areas had also been adopted.

(ii) Weight Reduction – This was achieved through adoption of IRSM-41 steel, use of composites for coach furnishing, use of PVC flooring, etc. The weight reductions enabled improvement to passenger amenities like provision of gangways, higher capacity water tanks, cushioned berths in second class coaches, additional fans etc.

(iii) Safety – Twin pipe compressed air graduated release air brake system was adopted in place of the original vacuum brake system. The capacity of couplers & draft gear was enhanced to arrest head stock damages and enable train lengths of upto 24 coaches followed by the recent development to gradually shift to Centre Buffer Couplers. Wear adapted wheel profile was adopted to improve wheel life.

(iv) Speed Potential – The speed potential of the coach was gradually enhanced from the original 96 kmph to 110 kmph on main line standard track through the following major changes :

  (a) The secondary stage laminated springs were replaced with helical springs.

  (b) Side bearers were provided to transfer the coach body weight in place of the earlier arrangement of transferring the load through center pivot.

  (c) The length of bolster hanger was increased to 410mm in place of 286mm.

  (d) Vacuum brakes ,were replaced with air brakes.

  (e) Bogie frame of AC coaches was redesigned to take up the higher load(16.25 t axle load)

6.1.3 Improved track condition (Rajdhani standard) further enabled the above coaches to be operated at speeds of upto 140kmph & introduction of Rajdhani Express trains to connect the capital of India with important metropolitan towns followed by fully air-conditioned inter-city trains with chair car formation.

6.1.4 High Speed Coach -IRX Shell & IR -15 Bogie : The following major changes were carried out to achieve the speed potential of 160 kmph:

(i) Secondary suspension made softer.

(ii) Dash pots of ICF coaches were replaced by shock absorbers to provide necessary damping. Besides, shock absorbers were provided in the secondary stage.

(iii) Bolster hanger length was increased further to 630 mm to achieve lower frequency of oscillation.

(iv) Wheel web was machined to reduce imbalance. Maximum diameter was reduced from 915mm to 865 mm & this reduced the unsprung mass.

(v) Bogie was fitted with taper roller bearings.

(vi) IRX shell was designed with straight side walls & no corrosion pockets. Body bolster was modified to take up IR-15 bogies.

6.1.5 High Speed coach with IRY Shell & IR20 Bogie: Limitations of ICF bogie design led IR to evolve a new bogie design, later designated as IR-20.The important features are enumerated below:

(i) The axle guidance was designed in such a way that its flexibilities in longitudinal & lateral directions may be optimized independently.

(ii) A different transverse suspension concept using flexi-coil secondary springs was adopted.

(iii) Bogie frames were designed without headstocks & with shorter wheel base.

(iv) Diameter of wheels was reduced from 915mm to 890mm.This improved curving & reduced the unsprung mass by about 142 kg per bogie which in turn reduces stresses on the track structure.

(v) Axle mounted disc brakes with wheel slide protection were provided. Two brake discs of 610mm dia. per axle were provided without tread brakes.

6.1.6 IRY Coach Shell: A new coach with lesser propensity to corrosion & improved interior was designed to accommodate IR-20 bogies and with a speed potential of 160 kmph. The salient features of this coach design were:

(i) IRY bare coach shell is 2.5 t lighter than ICF coach shell. Completely furnished coach is 1.5 t lighter than ICF coach shell.

(ii) The coach was provided with roof-mounted AC package units at either end.

(iii) UIC type vestibules were provided.

(iv) The under-frame consisted of 2 sole bars fabricated out of two folded pressed sections of IRSM-41 steel in 4mm & 5mm thickness. The sole bar has no corrosion pockets & is ideally suited for easy fixing of side walls & cross members.

6.1.7 The success of the two new coach designs, with speed potential of 160 kmph, gave IR enormous confidence in designing new coaches.

Some recent developments in coach technology have been as follows:-

(i) Fitment of Centre Buffer Couplers on main line coaches instead of screw couplings.

(ii) Bogie mounted brake system and adoption of composite brake blocks.

(iii) Development of hygienic and aesthetically pleasing modular toilets of FRP.

(iv) Designing of ten variants of the LHB coach imported from Germany.

(v) Provision of fire retardant upholstery and curtains in AC coaches.

(vi) Modifications in ICF coach design to minimize injury in case of accidents.

6.1.8 Carriage – Achievements

SN	Year	Area	Title	Description	Likely Benefits	Status
1.	2011-12	Passenger Safety	Development of Crashworthy Design of LHB Coaches in accordance with latest EN norms 15227.	In order to prevent deformation in passenger occupied areas, energy absorption in non-passenger areas through controlled collapse, low accelerations (decelerations) to avoid injuries to occupants and climbing of coaches one over the other, an improved design of LHB coach has been developed.	Safer passenger travel.	Final design of the crashworthy LHB GS coach is under development.
2.	2011-12	Passenger Safety	Development of Fire Retardant material for coaches	To prevent spread of fire & reduce the number of causalities owing to such accidents, specifications for a number of materials used in coach furnishing which delay/ retard propagation of fire, prohibit release of toxic fumes & smoke and do not melt & drop in case of fire inside passenger coaches have been developed.	Enhancement of passenger safety in case of fire related incidents.	Fire Lab is proposed to be set up at RDSO.
3.	2012-13	Throughput Enhancement	Development of Double Decker Coach Design	RDSO has developed design of AC Double Decker coach with an entirely new shell design. Commercial services have started from 01.10.2011. Next series of Double Decker coach with reduced width (3050 mm width Mark-I) are currently being manufactured at RCF, Kapurthala. Train services have been introduced on Delhi-Jaipur and Mumbai-Ahmedabad routes.	In the Double Decker coaches seating capacity is more than 50% as compared to standard Chair Cars. The Double Decker services provide cheaper & safer travel and carry more passengers.	Double Decker coaches will utilize the maximum moving dimension fully and provide greater comfort.

Double Decker Coach

6.2.0 DEVELOPMENTS /ACHIEVEMENTS IN COACH DESIGN

i. Bogie mounted brake system.
ii. Composition brake blocks for passenger coaches.
iii. High Capacity Buffer Springs.
iv. Air Springs for secondary suspension of EMU & mainline coaches.
v. High Capacity Parcel vans.
vi. Design of LHB variant coaches.
vii. Centre Buffer coupler.
viii. Crashworthy Design of Coaches.
ix. New Stainless Steel shell for EMU.
x. Double Decker Coaches.

6.3.0 AIR-CONDITIONED COACHES

6.3.1 Introduction and Background

Being the 2nd most populous country of the world and having 63,000 route km of Railway network, the total volume of passenger traffic in India is one of the highest in the world. Bulk of this passenger transportation is by the Railways and Roads. Summer conditions prevail for about 7 to 8 months throughout India (except in the hills). In southern and western India such summer conditions exist throughout the year. Some of these summer months in northern and central India are characterized by dusty winds, and at times with high humidity. Coastal regions are characterized by extreme humid conditions.

6.3.2 Initial Steps

The first step to provide some comfort to upper classes was taken when fans were introduced in 1905. This facility was extended to Intermediate classes then popularly known as Inter Class in 1936 and to lower classes in 1949. It was only in 1936, that efforts were made to provide a very simple type of cooling facility, but only for upper classes, when ice blocks placed in metal trays were made available at selected points (on payment) en-route with facility of loading into the compartments of the running trains. This system of providing cooling comfort to Ist class passengers continued till 1960.

6.3.3 Early Air Conditioning Systems

6.3.3.1 International Scene

Earliest known air conditioning of railroad coaches was by Pullman Company for their sleeper cars and by the Baltimore and Ohio Railroad for their coaches in 1927-29. By 1931 the latter put in operation the first complete air conditioned passenger train. By 1953 there were 20,000 air conditioned coaches on US Railroads.

Heating was necessary, and the norm under European conditions since the early days of the railways, with individual ovens and/or steam from the locomotive. With the advent of electrification, electric heating was introduced progressively. With increasing train speeds, traveling with open windows was uncomfortable (air draft noise) and even dangerous. Therefore air conditioning in trains started with the introduction of the first high speed train i.e. TEE train sets. Powerful electric supply was the essential requirement. TEE train sets fulfilled this condition by having Diesel Electric Generators for auxiliaries

With the change from steam to diesel and electric traction in the sixties, train heating changed from steam to electric. Thus air conditioning became feasible in individual coaches. It was gradually extended to other inter-city train sets in the beginning and later to individual coaches, with electric power being drawn from the locomotive, known as HOG (Head On Generation) system.

6.3.3.2 Indian Railways

Eastern Punjab Railway (EPR) got coaches running with ice-activated air-conditioning system after division of assets of the then North Western Railway (NWR) after Independence. In these coaches cold water was circulated in coils located in various compartments, and a blower fan circulated cool air in the compartment. The cool water was obtained from the tank located below the coach underframe in which ice was loaded at various nominated stations. NWR served the hottest part of undivided India and such coaches were running on the Lahore Karachi Mail.

Prior to 1948 some coaches were also provided with mechanical refrigeration system working at 48V DC. There is however, no mention of such coaches in any records.

6.3.3.3 Refrigerated Vans

Before 1949, Indian Railway had been using ice-cooled Refrigerated Parcel Vans for carriage of perishables such as fruits and vegetables. These vans used a straight ice system i.e. the use of wet ice only, without any equipment for pumping cold melt, as in the case of ice-activated system described earlier.

6.3.3.4 Construction of Self Generating Wooden Body Air-Conditioned Coaches

Railway Board (RB) subsequently approved a programme to build 14 nos. BG fully air-conditioned and 36 Nos. BG & MG partially air-conditioned self-generating wooden coaches on a priority basis.

6.3.3.5 Fully Air Conditioned BG Coaches

Railway Board in 1950, ordered such coaches on M/s J Stone on a turnkey basis, who imported it from UK. The air-conditioning plants were of 5-ton capacity, used open type compressors. The power generating plant, consisted of a DC generator directly coupled to a 3 phase AC motor and driven by a propeller shaft. These coaches were provided with a single battery of 56 nos. cells each of 330 Amp. Hour capacity. The entire plant was of under-slung type.These coaches had large underslung water tanks and an electrically driven *air* pressure controlled Water Raising Apparatus (WRA) to raise the water to a small service reservoir located in the roof of the lavatories.

The work of building these coaches was shared by Matunga Workshop (CR) and Kharagpur Workshop (SER).

6.3.3.6 Partially Air-Conditioned Wooden Body BG and MG Coaches

In 1952 a decision was taken to build 36 BG and MG partially air-conditioned self-generating coaches using 24- V DC system. These coaches accommodated eight passengers in air-conditioned portion and 8 to 10 persons in non-air-conditioned 1st class portion.

6.3.3.7 Experimental Air-Conditioned Train (Deluxe Train)

This experimental train service having air-conditioned 1st Class coaches and airconditioned Chair Cars was conceived in mid fifties and was meant to be a very prestigious service between Delhi-Howrah, Delhi-Mumbai and Delhi-Madras (now Chennai).The turn key contract for the supply of equipment and supervision of installation including commissioning was given to M/ s. J Stone. These wooden body coaches on IRS under-frames were built in railways' own workshops and involved construction of about 90 air-conditioned coaches. This service, popularly called Deluxe Expresses, was introduced in mid 1957. These trains had one air-conditioned 1st Class, five air-conditioned Chair Cars and an air-conditioned Dinning Car. All coaches were designed to receive power at 400 V AC 3 phase from two power cars carrying Diesel Generating Sets located at either end of the train.

Each Power Car had 2 nos. DG sets each of 165 KV A capacity along with its control panel, and provided sleeping accommodation for operating staff. The air-conditioned coaches had under-slung plant except for control panel, which was floor mounted.These services were very popular in spite of the fact that over-night travel in a chair car was rather uncomfortable.

6.3.3.8 End-on-Generation System Standardisation

Adoption of 3-phase supply enabled the use of ac induction motors. Use of these robust motors without any brush and totally enclosed type became a reality giving ample benefits. Having a three phase supply eliminated the limitations of starting torque for the compressors and opened up scope for use of robust sealed refrigeration compressors with higher speed, thus affording significant system benefits.

6.3.4 Air Conditioning of Metal Body Coaches

6.3.4.1 Metal Body Fully Air-Conditioned BG 1st Class Coaches

In 1967, the ICF built and turned out 24 nos. of these coaches, which were distributed to various BG railways. M/s. **J** Stone supplied the plant required for these coaches, and also supervised the installation and commissioning of the same in ICF. The plant used for this batch of coaches was different from that used for earlier batch of wooden body coaches.The manufacture of ten of these BG coaches was taken up by ICF in 1971-72. These coaches were provided with 10-berths in air-conditioned 1st Class and another 10-berths in non-air-conditioned 1st Class portion.

Bulk of these coaches had air-conditioning and power supply plant supplied by M/ s. J Stone, and installation carried out by ICF. These coaches used 110 V DC system as used in the earlier batch of fully air conditioned coaches along with Hypoid Gear Drive, but the size of Alternator was scaled down to 12.5 KW.

6.3.4.2 Metal Body 2-Tier Fully Air-Conditioned BG Coaches

So far the facility of air-condition travel was available only to those passengers who could afford to travel by the costliest class. With a view to extend this facility to passengers who could only afford to travel in non-air conditioned 1st Class, these BG coaches were developed which could accommodate passengers roughly equal to two ordinary 1st class coaches. Thus against 24 passengers carried in an ordinary 1st Class, air-conditioned 2-tier BG coaches accommodated 44 passengers. This was the first time that Indian Railway undertook the responsibility of design and procurement of plant on its own.

Initially twenty such coaches were produced in 1975-76. The air-conditioning and power generation plant used in these coaches was similar to earlier batches of metal body coaches with following major departures:

i. For the first time these coaches were provided with Bogie Transom Mounted Brushless18 KW Alternators provided with end-less V-belt drive from the bogie axle.

ii. The 18 KW Alternator along with its rectifier and transistorised output regulator was designed and built by complete indigenous effort by BEACON.

iii. For the first time indigenous refrigeration compressor manufactured by ACCEL was used in self-generating coaches.

iv. For the first time air-conditioned self-generating coaches with two sets of underslung air-conditioning plant and two sets of power generating plants were produced.

These coaches were well received by the travelling public and seeing the good response, ICF starting producing similar coaches at the rate of 40 to 50 coaches per annum for the next 10 years.

6.3.4.3 Two Tier MG Air-Conditioned Coaches

Following the success story of BG two tier AC coaches, it was extended to MG in mid eighties. These coaches had only a single set of underslung air-conditioning plant with double set of power generating plant with endless V-belt drive, but with smaller size of alternator than their BG counterpart.

6.3.4.4 Composite Metal Body Air-Conditioned Coaches

With the concept of self generating air conditioned coaches having stabilised, it was extended to build composite coaches having non air-conditioned first class in one half and air conditioned second class sleeper or chair car in the other half. These coaches had power generating and air-conditioning plant similar to that used in 2-Tier coaches.

6.3.4.5 Metal Body 3-Tier BG Air-Conditioned Coaches

A Roof Mounted Package Unit of indigenous make was successfully developed at Rail Coach Factory (RCF) Kapurthala, in the early nineties. This could provide extra head room for a third tier berth. Thus a 3-tier AC coach got evolved. As the package units could work only from a AC 3 phase supply, the initial lot of these coaches was built to work only on Rajdhani Expresses where this power supply was available from the power cars. The self-generating version of these coaches had to wait for few years more and could be produced only in the mid-nineties, by which time the floor mounted version of a forced cooled inverter of 25 KVA rating was successfully produced by the Indian Industry. However these coaches could accommodate only 64 passengers and it took another 5 years to produce an underslung version of the invertor when the carrying capacity of these coaches could be raised to 72 passengers.

6.3.5 Regular air-conditioned trains

6.3.5.1 Rajadhani Expresses

These trains were conceived to be completely air-conditioned, high speed (120 KMPH) services and were initially provided with only two classes for travel, namely 1st Class and Chair Cars, with fully air conditioned pantry car and brake vans. Each coach had sub pantries with hot cases and other equipment.

As in case of Deluxe trains, two power cars located at each end of the train equipped with generators supply power at 415 V three phase AC. A major improvement in these services took place in mid-nineties when 3-Tier coaches replaced the existing chair cars. This improvement increased the popularity of Rajdhani Services immensely, as over-night journey in a chair-car was uncomfortable.

Initially this service was introduced with 14 coaches, but later the composition was raised to 22 coaches in late seventies. As the power cars generated power at 415 V, it was not possible to distribute the same to all the 22 coaches even if the generator capacity was raised to suit the new loads. As an immediate measure an additional power car was provided in the middle of train. This was followed by development of high capacity power car with 350 KW DC sets (against 250

KW in the existing ones) and generation and distribution voltage increased from 400 to 750 V.

6.3.5.2 Shatabdi Expresses

This service was conceived as a short distance intercity service with only seating arrangement. These services initially introduced in 1989 are fully air-conditioned and, like Rajdhani trains, work on EOG system with two power cars. Each coach has a small pantry with electrically operated equipment.

6.3.5.3 Super Luxury Trains

Mainly to attract foreign tourists, these super luxury trains have been introduced on dedicated tourist circuits, providing lavish comfort and unmatched regal luxury. These trains have been benchmarked with the best trains of the world like Blue Train of South Africa, Orient Express of Europe and Eastern and Oriental of South East Asia. The technical aspects of air conditioning and power supply have been based on systems already developed for Rajdhani Trains. Some of these are-

- Palace on Wheels
- Deccan Odyssey
- Heritage on Wheels (Meter Gauge)

6.3.6 Linke Hoffmann Bosch (LHB) Coaches

These coaches are being manufactured at RCF with TOT from the German Firm LHB. Initially AC coaches were manufactured for EOG stock of Rajdhani and Shatabdi Expresses but presently self-generating are also being manufactured. In addition to the special features of these coaches mentioned earlier, the additional features provided on AC Coaches are:

1. Roof mounted Microprocessor based AC package unit for the control of AC plants.
2. Integrated single switchboard cabinet based on modular system incorporating complete control of train lighting, Air Conditioning, pantry etc.
3. Light weight rigid epoxy molded 60 KVA transformers.
4. For Rajdhani stock state-of-art integrated modular pantry unit.

6.3.7 Development of Roof Mounted Package Units (RMPUs)

This type of unit was used for the 1st time in the early eighties by the Hong Kong Metro. On Indian Railways, their use was considered for development of 3-Tier air-conditioned Sleepers for Rajdhani Services for replacing the existing Chair Cars. After initial trials and modifications, two Indian firms M/s Sidwal and M/s Fedder Lloyds succeeded in producing an acceptable prototype. The refrigerating medium initially used was R-12, which was later replaced by R-22, and later changed to R-134A,being environment friendly. These RMPUs initially used reciprocating compressors but later changed to imported scroll type rotary compressors. Each compressor is rated at 3.75 tons. A RMPU consists of two sub-units, each with its independent cooling system, but mounted in the same housing. For winter months each RMPU is provided with a common heater of 6 KW capacity. Thus, each RMPU is rated at 7.5 tons and has a facility to cut-off one of the sub-units under low heat load conditions. Two RMPUs are provided in each 2 or 3-Tier Sleeper or Chair Car carrying over 46 passengers.

6.3.8 Major Technology Developments

It is a historical coincidence that the entire development and expansion of air-conditioned services to keep up with the demand and expectation of traveling public happened during the post independence period. Some applications of these developments are mentioned hereunder :

6.3.8.1 Endless V Belt Drive

This type of drive was developed by RDSO for bogie-transom mounted machines in late sixties and was cleared after carrying out oscillation trials. The drive was adopted for 2-Tier air-conditioned coaches built by ICF in mid-seventies to drive the 18 kW brush-less generator. This drive used all indigenous materials and proved to be much cheaper than imported Hypoid Gear drive used on the first batch of metal body air-conditioned coaches built in late sixties. The success of this drive was one of the major contributory factors for the decision to replace all old non air-conditioned coaches with 2-Tier air--conditioned coaches.

6.3.8.2 Development of Bulk Inverters

The development of indigenous inverters to convert 110- V DC to 415- V AC 3-phases, with capacity of 25 KVA which could supply power to each RMPU was initiated in mid nineties. Development of a naturally air-cooled underslung Inverter was taken up in 2003. This development was completed in 2005. With this development railways could satisfy the demand for self-generating 3-Tier air-conditioned coaches for use in other trains. Future builds of air-conditioned coaches only employed bulk inverters. The production of air-conditioned coaches with under-lung plant was totally given up in 1996.

6.3.8.3 Electronic regulating and rectifying units (ERRUs)

Majority of the self-generating air-conditioned coaches now use 2 nos. 18 KW alternators, along with their independent rectifier regulating units. These ERRUs (developed in 2003) is a combined unit for both the alternators which ensures equal loading for each alternator, and are of under-slung design.

6.3.8.4 Control Units for RMPUs

These Microprocessor based units, (developed in 2004), control the temperature of the return air from the coach by switching ON and OFF the compressors in the RMPUs in summer and switching ON and OFF the heaters in winter. They ensure that more than one compressor does not start at a time and the next compressor starts after a preset time delay from the starting of the last compressor.

6.3.8.5 Refrigeration Gas

Initially wooden body, as well as metal body, coaches had used R 12 gas as refrigerating medium. The RMPUs when initially developed had used R 22 gas as refrigerating medium. As both these gases are not environment friendly, the latest RMPUs built after 2004 use R 134 A, which is environment friendly.

6.3.8.6 Sealed Batteries

From 2000 onwards, only sealed batteries are provided on all self-generating coaches, in capacities ranging from 330 Amp. Hrs. in full air-conditioned 1st classes to 800 Amp. Hrs. in 2-Tier and 1100 Amp. Hrs. in 3-Tier-coaches. This has considerably reduced running maintenance man-hours as need to add distilled water has reduced considerably.

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CHAPTER 7

ELECTRICAL MULTIPLE UNITS

7.1.0 BRIEF HISTORY

7.1.1 DC EMUs

With Railway Electrification starting in India in Mumbai region of the erstwhile GIPR (now Central Railway) and BBCR (now Western Railway) at 1500V DC, both Railways decided to run commuter train suburban services based on **Electrical Multiple Units (EMUs)**. The first service ran on 3rd February 1925, from Victoria Terminus to Kurla via Harbour Line.

While choosing the EMU stock, width of the stock became an important parameter. It was decided that 12' wide coaches would be used instead of 10'8" wide coaches which was the all India standard moving dimension. The 12' wide coaches provided over 22 % more passenger carrying capacity under dense crush peak hour loading condition. A 4-car unit could carry almost 250 more passengers.

After Independence, with the increased traffic requirement, other imported stocks were introduced from 1951 onwards. While the earlier units were with vacuum brakes, all further stock was with pneumatic brakes. Initially all the stock was imported from Europe. However, subsequently imports of the entire stock or the electrics were made from Japan also. In due course manufacture of EMUs was started in India, including the electrics.

All these EMUs were of straight DC type, drawing 1500 V DC from OHE and driving DC Traction Motors with cam shaft voltage control.

7.1.2 A.C. and A.C./D.C. EMUs

By mid fifties electrification had started in Eastern region, first on 3000 V DC system and then on 25 KV AC. To meet the requirements of suburban system, in 1958-59 Railways inducted 16 nos. 3- coach units with one spare motor coach of 3000 V DC/ 25KV BG EMU stock purchased from M/s Machison Fabric Augsburg Nuraberg (MAN) with electrics supplied by Allgeneine Electricitats Gesellschaft (AEG). This stock was put in service on the Eastern Railway.

In the same year (1958-59) another 16 three coach units of 3000 V DC BG EMU stock were inducted, purchased from M/s SIG Switzerland. One of these units was later converted to1500 V DC operation and put into service on Western railway in 1960-61. Twelve of these units were also converted to dual voltage (3000 V DC / 25 KV)

By this time (1959), M/S Jessop & Co based at Calcutta were ready to build coaches for EMU stock and sixteen three- Coach units with one spare motor coach of these first time indigenously built units were purchased from them in 1959-60. Electrics for this stock were imported from AEG.

By the end sixties Indian public sector giant, Bharat Heavy Electricals Ltd. (BHEL) started manufacturing electrical equipment for EMUs and with coach manufacture by M/S Jessops, **history was made as totally indigenous EMUs started entering Indian Railways.**

In the mean time, by late sixties, Integral Coach Factory (ICF) of Indian Railways, situated at Madras (now Chennai) also established capabilities to manufacture EMU coaches, both 1500 V DC for Central & Western Railways and 25KV AC for Eastern Railway. Since then all EMU stock requirements have been met by ICF for all Indian Railways where EMUs have been progressively introduced for commuter traffic.

With the conversion of Sothern Railway's Meter Gauge suburban section at Madras to 25 KV AC system, ICF also supplied the required MG AC EMUs.

7.1.3 Three Phase EMUs

By mid nineties, Indian Railways had taken two important decisions:

- To upgrade the technology of EMUs to the energy efficient and maintenance friendly Three Phase Drive, and
- To convert the 1500V DC system of electric traction in Mumbai area, to 25 KV AC system, in uniformity with the entire Indian Railway system.

The process of conversion to 25 KV system necessitated induction of dual voltage (1500V / 25 KV) EMUs for the period of conversion. Technologically the three phase drive was ideally suited for dual voltage EMUs.

Thus, it was decided to procure three phase drive kits to be used for retro fitment in the existing DC stock and also for manufacturing new EMUs at ICF. To start with, three phase drive kits were procured from M/s ALSTOM and M/s BHEL.

7.1.4 Main Line EMUs (MEMUs)

Apart from metropolitan areas of Mumbai, Kolkata, Delhi and Chennai, Indian Railways run a large number of short distance commuter trains around other important towns. These trains had the disadvantages of slow speed, low acceleration and braking, less passenger capacity due to having normal main line coaches, and lower efficiency as one loco was hauling only 8 to10 coaches. The average speed of these trains was very low. Being slow and having frequent stoppages, these trains drastically reduced the sectional capacity.

It was felt that EMU type trains, with their characteristic fast acceleration and braking, could be used for such services. However traditional EMU stock posed severe limitations as high level platforms are required at every station and major structural modifications are required to run the 12 feet wide EMU stock as against the clearances being available only for the traditional 10 ft. 8 inches stock.

Thus came up the idea to develop a new type of stock, incorporating the required features of both the main line coaches and EMU type drive. This stock has been named as Main Line EMUs, MEMUs in short.

The 10’-8”or 3250 mm wide 25 Kv AC BG stock designed by RDSO was manufactured by ICF during the last quarter of 1993-94. It was initially commissioned by the Eastern Railway on Bardhman- Asansol section in Septembr1994. The bogies of these coaches are similar to existing AC EMU stock, while the shell is 3250 mm wide, similar to main line coaches with the provision of stairs and vestibule. The four-coach unit formation is DMC-TC-TC-TC. All electrics on MEMUs are supplied by M/s BHEL similar to 12ft AC BG EMUs. The units are provided with Electro- Pneumatic brakes similar to existing EMUs.

The MEMU services are fast becoming very popular on all electrified sections and have already been introduced on East Central, Western, Northern, Eastern, South Eastern, South Central, and Southern Railways.

Main advantages of MEMUs over conventional loco hauled trains can be listed as under:

- Higher acceleration and braking resulting in reduced travelling time between stations – on an average there is a saving of 11 minutes per 100 kms. in travelling time as compared to loco hauled passenger trains.
- Higher average speed.

- Better reliability, as failure of one motor coach does not affect the train running.
- Quick reversal, as driving cabs is at both ends.
- Higher passenger capacity per coach - 230 passengers per MEMU coach, as compared to 185 passengers in normal passenger train coaches.
- With abundant power available from OHE, coaches are provided with better illumination
- Lower overall capital costs

Optimisation studies by computer simulation of MEMU vs. loco hauled passenger train services in Tundla - Kanpur section of Northern Railway (taking it as a representative main line section) were carried out in October 1999 by RDSO and it was found that there is a saving of 24 mins. in total running time in MEMU trains as compared to loco hauled trains. These findings were further verified with actual trials in the same year in Tundla - Kanpur section with a 12-car MEMU train and 12 coach loco-hauled passenger trains. A saving of 60 min. in total running time with MEMU was observed.

7.2.0 CAPACITY AUGMENTATION

7.2.1 With a given infrastructure, the line capacity is totally dependent on inter-sectional running time. Lower the inter-sectional running time, higher the line capacity. EMUs and MEMUs make the most significant contribution in increasing the line capacity due to their intrinsic characteristic of higher acceleration and deceleration. Essentially, there is severe limitation to maximum acceleration and deceleration in a loco hauled train, which is limited by adhesive capacity or "ADEHSION". In case of EMUs and MEMUs, since tractive power is distributed all along the train, much higher values of adhesion are achieved resulting in higher acceleration and deceleration. This, in turn, provides greatly reduced inter-sectional running time contributing to augmented line capacity.

7.2.2 There are some other factors that also contribute to capacity augmentation with EMUs and MEMUs. These include:

- With driving cabs at both ends there is no time lost in reversal of motive power at terminals, thus making it possible to run increased services with a given number of coaches.

- As the tractive power is mounted under-slung, loco space is replaced by revenue earning coach.

7.3.0 WAY AHEAD

7.3.1 IGBT based three phase technology has already proved to be a more efficient and maintenance friendly technology. Its energy efficiency is further improved by almost 35 to 40 % due to use of regenerative breaking. Indian Railways are now gradually switching to the three phase propulsion in EMUs and MEMUs.

7.3.2 With adequate power available from OHE, public demand of running air conditioned suburban trains can be easily met. There is already a proposal to manufacture two air conditioned EMU rakes for Mumbai area on experimental basis.

7.3.3 The intrinsic advantage of higher acceleration and deceleration in EMU type trains is now proposed to be utilized in some of main line trains. Such trains are called 'Train Sets'. It has been estimated that more than three hours' running time can be knocked off Rajdhani train between Delhi and Mumbai. Besides, such train sets will not need power cars as all the electric load can be drawn from OHE, thus releasing revenue earning capacity.

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CHAPTER 8

DIESEL MULTIPLE UNITS

8.1.0 DMU's were developed for meeting the needs of the fast growing population centers to reap the following benefits:

- Fast and frequent services
- No need for reversal facilities
- Low capital & maintenance cost
- Minimum damage to environment
- Efficient use of rolling stock.

8.2.0 BG DMU : Two types of stock were conceptualized: Diesel electric (DEMU) and Diesel hydraulic (DHMU).

- DEMU : This is a three coach unit consisting of one power car, one trailer car and one trailer cum drive unit. The manufacture was undertaken by ICF. After oscillation trials, the prototype was commissioned in October '94. Up to 2002, 56 sets of DEMUs (each consisting of 3 coaches) had been manufactured. Combination of diesel engine model VTA 17102/INTAC 3412 TA and electrics supplied by NGEF/BHEL/KEC were used. The DEMUs were earlier cleared for operation upto 80 km/h. Later they were suitably modified for operation upto 100 km/h .

- DHMUs: DHMU incorporates under-slung power pack and transmission for 3 coach set unit. After oscillation trials, the prototype was put to commercial use in July '97. Uptil 1202, 3 sets of DHMUs each having 3 coaches had been made. The DHMU is powered by twin underslung power pack, each consisting of engine NTA 855R and Voith transmission T 2111rz. The DHMUs were cleared for operation upto 95 km/h.

- 1400 HP high power DEMU : It was decided to develop a high horse power diesel multiple unit for suburban sections on Indian Railways. A feasibility study brought out immense potential of such stock for non- electrified sections of IR. The prototype 1400 HP DMU was manufactured at ICF /Chennai & cleared for operation upto 100 km/h. Later, more than 20 nos of these DEMUs were manufactured.

8.2.1 The DEMU incorporates the following equipments:

(a) One Cummins KT A 3067 L fuel efficient diesel engine capable of producing 1400 hp under standard conditions along with accessories and excitation control & speed governing LCC system.

(b) One BHEL make traction alternator model TA 7003 AZ.

(c) One BHEL Make three phase bridge type rectifier.

(d) Four BHEL Make 4303 AZ model traction motors.

(e) One Kerala Electrics Make Auxiliary alternator with voltage regulator.

(f) One complete set of BHEL Make propulsion control equipment.

8.2.2 The operating requirements were:

(a)	Maximum operating speed	100 km/h
(b)	Gear ratio	20.91
(c)	Motor Grouping	4 P Permanent
(d)	Maximum tractive effort at start	15,000 kg.
(e)	Continuous rating tractive effort.	7100 kg.
(f)	Installed power (standard condition)	1400 hp.
(g)	Installed power (site)	1370 hp.
(h)	Power input to traction (site)	1250 hp.

8.3.0 MG DMU : The following types were conceptualized:

- On board electric transmission version.
- Underslung hydraulic transmission version.
- It was also decided to convert MG coaches to DMU in Izatnagar Workshop of N.E.Railway. Railway Board directed that initially only one MG DMU set of 3 coaches should be manufactured and based on field performance two more sets of DMU will be ordered. The prototype DMU was manufactured and cleared for operation at a speed of 55 km/h.
- MG DEMU : Development of 350 HP MG diesel Electric Multiple Unit was also done.

Achievements

SN	Year	Area	Title	Description	Likely Benefits
1.	2007-08	Passenger amenities	Development of 3-phase 1600 HP AC-AC DEMU	Design and development of 3 phase AC/AC DEMU has been undertaken by RDSO.	Less requirement of maintenance of DEMU.
2.	2008-09	Passenger amenities	BG DEMU for J&K	Diesel Electric Multiple unit for J&K section with speed potential of 100km/h has been designed with provision to meet the cold climate of J&K.	DEMU (J&K) has provided an economic, efficient and reliable supplement to the existing means of transportation in J&K.

Achievements: Design Development of Traction Stock for IR

Diesel Hydraulic Multiple unit Passenger Service Broad Gauge

- 700 hp gross power
- Speed potential upto 95 km/h
- Axle load 17 t Under-slung Cummins engine and Voith transmission Passenger capacity 854.

	**Diesel Hydraulic Multiple unit Passenger Service Meter Gauge** • 350 hp gross power Speed potential upto 75 km/h Axle load 11.96 t • Electric transmission Passenger capacity 1184.
	**Diesel Electric Multiple unit Passenger Service Broad Gauge** • 1400 hp gross power Speed potential upto 100 km/h • Air springs on the bogies for comfort riding • Transmission-electrical • Passenger capacity 1092.

Current / Future Projects

- Development of 1600 HP AC-AC Diesel Electric Multiple Unit (DEMU).

8.4.0 RAILBUS

Rail Bus was developed for sparsely populated areas with requirement of frequent service and to have the following benefits:

- Low capital investment.
- Minimum facilities for maintenance.
- Low operation & maintenance cost.
- Low axle load & track friendly.

- Frequent and efficient service.
- Use of indigenous equipment with easy inter-changeability.
- For BG, these were conceptualized as 2-axle light weight vehicles. With assistance from RDSO development work was taken up by M/s BEML, Bangalore for 5 BG railbuses. After oscillation trials, the prototype was put to commercial service in Oct. '94. The remaining 4 railbuses were commissioned subsequently. The railbuses were cleared for operation up 60 km/h.

Railbus
Passenger Service Broad Gauge

- 152 hp gross power
  Speed potential upto 70 km/h
- Axle load 14 t
  Frame mounted Cummins engine & hydraulic transmission
- Passenger capacity 152.

Railbus
Passenger Service Meter Gauge

- 120 hp gross power
- Speed potential upto 55 km/h
- Axle load 11 t
- Frame mounted Ashok Leyland engine & hydraulic transmission
- Passenger capacity 120.

8.4.1 Later, another order was placed for 5 nos. more to the same specification. The manufacturer was completed & the same were commissioned.

- With the experience gained in the working of rail-buses, development for an upgraded version calling for an operating speed of 70 km/h was taken up for 10 nos. of rail-buses .

- For MG, two designs were developed one consisting of two-axled vehicle with new design body and another by conversion of 4-axled MG steel bodied coach. For the 2-axle design, a development order was placed on M/s Phooltas Tampers, Patna for 5 nos. of rail-buses. After oscillation trials the prototype was commissioned in Oct.'97. The railbuses were cleared for operation upto 55 km/h. For the 4-axle design, a decision was taken in 1995 to convert some surplus MG coaches to rail-buses. The first rail-bus was commissioned in mid ‘96. Later, 10 such rail-buses have been manufactured by NE Railway. After oscillation trials, these rail-buses were cleared for operation upto 55 km/h.

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CHAPTER 9

MOTIVE POWER – STEAM

9.1.0 STEAM LOCOMOTIVES

9.1.1 George Stephenson, (b.1781), is considered as the inventor/builder/ father of the steam locomotive and the railways. He had a strong practical bent of mind and maintained pumps and engines of local collieries and had made several experiments and improvements. He was appointed by a consortium of Tyneside coal-owners to take over the chief responsibility of all their machinery. Stephenson built the first locomotive, Blucher, which ran in 1814. Between 1814 and 1826, Stephenson was the only engineer in Britain building steam locomotives. The Stockton and Darlington railway achieved historic distinction when George Stephenson was appointed its engineer in 1821 and laid out its 22 miles main line for locomotive haulage. At the time of its opening Stockton & Darlington railway was worked by a mixture of steam and horsepower. The first public passenger train ran hauled by the locomotive "Locomotion" on 27th September 1825. In 1827, the railway claimed a saving of 30 % in the haulage cost per ton-mile – in a comparison between locomotives and haulage costs with horses. Thus the future of locomotive haulage was established.

9.1.2 Another railway, Liverpool and Manchester, started in 1826 and had heavier double tracks throughout. It was the world's first line intended to form a link between two large cities for all classes of traffic. The company decided to experiment to prove whether steam power could be used in the form of locomotive engines. The company advertised during 1829 that they would give a prize to the builder of the locomotive which would meet their difficult conditions. Several locomotive builders competed with their products. "Rocket," built by father and son, Stephensons, was simpler, more robust, more efficient, meeting all the conditions and won the prize and proved the superiority of the steam locomotive.

9.1.3 Soon the Railways caught the imagination of Europe and USA. The imperialist countries particularly the Britain quickly spread railway networks in their colonies. The first steam locomotive that came to India was called "Thomason" named after a dynamic administrator and later principal, Thomason College of Engineering of Roorkee. This locomotive was of 4' -8” wide gauge and it was used for starting earthwork near Roorkee on 22nd Dec.1851 for constructing the Ganges canal. However

"Thomason" was not very successful and there was rejoicing when she accidentally blew up her boiler within six months during a cyclonic storm.

9.1.4 The G.I.P. Company ran the first passenger train in India, and indeed in Asia, on the Indian standard gauge (5'-6") from Bori Bunder to Thane at 15-35 hrs, on 16th April,1853 with 14 carriages and 400 guests hauled by three steam locomotives Sindh, Sultan and Sahib. The second most important train ran on 15^{th} August 1854 from Howrah to Hooghly and was later extended to Pundooah with an unnamed and now forgotten locomotive. However, two locomotives "Fairy Queen" and "Express", of a slightly later vintage (built in 1855), have become very famous, not only in India, but also in the locomotive world. The Fairy Queen is still running a tourist train on Indian railways, and the sister engine "Express" is preserved in the well-known first locomotive POH workshop at Jamalpur, India.

9.1.5 George Stephenson, became the head of a coal mine and the Chief Engineer of a railway and laid over 20 miles of railway lines/track. Stephenson decided to apply to become an accepted qualified civil engineer but his request was turned down, since he had not built any conventional civil engineering works. On hearing this, Stephenson and his tribe, decided to call themselves 'Mechanical Engineers,' and ran the Railways in UK. Same or similar groups of persons came to India to build, maintain and operate the railways. All mechanical engineers, in one railway system, came under the control of a Locomotive Superintendent (later called Chief Mechanical Engineer), who became responsible for design, manufacture, maintenance of locomotives, rolling stock, and all machinery in workshops and loco-sheds, carriage and wagon depots. All Chief Mechanical Engineers, however, continued to report to Member Engineering, of the Railway Board. Member Engineering was assisted by a mechanical engineer, called Director, Mechanical Engineering, till 1947. In view of increasing complexity, volume and specialisation of mechanical engineering work, Director, Mechanical Engineering was elevated to become an Additional Member Mechanical, Railway Board. Finally, in 1952, a full-fledged Member Mechanical, took charge of the Mechanical and Electrical departments, relieving the existing Member Engineering of these responsibilities.

9.1.6 Again, in 1987, with increasing general electrical engineering work and electrification of the railways, another member, designated as Member Electrical, took independent charge of the Electrical Department and the Signalling department was also placed under his charge.

9.1.7 The first challenge the Indian Railways presented before the railway builders for Indian railway system was the selection of a 'gauge' from the different gauges prevalent. The next challenge was that of standardisation of moving dimensions, sizes and types of locomotives and boilers suitable for inferior quality of coal available in India, in contrast to the high quality coal available in UK. The following extract from the administrative report on the railways in India for the year 1902 by Bremerton, Secretary to the Govt. of India, PWD (Railways) dated 23rd May 1903 is interesting.

9.1.8 "Mr. C.W. Hodson, Director of Railway construction was deputed while in England, by his Majesty's Secretary of State, India, to consult the English authorities regarding -

- the relaxation of existing standard dimensions for Indian Railways in relation to the fixed and moving dimensions and the regulations regarding the strength of bridges and axle loads and the weight of rolling stock, and
- the placing of orders for rolling stock in advance.

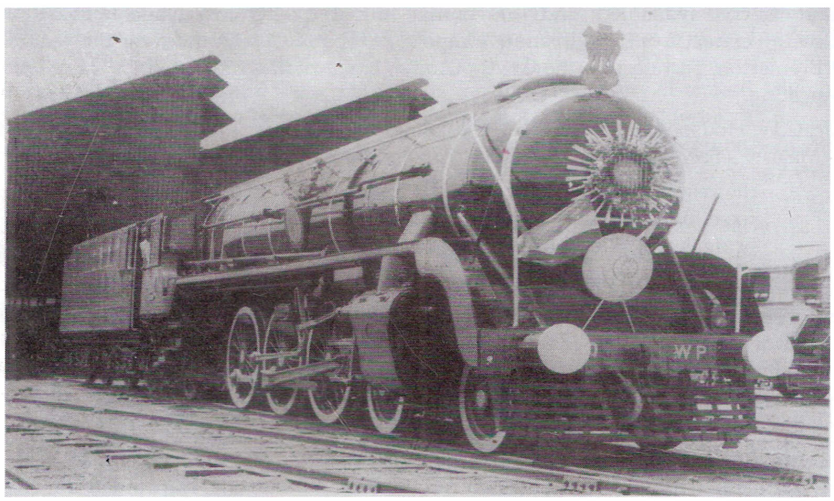
9.1.9 The policy of Standardisation of locomotives in India started around 1901. It was felt that if standardisation could be adopted (in place of each Railway Administration developing its own locos) it would facilitate of exchange of power (locos) between different railways, limit the requirement of spare parts and enable manufacturers to deliver engines in shorter time-frame and at lesser cost.

9.1.10 Accordingly, in 1903, the Secretary of State approached the British Standards Association (B.ES.A.) and a committee was set up representing all interests. It included a member with first-hand knowledge of Indian conditions, namely a representative of the Indian Loco Superintendents Committee of Indian Railway Conference Association. As a result, B.E.S.A. design was completed for seven BG types and three MG types. The designs made provision for maximum degree of interchangibility of various components between the various types. By 1910, orders had been placed for 840 BG and 470 MG standard B.E.S.A. engines.

9.1.11 The Great War (1914 to 1919) forced the system to stagnate and further development work almost stopped. The War also resulted in an increase in the cost of first grade Indian coal. The Board and Railway Companies (particularly BB&CI) and ER felt an urgent need for economy measures and pursued them rigorously.

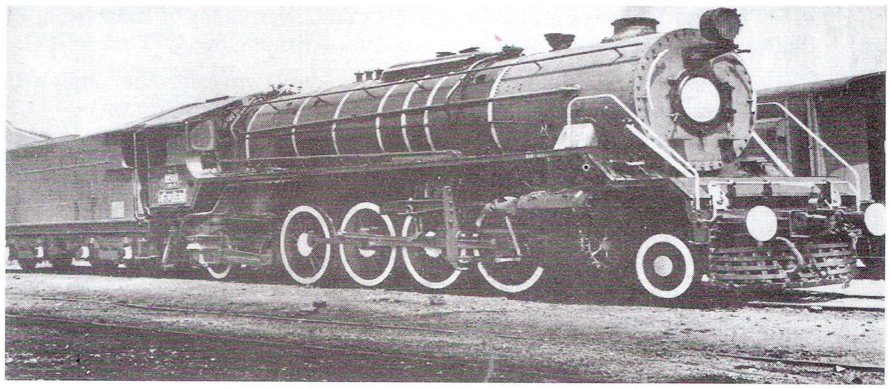
9.1.12 One way was by extending the use of second grade coal, supplies of which were ample particularly in certain collieries acquired by the Railway

Board. Investigations into boiler ratios of existing types of locos indicated that existing locos would be unsuitable for economic use of this (second grade) coal and to obtain necessary boiler horse power, wide fireboxes were essential. There was a demand for the wheel arrangement of the Pacific type (4-6-2) in place of existing narrow 4-6-0 type to obtain sufficient power to meet anticipated need for heavier loads. The BB&CI initiated certain experiments on MG engines in 1919. It was proposed to introduce new types of engines (Pacific wide Fire box Type), boilers of goods and passenger engines being interchangeable. The cylinders and moving parts,(with the exception of connecting, coupling and eccentric rods), were also interchangeable.



1st WP Steam Locomotive 'Vivekananda'

9.1.13 The success of the trials with extra-wide fireboxes, encouraged the adoption of a similar arrangement for BG too. Six Pacifics accordingly arrived in 1924. After sufficient running of these engines, the I.R.S. designs for series of engines (XA, XB, XC, XD, XE, & XF) were finalised. A large number of these new IRS design locos., XA, XB, XC, arrived from 1928 onwards and continued in service. One of these locomotives, XB, working a passenger train running at about 45 miles an hour derailed in mid section near BIHTA railway station in Bihar in July,1937. The cause of the accident could not be easily ascertained. A high level inquiry committee called Pacific Locomotive Committee, consisting of locomotive engineers of international standing, was constituted by the Govt. of India. The committee's findings highlighted the little known, but important, factors of vibrations, oscillations, hunting and nosing of these types of locomotives. These findings substantially influenced the design and manufacture of future locomotives. IR evolved the new designs of W Series (WP, WG, WT, WL, CWD for broade-guage & YP, YG, YL, YT for metre-guage) of IRS locomotives. These Indian locomotive designs were the last to be manufactured in India, indeed in the world, and put into service on IR. These faithful warriors served IR from 1940 onwards till 1995.



WG Locomotive

9.1.14 In Oct.1923, Railway Board decided, in consultation with the Agents, that a Committee (to be known as Loco Standards Committee) be constituted to give effect to the Board's policy of "progressive standardisation as a continuous process." The Loco Standards Committee (L.S.C.) continued to function till 1930, up to which time the technical work of the committee, in the way of design and preparation of drawings, etc. had been carried out by the Consulting Engineers and by a Technical section of the Railway Board's office. The objective of forming the Central Standards Office in 1930 under the Chief Controller of Standardisation was to standardise all equipment commonly in use on Railways and to provide means whereby "standardisation could be progressively effected in accordance with changing conditions and as a result of practical experience". On the Mechanical side, the office appears to have confined its attention, until 1936-37, almost exclusively to I.R.S. designs of rolling stock. In 1937, a decision was taken that part-drawings system should be extended to all the standard types of locomotives. As a beginning, the Consulting Engineers were asked to arrange with the builders for the preparation of drawings as a part of fulfilment of current contracts. Subsequently, in 1957, the organisation became R.D.S.O., to serve all the needs of IR in Research, Design, Testing and Standardisation.

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CHAPTER 10

MOTIVE POWER – DIESEL

10.1.0 The history of dieselisation of Indian Railways dates as far back as 1911 when a few low horse-power diesel locos were obtained by the tea plantations. Much later, around 1930, two broad gauge 350 hp BO-BO diesel locos were procured for North Western Railway. Thereafter, in 1936, one broad gauge 330 hp Armstrong-Sulzer diesel electric shunting loco was obtained for Bombay Baroda Indian Railway. This loco gave service for a number of years. Apart from these experimental engines, no other procurement was done and dieselisation was confined only to a few diesel rail-car services.

10.1.1 In the forties, the company owned Railways, and subsequently the Government of India too, went in for bulk purchases of diesel locos -

(i) In 1945, sixteen WDS1 diesel shunters powered by twin caterpillar engines (2x193hp), manufactured by International General Electric company of USA were purchased. Most of them were utilized in the BB&CI Railway.

(ii) In 1954, another batch of 30 diesel Hydraulic shunters (400 hp) WDS2, manufactured by M/s Krauss & Maffei of West Germany, were procured. These locos were powered by MAN engines and were allotted to Western Railway and subsequently homed at Kurla Diesel shed of Central Railway.

(iii) The year 1955-56 saw the arrival of 20 YDM1 Meter gauge main line locos supplied by North British Locomotive Company. These locos had five 634 hp Paxman Engines and with hydraulic transmission. These locomotives were allotted to the Western Railway and stationed at Gandhidham for operation on Palanpur--Deesa-Kandla section.

(iv) In the same year,(1955-56), eight N/ZDM1 locos were received from M/s ARN JUNG & Co of West Germany. Out of these locos, 5 were ZDM1 to suit 762 mm gauge for operation in Kalka-Simla Section of Northern Railway. The balance three locos were for 610 mm gauge for operation in Neral-Matheran Section of the Central Railway. These locomotives, which were powered by MWM engines, developing 125 hp were specifically designed for hilly section for negotiation of steep grade up to 1 in 20 and sharp curves of upto 15 metre radius.

10.1.2 All these procurements were sporadic and for specific needs. In the fifties, rapid industrial development in the country started having its impact and demanded much larger transport capacity from the Railways. The Five-Year plans were formulated and, In order to meet the challenge, the Railway Ministry arranged immediate procurement of 100 Broad Gauge (1950 hp) locomotives manufactured by M/s American Locomotive Co (ALCO). These locos were temporarily stationed at Gaya on Eastern Railway and at Chakradharpur on South Eastern Railway in 1958-59. These locos were crucial for meeting the power reuirements of these two railways. The locos were subsequently transferred to the newly built sheds at Patratu and Bondamunda. The Railway Ministry simultaneously embarked on a global survey for large scale procurement of diesel locomotives for both broad and metre gauges. (Indigenous manufacture of diesel locos was also kept in view). As a result, between 1958 and 1973, various types of diesel locos were procured from different countries, particularly from the USA and West Germany.

(i) 7 numbers of WDS3 broad Gauge shunting locos powered by 618 hp Maybak engines were imported from West Germany and put on line in year 1961. The locos were manufactured by M/s Henschel on the basis of RDSO's design and incorporated novel features like the SURI transmission and the SURI reverse Governor. These locos were housed on Northern Railway.

(ii) In 1962, 30 numbers of Metre Guage main-line YDM3 locomotives were imported from the USA. These locos were manufactured by General Motors and were powered by 12 cylinder two-stroke cycle engines developing 1390 hp. These were based on Western Railway's Abu Road shed.

(iii) Subsequently during 1962-63, 72 WDM4 locos manufactured by General Motors, USA for use on mixed traffic service were procured. These locos were powered by 16 cylinder 2-stroke cycle VEE engines. They were originally allotted to SE Railway and subsequently transferred to N. Railway and are presently based in MGS Diesel shed.

(iv) Another bulk purchase was under-taken in 1962, when 40 BG main-line WDM2 locos, powered by 16 cylinder 4-stroke cycle VEE engines producing 2600 hp, were purchased from American Locomotive Company (ALCO). This was followed by purchase of another 212 locos. Along with this purchase contract, collaboration for setting a Diesel Loco manufacturing shop was also signed for manufacture of the Broad Gauge and Metre Gauge locos to ALCO design in India. Altogether, 252 locos including 12 in knocked down condition were purchased between 1962 and 1965. Simultaneously, manufacturing facilities for diesel locos and components were set up at Diesel Loco Works, at Varanasi.

(v) In the same period, i.e. in 1962, 30 numbers of YDM-4 Metre Gauge main-line locos with electric transmission were supplied by ALCO. Subsequent to this, in 1964, another 25 locos were imported. From 1967 to 1971, 170 locos of the type were manufactured by DLW.

(vi) 25 numbers of General Motors, USA built YDM5 locos were put on line on Western Railway and stationed in Abu road Shed. These locos have 12-cylinder 2-stroke engines developing 1390 hp and have electric transmission.

(vii) In 1964-65, 25 numbers of ZDM2 locos built by MAK of West Germany and powered by 700 hp Maybak engine were put online. These locos have SURI transmission with Brockhouse converter coupling and were based at Motibagh Shed of Nagpur, S.E. Railway.

(viii) Between 1964-69, 99 numbers of YDM4A locos were imported from M/s M.L.W. Canada. These locomotives were similar to ALCO locomotives YDM4 and distributed to be based in Metre Gauge main line sheds, Golden Rock (TPJ) and Guntakal Shed of Southern Railway.

(ix) In 1967-68, 31 WDS5 broad gauge shunting locos were imported from M/s ALCO. These locos were powered by 6-cylinder 4-stroke cycle in- line engines developing 1050 hp. The transmission of these locos is electrical.

(x) Between 1979 and 1972, 28 WDS4 locomotives were manufactured in Chittaranjan Locomotive Works and put on line. These locomotives are the improved version of WDS3 locomotives of RDSO design. These are powered by 6-cylinder in-line engines manufactured by MAK producing 600hp at 1000 RPM and are provided with SURI hydro-mechanical transmission.

(xi) Chittaranjam Locomotive Works subsequently built 5 WDS4A locos which are similar to WDS4 except that:

(a) Engine is capable of producing 660 hp at 960 RPM.

(b) Voith transmission is fitted in place of SURI hydro-mechanical transmission.

From 1972 onwards, CLW went into regular production of WDS4B locos which have similar features as WDS 4A locos with the following changes incorporated:

(a) Engine rating 700 hp at 1000 RPM

(b) SURI transmission has been provided; later versions of these locos are simplified SURI transmission WDS-4, 4A and 4B and the locos are distributed all over Indian Railways BG sheds attached to major yards.

(xii) The last type of diesel loco indigenously produced at CLW was the ZDM3 loco. Ten of these locos were manufactured in 1970-71. These locos were powered by a 6-cylinder in-line engine developing 700 hp (same as the MAK design engines fitted on WDS-4 locos). The major equipment/ assemblies/ components are inter-changeable with WDS4 locos. They have hydro-mechanical SURI transmission. These locos are being utilized on the Kalka-Simla hill section of Northern Railway.

In the last 10 years, the following new designs of locomotives developed by RDSO have been manufactured by DLW. These locomotives are now performing very satisfactorily on Indian Railways.

(i) 3100 hp Mixed Traffic Locomotive - WDM2C

(ii) 3100 hp Freight Locomotive-WDG2

(iii) 3100 hp High Speed Passenger Locomotive-WDP2

(iv) 2300 hp High Speed Passenger Locomotive-WDP1

With renewed thrust to tap the export market, new locomotive designs were developed during 1995-2002.

(i) 2600 hp BG locomotive for Bangladesh Railways

(ii) 2300 hp BG locomotive for Sri Lankan Railways

(iii) Full width 2300 hp Metre Gauge/ Cape guage Diesel electric locomotive

(iv) 2300 hp Metre Gauge locomotive for Malaysian Railways.

(v) YDM4 locomotive for Vietnam Railways.

10.1.3 To give further impetus to the development of diesel locomotives, 4000 hp locomotives, both for freight (WDG4) and passenger (WDP4) operations, were imported from General Motors, USA during 1999-2001. DLW has already started manufacturing both WDG4 and WDP4 locomotives indigenously.

10.2.0 ACHIEVEMENTS

10.2.1 Over the years, a number of developments/improvements in areas of **safety**, **reliability**, **increased through-put**, **green technology**, crew comfort etc. were incorporated by RDSO/DLW/CLW in loco design. These are summarized below.

S.N.	Year	Area	Title	Description	Likely Benefits	Status
1.	2007-08	Crew comfort	Development of Cab Air Conditioning System for Diesel Electric Locos	Cab air conditioning system includes one AC unit in the driver's cab with input power supplied by an auxiliary source.	The locomotive cab air conditioner assembly will provide interior cab temperatures in a comfortable range throughout the year.	Installation of Cab ACs have started at DLW.
2.	2007-08	Freight Throughput	Development of WDM3F 3600 HP locomotive with GE Electrics.	GE electrics with enhanced capacity	Increased horse power.	Manufactured
3.	2007-08	Reliability	Design and development of Advance trimount high speed (ATHS) bogie frame for WDM3A & WDS6Adt locomotives	The bogie has been designed with advanced suspension elements	Ease of maintenance and cost reduction	Running in service since 2011
4.	2007-08	Safety	Development of WDP4B 4500 HP locomotive in place of WDP4 locomotive.	Improved driver visibility at long hood direction with wider cab	Improved visibility, Increased Tractive effort.	Switched over to this design from 2009

5.	2008-09	Reliability	Design & development of High adhesion, high-speed (HAHS) equaliser less bogie for WDM3D locomotive	Reduction of un-sprung mass of the bogie by elimination of compensating and equaliser linkage	Ease of maintenance	Running in service since 2009
6.	2008-09	Reliability	Design of new, reliable and maintenance friendly bogie for WDP1 locomotive	Bogie has been designed with provision of rubber spring in secondary stage and wing type axle box	Rehabilitation of old WDP1 locomotives	A locomotive had been modified and running since June'10.
7.	2009-10	Passenger amenities	Design of EMD family WDP4 variant locomotive with Hotel Load capability	To eliminate power car from Rajdhani / Shatabdi rakes by providing hotel load facility in the locomotives.	Reduction in number of power cars results in increased passenger throughput.	The first locomotive has been deployed in passenger train.
8.	2009-10	Safety	Development of 4500 HP dual cab WDP4D loco.	Provision of cab at both ends.	Crew visibility improved In the both direction.	Locomotives have been manufactured and are successfully in the service.
9.	2010-11	Export	2300 HP Diesel loco for Sri Lanka Railways.	Roof-mounted DBR, stainless steel superstructure.	Stainless steel super-structure is corrosion resistant in coastal and tropical area	Manufactured and exported
10.	2011-12	Freight Throughput	Design & development of 5500 HP WDG5 Diesel locomotive	20 cylinder engine, unitized E locker, radial DBR.	High horse power, higher T.E	Loco will be deployed after oscillation trial

11.	2011-12	Green Technology	Development of Specification for procurement of New Generation Power Pack keeping in mind state-of -the-art emission control and fuel injection system	Specification for New Generation Power Pack has been finalized.	To achieve higher horse power i.e in the range of 3300 HP with low emission and high fuel efficiency.	DMW Patiala will be taking further action.

WDM2 Diesel Electric Locomotive

- Mixed Service Broad Gauge
- 16 cylinder fuel efficient 251B engine 2600 hp gross power
- Axle load 18.8 t Maximum operating speed 120 km/h
- Co-Co tri-mount bogie
- AC-DC transmission

	**WDM3D Class Diesel Electric Locomotive** • Mixed Service Broad Gauge 16 cylinder up-rated fuel efficient 251B engine • 3300 hp gross power with hotel load facility • Axle load 19.5 t • Maximum operating speed 120 km/h Co-Co high adhesion bogie • AC-DC transmission with micro-processor based control system

	**WDG4 Class Diesel Electric Locomotive** • Freight Service Broad Gauge 16 cylinder 2-stroke fuel efficient 710GB engine • 4000 hp gross power Axle load 21 t • Maximum operating speed 100 km/h High Adhesion HTSC Co-Co bogie • 3-phase AC-AC transmission EM2000 microproceesor control computer

WDP3A Class Diesel Electric Locomotive

- Passenger Service Broad Gauge 16 cyl. uprated fuel efficient 251B engine
- 3100 hp gross power
  Axle load 19.5 t
- Maximum operating speed 160 km/h
  Co-Co 2-stage 3-axle flexi coil bogie
  AC-DC transmission

WDP4 Class Diesel Electric Locomotive

- Passenger Service Broad Gauge 16 cylinder 2-stroke fuel efficient 710G3B engine
- 4000 hp gross power
  Axle load 19.5 t
- Maximum operating speed 160 km/h
  High Adhesion HTSC (A-A-I 1-A-A) bogie
- 3-phase AC-AC transmission
  EM2000 microprocessor control computer

10.3.0 CURRENT / FUTURE PROJECTS

- Development of high speed self propelled accident relief train (SPART) for faster travel to accident site.
- Design of disc brakes for WDP4 locomotives.

- Development of compact Computer Controlled Brake (CCB) system for both EMD & ALCO locomotives.
- Design and development of IGBT-Inverter based 4500 HP locomotive with hotel load capability.
- Development of 3600 HP mixed-service locomotives.
- Design and development of 5500 HP freight locomotive.
- Remote Monitoring and Management of Locomotive and Trains.
- Design and development of Cape gauge version of WDM2, WDP1 & WDM7 for NRC.

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CHAPTER 11

MOTIVE POWER – ELECTRICAL

11.1.0 BRIEF HISTORY

The story of Electric Motive Power on Indian Railways can be told in two distinct parts consisting of 1500 V DC Electrification and 25 KV AC Electrification.

11.1.1 DC Electrification

Railway Electrification first came to India, in the form of 1500 Volt DC Traction, in the decade of 1920s, essentially for handling the ever increasing commuter traffic in the then Bombay area and for movement of freight and passenger trains from Bombay to hinterland involving movement across the Thull and Bhor ghats (hill sections) with ruling gradient of 1 in 37.

11.1.1.1 First Electric Locomotives

Two types of electric locomotives were imported. i. EF/1 locomotive, weighing 125 t with maximum speed of 72.5 kmph and delivering maximum Tractive Effort of 42800 kg, for main line freight operation and banking duty on the ghat sections. ii. EA/1 locomotive for passenger trains, weighing 103 t with a maximum speed of 136.5 kmph, delivering maximum Tractive Effort of 15241 kg.

11.1.1.2 Mixed Traffic Locomotives (Imported):

Soon after independence, with increase in traffic, there was need for augmentation of locomotive fleet. It was decided to import Mixed Traffic Locomotives (known as WCM types) which could be used for both the Passenger as well as the Freight traffic.

11.1.1.3 In the mean time electrification at 3000 V D.C. had started in Eastern region around Kolkata. Again mixed traffic locomotives were imported. Subsequently, with conversion of traction system in Kolkata area to 25 KV A.C., these locomotives were converted to 1500 V D.C. and shifted to Central Railway.

11.1.1.4 Following different types of mixed traffic locomotives were imported:

S. No.	Particulars	Class of locomotive			
		WCM/1	WCM/2	WCM/3	WCM/4
1	Year Put on Line	1955	1957	1958	1961
2	System Voltage	1500V DC	3000 V DC (Subsequently converted to 1500 V DC)	3000 V DC (Subsequently converted to 1500 V DC)	1500 V DC
3	Max Speed	120.5 kmph	120.5 kmph	65 kmph	120.5 kmph
4	Max T.E.	31000 kg	31298 kg	28200 kg	31250 kg

11.1.1.5 CLW Built DC and Dual Voltage Locomotives:

i. WCM/5 Locomotives:

By late fifties it was decided to convert Chittaranjan Locomotive Works (CLW) of Indian Railways to manufacture Electric Locomotives. The first electric locomotives built by CLW in 1961 was designated as WCM/5 class DC locomotive meant for 1500 V DC operation on Central Railway.

ii. WCG/2 Locomotives:

By late sixties it was time to start retiring the initially imported EF/1 locomotives, by which time, both RDSO and CLW, had acquired fairly good expertise in design and manufacture of electric locomotives with some equipment support from Indian Industry. A new DC loco of WCG/2 class (for freight operation) was manufactured at CLW.

iii. WCAM Locomotives:

Electrification beyond Mumbai was done on 25 KV AC, and the existing DC section, particularly on Western Railway, was too small to support fleet of DC locos. It was therefore decided to go in for dual voltage locomotives, which could work on both the systems – 1500 V DC as well as 25 KV AC. This gave rise to a new hybrid design loco of WCAM series (WCAM/1 and WCAM/2)

11.1.2 A.C. Electrification

It was in 1957 that Indian Railways decided to adopt 25 KV, 50 cycles, single phase AC system for Railway Electrification, simultaneously starting the process for acquiring AC locomotives. The progress of AC locomotives on Indian Railways can be divided into following three distinct phases:

i) Imported Design

ii) RDSO Design

iii) Modern Three Phase Technology (including High Horse Power Thyrister Locomotives)

11.1.2.1 Imported Design

Initially two makes of the mixed traffic locomotives, were imported, WAM 1 from the European Group – called The 50 Cycles Group, and WAM 2 from the Japanese Group – led by Mitsubishi. Both types were fitted with ignitron type mercury arc rectifies and the first WAM1 loco arrived on 30th November 1959. Later, for haulage of heavier goods trains, need was felt for a higher tractive effort locomotive with higher adhesion coefficient, dedicated only for goods traffic. Again, three types of such locos were imported, with an option for transfer of technology (TOT) with intention to take up their manufacture by CLW. These consisted of WAG1 and WAG3 class from the 50 cycles European Group and WAG2 class from Japanese Group. Ultimately WAG1 class was selected for series production in India at CLW. First loco was turned out in 1963. Further, in order to meet the ever increasing locomotive haulage capacity requirements, these locomotives were upgraded from 3000 KVA rating to 3460 KVA rating by upgrading the traction motor from MG-1420 (1420 KW) to MG–1580 (1580 KW). This is the maximum power which could be fixed within the existing monomotor bogie of WAG1. The rating of the transformer was also suitably increased.

Keeping pace with the rapid technological developments, particularly in the field of solid state electronics, the WAG1 class locomotives were upgraded to WAG4 class, replacing ignitrons/excitrons with silicon rectifiers and modification/up gradation of other major equipments like transformers, Arno converters, auxiliary machines, blowers, compressors, exhausters, circuit breakers, pantographs and tap changers, mostly developed through Indian industries.

11.1.2.2 RDSO Design

Six Axle Locomotives

During the period of nineteen sixties and seventies the rapid increase in rail traffic was far ahead of development of railway infrastructure – track, bridges and even length of loops to accommodate freight trains. Call of the time was to increase throughput with existing infrastructure. The motive power was called upon to give higher tractive effort with higher balancing speeds and reliability. AC locomotives of 'Imported Design' fell far short of such requirements. **It is at this time that RDSO, who had so far not gone beyond writing simple performance specifications, was landed with the task of designing an AC Electric loco that could meet the stringent performance requirements**. Thus started the evolution of six axle AC locomotives on Indian Railways.

The first six axle AC locomotive was mixed traffic WAM4 type, introduced in 1970.

Since then, in order to meet the ever increasing capacity demand of higher loads and speeds, **without having to invest in infrastructure**, many different versions of six axle AC locomotives were developed and manufactured. Salient features are given in the table below:

Class of loco	**WAM 4**	**WAG 5**	**WAP 1**	**WAP 3**	**WAP 4**	**WAP 6**	**WAG 7**
Service	**Mixed**	**Goods**	**Passenger**				**Goods**
Year of introduction	1970	1984	1980	1987	1994	1998	1992
HP rating	3640	3850	3800	3760	5000	5000	5000
Maximum speed (kmph)	120	80	130	140	140	160	100
Total weight (tones)	112.8	118.8/123.0	108.3	112	112.8	113	123
Maximum tractive Effort (tones)	33.8	33.5	22.4	22.4	32.4	30.8	44

Any special feature	Trimount Bogies first adopted for Electric Locomotives. French designed TAO 659 Traction Motor adopted in Series and Series-Parallel combinations.	A higher rated transformer HETT-3900 replaced BOT-3460. Smoothing reactor SL-42 replaced by higher rated SL-30. All six TMs connected in parallel.	Motors are grouped in 2S-3P combination with weak field. Modified for MU operation.	Flexicoil bogies, with higher speed potential, introduced.	Quantum jump with Indigenously designed higher power rated silicon rectifiers, 5400kVA transformer & Hitachi traction motors.	Inducted High-adhesion fabricated bogies (Flexicoil Mark IV).	Quantum jump with Indigenously designed higher power rated silicon rectifiers, 5400kVA transformer & HS-15250 Hitachi TMs.

11.1.2.3 High Horse Power Electric Locomotives:

i. 6000 HP Thyrister Locomotives – WAG6

By mid eighties, Indian Railways were planning for a quantum jump in traffic offering and it was recognized that the available infrastructure can be put to optimum use by introducing higher HP locomotives, enabling hauling of higher loads at higher average speeds. As packing higher power in a single locomotive would not have been feasible with existing tap changer technology, it was decided to go in for microprocessor controlled electronics for voltage control for higher horse power locomotives. By that time conventional Thyrister Technology with micro processor control, still using the DC traction Motors, was well established. With a view to select an appropriate and tried design, 18 locomotives of 6000 HP rating of three different designs (six of each design) were imported with the intention to try them extensively and select one for taking up manufacture in CLW, through Transfer of Technology.

In the mean time, with the commercial development of high power rated Gate Turn Off (GTO) Thyrister, use of more robust and reliable Three Phase

Induction Motor for traction had become a reality. It was therefore decided not to proceed with the conventional Thyrister technology and instead adopt the Three Phase Technology which had been fully developed by that time. The 18 locomotives with conventional Thyrister technology have been confined to an isolated section of K-K line of South Eastern Railway.

ii. Three Phase Locomotives:

In July 1993, a contract was placed on ABB, Switzerland (now Bombardier), to procure 30 nos. (20 freight-WAG9- and 10 passenger-WAP5) 6000 HP 'State of the Art' energy efficient, microprocessor controlled, three phase electric locomotives, together with Transfer of Technology (TOT) for eventually manufacturing them at CLW.

Indian Railways were quickly able to absorb the new state of the art technology, both for maintenance and manufacture. **With this development, India became first developing country, second in Asia (after Japan) and fifth in the world (after Switzerland, Germany, France and Japan) to have acquired this capability in the field of three phase GTO technology locomotives.**

CLW has further developed another version - WAP7 – for hauling longer passenger trains at speeds of 130 KMPH. This has been done by minor modifications, particularly in the software, to the WAG 9 locomotive.

These high horse power locomotives have been responsible for making a quantum jump in line capacity on the electrified sections within the existing infrastructure.

11.2.0 CAPACITY AUGMENTATION

Electric Motive Power has made significant contribution in Capacity Augmentation in three distinct directions:

i. Increased horse power per locomotive as compared to other types of traction:

Electric locomotives intrinsically pack higher power for the same axle load and number of axles, with the distinct advantage of hauling higher loads at higher average speeds, resulting in increased line capacity without investment in augmenting the existing infrastructure. Table below provides some examples of comparative data, indicative of the fact that **Electric locomotives have provided comparatively higher Tractive Effort and Higher Horse Power per locomotive within the existing infrastructure:**

Year	1976-77	1986-87	1996-97	2006-07	2007-08	2008-09	2009-10	2010-11
Locomotives in service								
Diesel	1,198	2,032	2,969	3,809	3,933	4,113	4,279	4,470
Electric	824	1,346	2,499	3,294	3,443	3,586	3,825	4,033
Total Tractive Efforts in kgs								
Diesel	31,163,604	54,710,238	83,226,200	120,739,470	124,888,781	135,835,314	140,789,130	151,055,252
Electric	22,105,260	37,808,855	70,594,210	115,283,800	122,193,849	125,684,514	136,951,893	145,623,488
Total Horse Power								
Diesel	2,848,503	4,790,830	7,053,881	10,372,089	10,865,967	11,680,211	12,305,524	12,134,865
Electric	2,715,350	4,657,230	9,118,014	14,583,120	15,501,646	16,342,238	17,519,437	18,825,535
Average Tractive Efforts per locomotive								
Diesel	26,013	26,924	28,032	31,698	31,754	33,026	32,902	33,793
Electric	26,827	28,090	28,249	34,998	35,521	35,049	35,804	36,108
Average Horse Power per locomotive								
Diesel	2,378	2,358	2,376	2,723	2,763	2,840	2,876	2,398
Electric	3,295	3,460	3,649	4,427	4,506	4,557	4,580	4,668

Source : Indian Railways-Annual Statistical Statements (ASS) of respective years.

ii. Continuous increase in horse power/tractive effort through technology up gradation

Electric Locomotives have seen continuous increase in horse power/tractive effort per locomotive through technology upgradation, as brought out under 'History' earlier, **resulting in increased throughput/line capacity.**

iii. Increase in Line Capacity and Asset Utilization through improved reliability:

Reliability of locomotives has a direct bearing on system traffic handling capacity. A loco failure on line eats into line capacity, while a loco under repair is not available for traffic.

There had been continuous effort towards improving reliability of Electric Locomotives. Some of these measures are listed below:

- Switch over from DC auxiliaries to AC auxiliaries.
- Switch over from Mercury Arc Rectifiers (Ignitrons and Excitrons) to solid state Silicon Rectifiers
- Up gradation of Tap Changer technology
- Gradual up gradation of traction motor insulation from class 'H' to class 'C'
- Switch over from SL-42 smoothing reactor to SL-30
- Introduction of running traction motors in 'All Parallel' combination
- Up gradation from trimount bogies to fabricated bogies
- Change over from TAO 659 traction motors to HS 15250
- A leap jump in technology by adopting Variable Voltage Variable Frequency (VVVF) drive three phase technology, using GTOs

These steps have resulted in significantly improved reliability, with improved asset utilization, of electric locomotives, as can be seen from the following table:

Year	**1976-77**	**1986-87**	**1996-97**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**
Electric Traffic engine kms in Thousands (a)*	87,809	148,306	304,953	466,863	507,071	524,249	555,557	589,832
Statistical electric loco failure (b)$	Data not available		4956	2653	2198	1659	1668	1574
Engine kilometer per loco failure (a/b)			61,532	175,975	230,697	316,003	333,068	374,734

*Source: IR-Annual Statistical Statements (ASS) of respective years.

$ Source: Figures published on website by E&R directorate, Railway Board.

All these measures have finally translated into generating additional capacity with Electric locomotives progressively carrying additional GTKMs per loco holding, as seen from figures given in table below:

Year	**1976-77**	**1986-87**	**1996-97**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**
Electric GTKMs (Millions)	19,330	47,633	106,208	776,995	835,030	900,376	956,420	1,008,382
GTKM per Electric loco holding (Thousands)	23,459	35,388	42,500	235,882	242,530	251,081	250,044	250,033

Source: IR-Annual Statistical Statements (ASS) of respective years.

11.3.0 WAY AHEAD

11.3.1 Migration from GTO Technology to IGBT technology

The heart of the 3-Phase locomotive is traction converter which is responsible for conversion of single phase AC drawn from OHE to 3-phase AC which drives the traction motor. In addition, the auxiliary converter feeds the power to all the auxiliary motors in the locomotive machine room. At present, switching device used in these converters are based on Gate Turn Off (GTO) technology. Considering the obsolescence of the GTOs and inherent advantages of Insulated Gate Bipolar Transistor (IGBT), Indian Railways have undertaken project to migrate from GTO technology to IGBT technology retaining same transformer and traction motors.

11.3.2 Features

a. Superior switching speed which enables better control over the voltage and current waveform.

b. Modular design resulting in better maintainability.

c. The existing GTO based traction converter is a group drive, i.e., all the traction motors in a bogie are connected in parallel. While, the IGBT based converter has single axle drive capability giving it capability of isolating individual TMs with attendant better operational reliability and better adhesion performance.

d. Due to the smaller size of IGBT converters it is possible to install additional equipments like hotel load converter in the locomotive.

e. The control hardware of the IGBT converter is based on latest technology with higher processor speed and better control algorithm vis-à-vis existing GTO converter. Due to miniaturization and higher speeds of processors, the number of PCBs has reduced, thus increasing the overall reliability.

f. Availability of electronic components and devices with higher operational temperatures shall give better long term reliability and requirement of less maintenance.

g. The IGBT based Auxiliary converter is equipped with sine wave filter which will improve the life of the auxiliary motors.

h. The IGBT based converters are Train Communication Network (TCN) Compliant.

11.3.3 Current Status (2013-14)

Steps have already been taken for development of the IGBT based converter and developmental orders placed on Indian industry. Almost 50% of total production of 3-Phase locomotive for year 2012-13 and 70% for 2013-14 are with IGBT based converters. It is expected that production of all three phase locomotives from 2016-17 will be with IGBT based convertors.

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CHAPTER 12

RAILWAY ELECTRIFICATION

12.1.0 BRIEF HISTORY OF RAILWAY ELECTRIFICATION

Electric Traction started on Indian Railways with Electrification of Bori Bandar-Kurla section of the erstwhile Great Indian Peninsular Railway on 3rd Feb 1925 on 1500 volt DC system.

Around the world first attempt on Railway Electric Traction is due to Thomas Devenport who successfully demonstrated a small circular railway system driven by a rotary electric motor. This is preserved in Smithsonian Museum in Washington D C. However in 1838 first successful Electric locomotive was run on a 2 Km section of the Railway Line between Edinburgh and Glasgow.

Around 1890, after Electrification of Tramways and Mountain Railways, thinking started on feasibility of provision of AC Electric Traction. On 16th Jan 1905 trials commenced between Seebach and Affoltern (Swiss Federal Railways) of the first Single Phase Electric Locomotive.

12.1.1 Progress of Railway Electrification in India

12.1.1.1 Adoption of 25 kV AC Electric Traction at 50 cycles by Indian Railways

Though Electric Traction had started on Indian Railways (IR) in 1925 on 1500 Volt Direct Current (DC) system in Mumbai area, and extended to suburban section of Chennai, it remained stationary till after independence when it started again in areas around Kolkata at 3000 V DC, in 1957. Thereafter, with the success of the 25 kV Single Phase AC Electric Traction at 50 cycles on SNCF (French National Railway), IR decided to adopt and standardize this system for all future Electrification Projects. Mastering of this technology and successful indiginisation helped IR to become one of the largest Electrified Railway systems in the world. The move also ensured running of Railways at very low prices to the users as the Electrified system ensured insulation from peaking prices of diesel with India becoming increasingly dependent on costly imported Petroleum products.

12.1.1.2 Following events can be considered as some of the earlier landmarks of AC Electrification:

- 15th December, 1959: Official inauguration of the first run of electric locomotive on 3 km double track between the sub-station site and Kendposi Railway Station, marking the initial step of 25 kV Electric Tractions.

- 22nd December 1960: Electric traction on the 58 kms Asansol-Dhanbad (Grand Chord line) and the 18 kms Pradhankhunta (branch line) formally inaugurated by Railway Minister , Shri Jag Jeevan Ram by flagging off a goods train composed of 70 coal wagons with 2300 t trailing load hauled by the Eastern Railway Green coloured locomotive No. 20270.
- 1961: With energisation of Asansol/Kalipahari-Damodar-Chakradharpur and Kandra –Tatanagar-Sini sections and running of iron ore trains from Dongaposi to Burnpur and Durgapur and coal Trains from Dhanbad and Asansol to Tatanagar by Electric locos, the spine of the electrified industrial rail network was in place

12.1.3 Since then there had been significant progress in extending Electrification as can be seen in Table 1.

Table 1 : Progressive Electrification on Indian Railways (upto 2014-2015)

Year	RKM Electrified	Progressive Total
1925-56	529	529
1956-61	216	745
1961-66 (3rd Plan)	1,678	2,423
1966-69	814	3,237
1969-74 (4th Plan)	953	4,190
1974-78 (5th Plan)	533	4,723
1978-80	195	4,918
1980-85 (6th Plan)	1,522	6,440
1985-90 (7th Plan)	2,812	9,252
1990-92	1,557	10,809
1992-97 (8th Plan)	2,708	13,517
1997-02 (9th Plan)	2,484	16,001
2002-03	455	16,456
2003-04	504	16,960
2006-07	361	
2007-08	502	
2008-09	797	
2009-10	1117	
2010-15(5Years)	6157	25,241

12.2.0 CONTRIBUTION OF RAILWAY ELECTRIFICATION TO THE CAPACITY BUILDING OF INDIAN RAILWAYS

12.2.1 Electrification offers following distinct advantages in handling larger volumes of traffic with minimum overall capital inputs:

- Availability of inexhaustible power from Over Head Equipment
- High energy efficiency, particularly due to system's capability of using energy regenerated during breaking. Energy savings from regenerative breaking varies from 20% to 40%, depending upon type of train operation.
- Electric locomotives intrinsically pack higher power for the same axle load and number of axles, with the distinct advantage of hauling higher loads at higher average speeds, resulting in increased line capacity without investment in augmenting the existing infrastructure.
- Highly cost effective in regard to fuel cost using totally indigenous sources of fuel as compared to largely imported oil based energy.

12.2.2 Inputs in the Field of Railway Electrification which added to the Capacity creation

A number of inputs have helped in the capacity creation through Railway Electrification. Some of the more important contributions are covered here.

12.2.1 Standardisation of Electric Traction at 25 kV 50 Hz single phase system

The decision to Standardise Electric Traction at 25 kV 50 Hz system has helped in achieving economies of scale in not only Traction Distribution but also in Rolling stock as well as continuous operation over the expanse on Indian Railways. Thus a benefit not available in Europe due to presence of different systems of Electric Traction in different counties has been achieved in provision of Electric equipment of one system only in fixed structures as well as rolling stock. With completion of DC to AC system in Mumbai Suburban section (to be completed shortly) the process of Standardisation of Electric Traction at 25 kV 50 Hz system will be completed.

12.2.2 Progressive indigenisation of Components of Railway Electrification

Traction Installation Directorate in RDSO which was set up in 1968 has greatly contributed to the indigenisation on the system. At present, barring some components, the system is fully indigenous and multiple sources are available which has helped to contain the cost of electrification in the country.

12.2.3 Progressive Increase in Power Capacity of Railway Electrification (OHE)

The continuously increasing number of Trains on the Electrified network has put increasing demand on the power requirement of the Traction system. This has been so far met by increasing the capacity of Traction Transformers from 12.5 MW to 30 MW in stages, and reducing spacing of Traction substations to achieve requirement of power which is reaching one MW per Kilometer. In certain graded sections with heavy freight traffic, 2X25 kV system of power supply has been adopted to avail of the advantage associated with higher voltage transmission, without having to change the locomotive. Decision has also been taken to adopt 2x25kV system on Dedicated Freight Corridor Project.

12.2.4 Improvement in SCADA systems

Traction Supervisory Control and Data Acquisition (SCADA) system has been provided for remotely controlling 25 kV Traction Supply. From initial designs which were based on Electro Mechanical technology new SCADA systems based on Digital technology have been adopted thereby increasing RAMS (Reliability, Availability, Maintainability and safety) and at the same time allowing more Data to be obtained which is useful in better energy economy.

12.2.5 Setting up of Transmission line network

The first Transmission line (95 kV later upgraded to 110 kV) for Indian Railways for traction system was commissioned by GIP Railway (Central Railway) between Kalyan (Chola) Power House and Igatpuri (NE Section) and to Poona (SE Section) in 1929(Total length 497.17KM). After independence, with setting up of various State Electricity Boards, it was decided to use the Electricity Boards' transmission systems. It was soon realized that such system does not allow Railways to benefit from availing better tariff at High Voltage and benefit in maximum demand component of Tariff. Thus at many places IR opted to lay their own transmission lines, availing power supply at one point and distributing to various traction substations. At present Railways own a network of Transmission lines in Northern Railway and North Central Railway totaling 768 Kilometers and more lines have been planned. At present bulk of the Transmission lines are at 132 kV while in future 220 kV lines have also been proposed.

12.2.6 Availing Direct Power Supply from Power Plants and participating in power generation

At some points IR have also gone in to avail power supply directly from Power Producers (like NTPC), giving significant advantage in power tariffs. Recently IR has also set up a power generation corporation in collaboration with public sector power generation giant NTPC. It will be possible to make use of the recently legislated system of power trading, thus availing power at very economical tariffs. These measures have brought in considerable economy in operation with electric traction.

12.2.7 Organizational Structure

Electrification, being a new area, required massive organizational inputs, both in technology as well as in the field. These requirements have been met by setting up Traction Installations (TI) Directorate in RDSO and Central Organization for Railway Electrification (CORE) as an independent field organization. Both these organizations made phenomenal contribution resulting in furthering IR's capacity in handling larger and larger volumes of traffic.

12.2.8 Capacity Created as result of Electrification

12.2.8.1 Freight Sector

Table 2

Year	Total Route KM	Progressive Total Route KM Electrified	GTKM Revenue Earning	% of GTKM carried on Electric Traction	GTKM on Electric Traction per Electrified Route KM	GTKM on non Electric Traction per Route KM
	KM	KM	**In Billions**		**In Billions GTKM Per KM**	**In Billions GTKM Per KM**
1	**2**	**3**	**4**	**5**	**6**	**7**
1990-92	62,367	10809	235.78	41.4	8.96	2.215
1997-2002 (9th Plan)	63,028	16001	312.371	47.2	9.21	2.61
2007-08	63,273	18145	521.371	63.7	18.30	2.991
2008-09	64,015	18603	551.448	65.3	19.35	2.989
2009-10	63,974	19720	600.548	63.6	19.87	3.417
2010-11	64,460	20695	625.723	64.3	19.44	3.465

As observed from Table 2 from 1990 significant proportion of Freight Traffic was carried on Electric Traction. It was 41.4% in 1990-92 which increased to 64.3% in 2010-11 (55.3% increase). While route electrified increased from 17.33% in 1990-92 to 25.38% in 2010-11, the Revenue Earning Freight Traffic increased from 8.96 Billion Tonne KM per Electrified Km to 19.44 Billion Tonne Km per Electrified KM (116% increase). Thus bulk of capacity creation on Freight Traffic was contributed by Electrification.

12.2.8.1 Passenger Sector

Table 3

Year	**Total Route KM**	**Progressive Total Route KM Electrified**	**% Electrified GTKM**	**Passenger KM**	**% Passenger KM on Electric Traction**	**Electric Passenger KM per electrified Route km**	**Non electric Passenger KM per Rkm**
	KM	KM		**In Billions**		**In Billions Passenger KM per KM**	**In Billions Passenger KM per KM**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1990-92	62,367	10809	41.4	295,644	37.8	10.3387	2.778
1997-2002 (9th Plan)	63,028	16001	47.2	457.022	47.2	13.48	3.828
2007-08	63,273	18145	63.7	769.956	49.3	20.91	6.169
2008-09	64,015	18603	65.3	838.032	50.6	22.79	6.467
2009-10	63,974	19720	63.6	903.465	51.1	23.41	6.905
2010-11	64,460	20695	64.3	978.508	51	24.11	7.43

From 1990 significant proportion of Passenger Traffic was carried on Electric Traction. But the shift was less than Freight. It was 37.8% in 1990-92 which increased to 51% in 2010-11 (34.9% increase). Passenger Traffic measured in terms of Billion Passenger Kilometers increased from 10.34 Billion Passenger KM per Electrified Km to 24.11Billion Passenger Km per Electrified KM (75.09% increase). The percentage of route electrified increased from 17.33%

in 1990-92 to 25.38% in 2010-11. The increase of traffic carried by non Electric Traction mode rose from 2.78 to7.43. Thus bulk of capacity creation on Passenger Traffic though to a lesser extent than in case of Freight was also contributed by Electrification.

12.3.0 RAILWAY ELECTRIFICATION AND THE ENVIRONMENT IMPROVEMENT

Apart from capacity creation on the rail sector, Railway Electrification has also contributed in environment improvement by substituting polluting steam and diesel systems by cleaner electrical energy. Electrification also renders the transport sector capable of using energy produced from renewable sources, such as hydel, wind and solar.

12.5.0 FUTURISTIC TRENDS

12.5.1 OHE for working of Double Dekker Trains

Indian Railways have innovated and conducted successful trials of running Electric Locomotives with Contact Wire at a height of about 7.5 meters (Normal height of Contact Wire is 5.5 Meters) so as to enable running of double stack containers on the electrified sections. Adoption of this system has been proposed for Western Dedicated Freight corridor for running of Double Dekker trains. Globally the contact wire height is maintained at 5.5 meters and the Double Dekker containers are accommodated in well wagons to accommodate the contact wire Height.

12.5.2 High Speed on existing tracks

12.5.2.1 As per vision- 2020 document of Indian Railways maximum speed of passenger trains would be raised from 110 or 130 kmph at present to 160-200 kmph.

12.5.2.2 For creating of this capacity RDSO has identified improvements in existing OHE. These initiatives include up gradation of capacity of Traction substations, reducing Presag in OHE to 5mm, improvements in OHE components and increase of Contact wire size. Change over to 2x25 kV system of OHE on existing routes is also being considered.

12.5.3 High Speed Corridors

12.5.3.1 It is proposed to construct a High Speed railway line between Ahmadabad & Mumbai with Maximum speed of 350 kmph and also to undertake detailed studies for 6 other High Speed rail corridors.

Traction Distribution system including power supply of the order of 10 MW per Train as also Over Head Equipment system suitable for working up to a test speed of 450 KMPH, will have to be designed.

12.5.4 **Dedicated Freight corridors**. Construction of Dedicated Freight corridors (DFC) on Electric Traction is a Major policy initiative aimed at enhancement of Transport capacity in Freight sector. These corridors will have many innovative features.

Eastern and Western Dedicated Freight Corridors (3,338 Kms) are designed to run trains of 6500t and 13000 t hauled with single 12000hp and twin 12000 hp electric locomotives requiring higher power of up to 1-1.5 MW per kilometer. This proposed to be accomplished by selection of 2x25 kV AT feeding system of power supply. These corridors will be constructed with mechanized construction methods for overhead equipment erection. Maintenance will be carried out daily with fix 4 hours maintenance block using predictive maintenance tools and lean and thin workforce. Western corridor will have OHE height of 7.53 meter to facilitate double stack containers operation.

Mechanized Construction concept

Fig. 1

Successful trial of high reach pantograph under 7.45 meter high OHE in Jakhapura-Tomka section of East Coast Railway has established suitability of running of electric locomotive hauled train under high rise OHE for movement of DSC on flat wagon in proposed Western DFC of Indian Railways..

Fig. 2 : Loaded electric train running under 7.45 m OHE during test trials

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CHAPTER 13

RAILWAY WORKSHOPS

13.1.0 From 1853 onwards, railway lines were built by about 40 companies. Each built a mechanical workshop of its own. In 1952, when the Indian Railways decided to reorganise the entire railway system, existing 37 railways were rationalised to form six zonal railways. Similarly, their railway workshops were also rationalised and some were gradually closed.

13.1.1 With modern rolling stock and increase in the holding, the modernisation of Railway Workshops became imperative for their proper upkeep and operation besides achieving efficient use of rolling stock by reducing their down time during maintenance schedules. A Central Organisation for Modernisation of Workshops (COFMOW) was established in 1979 for this special task to be done in phases covering replacement of old outmoded machinery, and equipment by sophisticated, computer controlled units, improved handling and inventory systems to drastically reduce the wastage of time and space. In phase I, Chittaranjan Locomotive Works, Kancharapara workshops (ER), Kharagpur workshops (SER), Matunga workshops (CR) and Lower Parel workshops (WR) were taken up. Later in Phase II seven other shops were selected. Historical development of some important Railway workshops is given in the following paragraphs.

13.2.0 JAMALPUR WORKSHOPS (ER)

13.2.1 Jamalpur Locomotive Workshop was established on the 8th day of February, 1862. Jamalpur Workshop was the first full-fledged railway workshop facilities in India, set up by the East Indian Railway.

13.2.2 The Railway age in Eastern India started on August 15, 1854, exactly ninety-three years before Independence. A locomotive, carriage and wagon workshop was set up in Howrah to put to commission imported rolling stock of EIR and also

Jamalpur Locomotive Workshop

Founded	8 Feb, 1862
Founder	East Indian Railway
Headquarters	Jamalpur
Parent	Indian railways
Website	www.jamalworkshop.com

to render economic repairs to them but it proved unsuccessful because of problems with procuring supplies and getting skilled labor. The railways spread very fast, perhaps faster than the anticipation of EIR. Within a short span of eight years it became necessary to shift the site of workshop, as there was hardly any scope for expansion at Howrah. And then Jamalpur Workshop was established at Jamalpur.

13.3.0 HISTORY

13.3.1 Jamalpur Workshop has enjoyed the distinction of being the largest and the oldest locomotive repair workshop with the most diversified manufacturing activities on the Indian Railways. At first the Jamalpur shops were merely repairing locomotives and also assembling locomotives from parts salvaged from other or damaged locomotives. By the turn of the century they had progressed to producing their own locomotives. In year 1899, CA 764 *Lady Curzon* was produced by the Jamalpur Workshop. In 1893, the first railway foundry in India was set up at Jamalpur Workshop. It also had a boiler workshop for repairing and building boilers. A captive power plant of 5MVA was also developed in the Jamalpur Workshop. In 1870 it was equipped with a rolling mill of its own; unfortunately it's not working at present. In addition to various repairs of wagons, coaches, cranes and tower cars, and locomotives, Jamalpur also undertakes repair and production of permanent-way fixtures. It also manufactures some tower cars such as Mark II, Mark III and break-down cranes of 10, 20, and 140 tone capacities, besides various kinds of heavy-duty lifting jacks.

13.3.2 Finally, it also manufactures wheel sets for coaches and wagons. Jamalpur workshop was a significant supplier of cast-iron sleepers as well. Starting in 1961 it produced several rail cranes. It has also produced electric arc furnaces, ticket printers. The high-capacity synchronized lifting jacks known as *Jamalpur Jacks* were also produced by this workshop.

13.3.3 The school attached to the Jamalpur workshops eventually became the IR Institute of Mechanical and Electrical Engineering.

13.3.3.1 IRIMEE

13.3.3.2 The Indian Railways Institute of Mechanical and Electrical Engineering (also known as IRIMEE) at Jamalpur is the oldest of the Centralized Training Institutions (CTIs) of Indian Railway. IRIMEE started as a technical school attached to the Jamalpur Workshops in the 1900s, then the largest railway repair workshops in India. After the first World War, the technical school was greatly expanded for training of railway apprentices and supervisory staff involved with mechanical engineering. In the 1960s, a Diesel Traction Faculty was set up to conduct training courses and publish educational materials as IR engaged in desalinization.

13.3.3.3 In 1971 the school was renamed as the IRIMEE, and brought under the direct control of the Railway Board. In 1988 IRIMEE began conducting the various required courses for IRSME probationary engineers and various Mechanical Engineering staff. From 1997, IRIMEE has also been conducting various short-duration courses for other staff on various engineering topics. Topics include rolling stock and workshop technology, management science, and information technology aimed at officers and supervisory staff.

13.4.0 ***ACHIEVEMENTS***

- Jamalpur workshop is the only workshop in Indian Railways that has a captive Power house of 5 MVA
- The workshop has a number of FIRSTS in India to its credit, a few of which are:
  - The First to manufacture a steam locomotive and a locomotive boiler – 216 of which were manufactured between 1899 and 1923.
  - The First to have set up a rolling mill not only on the railways, but probably in the country in 1870. It had 3 mills, steam driven Power hammer, fish plate machine, billet shears, the mill was driven by steam from boilers placed on the top of the furnaces and heated by gas from the furnaces. It produced about 400 tons of rounds, channels, angles and fishplates per month.
  - The First to establish a railway foundry in the year 1893.
  - The First to manufacture a rail crane in the country with indigenous know-how in 1961.
  - The First to manufacture high capacity electrical lifting jacks and ticket printing, ticket chopping, ticket slitting and ticket counting machines.
  - The First and the only railway workshop to manufacture electrical arc furnaces of ½ tonne capacity in 1961 for production of steel castings.
  - The First to established Signal Equipment shop, more popularly known as “Points and Crossing and Interlocking shop” was started in 1894. produced entire requirement of Interlocking frames of different sizes for EIR

- The First and only to manufacture 140 Tonne Diesel Break-down Cranes.

13.5.0 CURRENT ACTIVITIES

13.5.1 With the gradual eclipse of steam traction on Indian Railways, steam locomotive activities, which had peaked to 600 standard units per month in 1962-63, started declining in the late 60's and finally the steam activities came to a complete end in August 1992. The shop kept pace with both, the technology change and technology up gradation on Indian Railways and diversified its activities to the Overhauling and Repair of Diesel Locomotives, Overhauling and Repair of various types of Wagons, Manufacture and Overhauling of Diesel Hydraulic Break Down Cranes up to 140 tonne capacity and Manufacture and Repair of various types of Tower Cars.

13.5.2 Apart from the above activity Jamalpur shops are also engaged following activities:

13.6.0 PERIODICAL OVERHAULING (POH) AND REPAIR OF DIESEL LOCOMOTIVES

13.6.1 Periodical overhauling (POH) and repair of diesel locomotives at jamalpur workshop started in 1982 the workshop caters full demand of Eastern Railway. The Workshop also deals with Special repairs to accident involved locomotives and locomotives owned by various Public Sector Undertakings like NTPC, CPT, SAIL in the eastern region. So far 84 such Locomotives from PSUs have been repaired and generated a cash inflow of Rs. 26 crores.

13.7.0 REBUILDING AND REPAIR OF BOX WAGONS

13.7.1 Due to generation of a large no of unloadable BOX wagons in Eastern Railway and thus limiting the usage of these wagons it was felt necessary to introduce special type of repair to BOX wagons in between POH to make them earn revenue. These scheme yielded results and Jamalpur shops gradually increased their production from 2445 FWUs in 95-96 to 3602 FWUs in 99-2000.

13.8.0 MANUFACTURING OF 20 T CRANE

13.8.1 20 tonne Diesel Crane is a Rail Mounted, Diesel operated, BG (Broad Gauge) transportation crane. The crane is extensively used by Mechanical Department of Indian Railway in sick lines for maintenance of wagons/coaches and Transportation Department Indian Railway for handling of Goods.

13.8.2 First four 20T Diesel Crane was manufactured in 1980-81 with mechanical control system.

13.8.3 Later the control system was changed to Pneumatic as per RDSO Specification No. CR.D.122/90. Since 89-90 the shop has been manufacturing the 20 Tonne cranes as per this specification and has manufactured many such crane.

13.9.0 MANUFACTURING OF JAMALPUR JACKS

13.9.1 The Jamalpur jacks have been gaining in popularity chiefly due to low initial capital investment and minimum maintenance needs. It is worthwhile to mention that the performance and cost factor of these Jacks have posed a serious challenge to capital intensive Electrical Overhead Traveling Cranes.

13.9.2 Besides Indian Railways, these prestigious Jamalpur Jacks have been operating successfully at various steel plants and allied industries.

13.10.0 SPECIAL FEATURES

13.10.1 The Jamalpur jack has a capacity to lift a load of 25 Tonnes and four such Jacks make one complete set with a total lifting capacity of 100 Tonnes. These Jacks can be operated simultaneously or individually.

13.11.0 TOWER CARS

13.11.1 Jamalpur workshop is also involved in manufacturing of different tower cars such as Mark-II, Mark-III, Mark-IV, DHTC/JMP

13.12.0 LOCOMOTIVE WORKSHOP, PAREL, BOMBAY (GIP)

13.12.1 The Central Railway Locomotive Workshop, Parel was set up by Great Indian Peninsular Railway as a Steam Loco Shed in 1879. Later repair and overhauling of Steam loco had started, and that had reached peak capacity of 32 Steam locos per month in 1962-63. With tapering of Steam traction, the Shop was upgraded to take up the work of Repair and Overhauling of Diesel locomotives from 1974-75 onwards.

13.12.2 It is one of the largest and oldest repair Workshops on the Indian Railways with diversified repair/manufacturing activities. Being located in the heart of Mumbai, it has ready access to road, sea and air transport. The Parel Workshop has the unique distinction of rendering services to the Armed Forces during the World Wars.

13.12.3 Parel Workshop has gradually diversified and is at present also carrying out the repair and overhauling of Diesel locomotives, Diesel cranes, Rehabilitation of Main Line Coaches. This shop also manufactures many components for diesel locos, Carriages and Wagon.

13.12.4 This workshop has also successfully manufactured Narrow Gauge locos for Neral - Matheran section and for Kalka - Simla section.

13.12.5 This is the only workshop, other than DLW and CLW, which builds Diesel Locomotives.

Major Activities

- Manufacture & Repair of Broad Gauge Diesel Locos
- Manufacture & Repair of Narrow Gauge Diesel Locos
- Rehabilitation of Coaches, Conversion of Coaches to carry cars, Conversion of coaches for working in Accident Relief Trains
- Repairs of 140T Crane used in Accident Sites of Indian Railways

13.13.0 KHARAGPUR WORKSHOP

13.13.1 Established in 1898 as a small workshop of Bengal Nagpur Railway, Kharagpur workshop evolved and grew over the years to become the largest workshop of the Indian Railways. It has the unique distinction of being the only workshop of IR which deals with all types of Rolling Stock viz., Coaches, EMUs, Wagons, Diesel Locomotives, Electric Locomotives, Diesel and Steam Cranes etc.

13.13.2 The BNR Board of Directors recorded their sanction for construction of an integrated workshop at Kharagpur in 1900 and the workshop came into operation in 1904. Initially it undertook periodic overhaul of steam locomotives, timber-bodied passenger cars fitted with plain bearings and freight cars comprising mainly of covered four-wheeler wagons with plain bearings and screw coupling. With changes in modes of traction and types of rolling stock, the workshop progressively diversified its working.

The main features of diversification include:

(i) Periodic overhaul of Diesel Electric Locomotives,

(ii) Periodic overhaul of Electric Locos,

(iii) Periodic overhaul of EMU Trailer and Motor Coaches,

(iv) Periodic Overhaul of new types of freight cars fitted with roller bearing and centre buffer couplers,

(v) Periodic overhaul of all steel coaches fitted with roller bearings and advanced designs of suspension,

(vi) Corrosion repairs to all steel coaches,

(vii) Periodic overhaul of Diesel Rail and Road Cranes, Rewinding of traction generators and traction motors,

(viii) Manufacture of sophisticated components of Diesel Electric, Diesel-Hydraulic and Electric Locomotives.

(ix) The first phase of Modernisation of Kharagpur Workshop was done from 1979 at a cost of Rs. 132.69 million. The major objectives covered by the project are :

    - Reduction in the number of davs taken for POH of Diesel Electric Locomotives from 21 days to 15 days.
    - Reduction in the number of days taken for POH of Coaches from 18.5 days to 17 days.
    - Reduction of POH cycle time for freight cars.
    - Replacement of low-production machine tools.

The Second phase of modernisation of Kharagpur workshop was done in 1985 which had the main objectives as:-

- Periodic overhaul of Electric Locomotives taking advantage of the infrastructure already set up for the POH of Diesel Electric Locomotives.
- Periodical Overhaul of EMU motor coaches.
- Reduction in the number of days taken for POH of coaching stock.
- Increase in corrosion repairs to coaching stock.
- Installation of self-contained coil spring shop.

13.14.0 PERAMBUR CARRIAGE WORKSHOP

13.14.1 Established in the year 1856, it is the oldest BG mechanical workshop in the SOl Railway System. Initially the workshop carried out periodic overhaul of locomotives, coaches and wagons belonging to the erstwhile Madras Railway and Madras & Southern Maratha Railways Company. In 1932, the loco maintenance was transferred to loco works, Perambur with the creation of Southern Railway. This workshop became an important part of the system as it was the only BG POH shop on Southern Railway. Till 1963, the Carriage workshop was rendering assistance to ICF by furnishing the newly manufactured shells. Being close to the Coaching depot at Basin Bridge, this workshop also undertakes periodic overhaul of coaches.

13.15.0 GOLDEN ROCK WORKSHOP TIRUCHIRAPALLI

13.15.1 This central workshop was set up in 1897 by South Indian Railways at Nagapattinam mainly to cater to the requirement of steam locomotive maintenance. South Indian Railways decided to shift the workshop to Trichinopoly, presently known as Tiruchchirappalli, owing to its locational advantage. Consequently foundation stone was laid by Mrs. R.P. MUNRO on 20.10.1926. It was shifted to Tiruchchirappalli in 1928 because of its strategic location. The Central Workshop, Golden Rock is functioning at Tiruchchirappalli since then.

13.15.2 The total area of this workshop is around 200 acres (0.81 km^2), out of which 26 acres (110,000 m^2) is covered under roof. At present 6,091 employees are working in this workshop. This workshop is primarily engaged in the activities of DSL Loco POH, heritage steam locomotive POH, coaching stock maintenance and wagon manufacturing and other sundry activities.

13.15.3 This workshop does have a long traverser way around 600 metres long and 80 feet (24 m) wide. This workshop was involved in repairing of Royal Air Force's air planes during World War II.

13.15.4 This workshop when built had state-of-the-art facilities rarely seen in those days. It had its own powerhouse which generated electricity for the workshop and the colony. In fact, Railway colony, Golden Rock was one of the first places to be lit by electrical lights in Tiruchirappalli city those days.

13.16.0 CORE ACTIVITIES

13.16.1 Diesel Locomotive Maintenance

Diesel Electric Loco periodical overhauling (POH) started in Goldenrock Shop in the Year 1969, to cater to the requirements of SR and SCR. It started with a capacity of 0.5 Loco/Month. The capacity was stepped up to 10 locos per month from July 1990 onwards to meet the needs of 5 Railways i.e. Southern Railway, South Central Railway, South Western Railway, West Central Railway and North Western Railway. Presently, Shop is capable of overhauling 12 locomotives per month.

In addition to the Locomotives overhauling, Diesel Shop is attached with the following Support shops.

1. Engine Block Reclamation Shop
2. Cylinder Liner Plating Shop
3. Coil Manufacturing Shop
4. Heavy Electrical Repair Shop

13.17.0 CARRIAGE MAINTENANCE

GOC Shop is undertaking the following major activities in carriage maintenance.

- Overhauling of BG AC and Non AC coaches,
- Coaches of Nilgiri Mountain Railways,
- Refurbishing of interior furnishing under midlife rehabilitation,
- Conversion and construction of ART coaches,
- Rehabilitation of in-service MG coaches for exports etc.
- Furnishing of inspection cars
- Retro fitment of stainless steel trough floor
- Refurbishing of toilet
- Implementation of POH periodicity from 12 months to 18 months

Apart from normal overhauling, GOC Shop had established its expertise in the following areas:

1. Conversion / construction of coaches for Nilgiri Mountain Railways.
2. Export of old MG coaches to other nations after Maintenance & Re-Modeling by RITES Limited.

13.18.0 WAGON MANUFACTURING ACTIVITY

- GOC Shop started manufacturing wagons in 1962; since then it had rolled out 34,901 wagons in 53 designs.
- Presently workshop is engaged in mass production of BOXNHL and BLC (container flat wagons for Container Corporation) wagons.
- During the five financial years GOC Workshop captured the majority of wagon building orders for total 2,905 Wagons of Container Flat type worth Rs.610 crores from M/s. CONCOR/New Delhi, of which GOC till date has manufactured 2770 BLC wagons worth Rs.575.6 Crores. Additionally in last five financial years GOC shops manufactured 830 BOXNHS wagons worth 127 crores. Further GOC shop have an order of 450 Nos. of BLC wagons costing Rs.157 crores.
- The GOC Workshop is gearing up for production of 1000 wagons per year from present level of 840 wagons under Modernisation project considering the huge Wagon demand by M/s. CONCOR and also Stainless steel wagons for Indian Railways.
- GOC Workshop has become the first railway workshop in Indian Railways to implement and adopt new state-of-the-art technology fasteners as Lock Bolts (Huck/ Avdel) Bolts in place of conventional rivets and successfully turned out 240 high-speed BOXN wagons.
- GOC Workshop is awarded with new orders from Railway Board for manufacturing 600 Nos of BOXNHL wagon, which is a Stainless Steel wagon with High pay load (71 tonnes against 68 tonnes in normal wagons) designed to overcome the problems of corrosion, body bulging and weak stanchions in the existing wagons. The new design enables to an extra loading of 2.92 tonnes per wagon and 169 tonnes per rake of 58 wagons which contributes an extra earning of Rs.5800 per wagon and Rs. 3.38 Lakhs per rake. GOC Shop has an order of 599 Nos. of BOXN HL Wagons costing Rs.187 Crores.

13.19.0 PRODUCTION WING

13.19.1 *Mechanical Mill Wright Shop*

Production wing of GOC focuses its attention mainly on manufacturing of components required for maintenance of locomotives and carriages and wagon manufacturing. It also take care of the requirement of various divisions by supplying wheels for rolling stock maintenance. Besides, Production wing has taken up the manufacturing of steam locomotives required for Nilgiri Mountain Railways and Darjeeling Himalayan Railways.

13.20.0 PRODUCTION WING COMPRISES THE FOLLOWING SHOPS

13.20.1 Foundry Shop, DSL Component Shop, Machine Shop, Wheel Shop, Fabrication & Smithy Shop, Erecting Shop, Tool Room & Mechanical Mill Wright shop

13.21.0 LILUAH WORKSHOP

13.21.1 Carriage and Wagon Workshop Eastern Railway, Liluah was set up in 1900.The saga of this workshop is inextricably linked with that of Eastern Railway and its precursor, the East Indian Railway (EIR).

13.21.2 The earlier history of non timely supply of imported materials led to the thinking that rolling stock should also be manufactured in India. Accordingly the first workshop was set up at Howrah, upgraded to a Carriage and Wagon workshop in 1863 and the facility shifted to Liluah in 1900 by setting up a modern Carriage & Wagon workshop.

13.21.3 Liluah was primarily assigned the task of manufacturing of coaches and wagons. 3000 coaches were manufactured upto 1972. Wagon manufacturing was also undertaken but discontinued in the post independence era. Apart from rolling stock required for the military, the workshop produced hundreds of ambulances, water cars, tanks, armoured vehicles, lorries and ammunition.

13.21.4 The workshop witnessed upgradation and modernisation of rolling stock like introduction of all steel coach shells in lieu of wooden bodied coaches, roller bearings instead of plain bearing, air brakes in lieu of vacuum brakes, bogie wagons instead of 4-wheelers.

13.21.5 The workshop has to its credit conversion of AC Coaches for the 'Great Indian Rover', rehabilitation of condemned EMU coaches, manufacture of first Diesel Multiple Unit 'Push-Pull' type trains for non-electrified sub-urban sections, upgrading and refurnishing Saloon no. ER-2377 in which the Noble laureate Tagore made his last journey.

13.22.0 DAHOD WORKSHOPS (BB & CI)

13.22.1 Dahod is situated on the Mumbai - New Delhi trunk route, almost mid-way between Vadodara and Ratlam. It is the district headquarters of Dahod district of Gujarat state. This is a tribal area and the home of the Bhil community. It has a long history, with origins dating back to the epic of Mahabharata.

13.22.2 Earlier, repairs to steam locos of BB & CI Rly were done at Lower Parel workshops. A separate shop became necessary with increasing workload. The foundation stone for Dahod workshop was laid on 14th January 1926 by Sir Clement Hindley, Chief Commissioner for Railways. The shop started functioning in 1931. It was originally planned for an outturn of 8 to 10 locomotives, but gradually the load increased upto 20 locos/month. Addition of some shops was made like separate Wheel shop & facilities for manufacturing loco duplicates. In June'92 all activities connected with steam loco repairs were closed.

13.22.3 The alternate work undertaken by the shop are :-

(a) All types of steam cranes of WR are repaired and spares manufacture,

(b) Rehabilitation of damaged Box wagons was started in June'92 with an initial out-turn of five wagons and since enhanced to 25 wagons per month.

(c) Electric loco POH and rehabilitation is done here.The present output is four locos per month.

(d) Since Jan.1997, POH of MEMU Coaches is being done.

(e) After 1965 war, repair to Arms of Railway Protection Force department was undertaken. These included rifles, muskets, stenguns and small arms.

(f) Rehabilitation of electric locos.

13.23.0 LOCOMOTIVE WORKSHOP CHARBAGH, LUCKNOW (NR)

13.23.1 The Railways came to Lucknow on 23 April 1867 under the banner of Indian Branch Railway Company as part of Oudh & Rohilkhand Railway (O& R R). For maintenance of Rolling Stock (Locos, Carriages & Wagons) the Railway set up a workshop south of its Charbagh station. The workshop was set up in the orchards owned by the Farooqui family around Fatehli Talab in Charbagh. They were offered land at Dalmau in lieu, at the scale of 3 acres of land at Dalmau for every one acre surrendered at Charbagh.

13.23.2 The workshop is known to have started with almost all its workforce coming from Britain. By 1870, the Charbagh Workshop was successfully employing native labour, a large number of people being brought from loyal princely states of Bihar. These immigrants came to be known as "Bhojpurias" and their presence was predominant in the Blacksmith Shop.

There was a parallel strength of Muslim artisans. In the mid 1870, low pay and poor conditions experienced by the low Ievel workers led the Anglo Indian employees to form India's first Railway Union, (The Amalgamated Society of Railway Workmen).

13.23.3 The first locomotives of the O & RR came from M/s Neilson. Till 1950 all the locomotives were imported from Britain. For every 20 locomotives imported in the assembled condition, one locomotive was imported in knocked down condition to provide vital spare parts. They were of the orthodox 0-6-0 and the strange looking 0-8-0 class.

13.23.4 One of the 0-8-0 class locos, after withdrawal from service was displayed for many years outside the steam shed in the Workshop. A 0-6-0 is preserved at the Railway Transport Museum at New Delhi. The workshop did the POH of locomotives. In the absence of industry capability to manufacture and provide components, broken or damaged in accidents, these were made in the workshops. POH shops had the basic engineering facilities of Blacksmithy, Foundry and Machining, where iron/ steel could be cast and formed to produce components for steam locomotives. This needed skilled local workers. Mr. HR. Neville, ICS writing in 1904 Gazetteer of United Provinces of Agra and Oudh reported. The workshops of the Oudh and Rohilkhand Railway to the south of the Charbagh station, employ many hundreds of hands; including several pupils from the Martiniere school as well as many other Europeans and Eurasians."

13.23.5 The shops were taken over by EIR in 1925, and rationalised in regard to distribution of workload in their other shops like Jamalpur etc. During the First & Second World Wars ammunitions were produced in the workshops, particularly hand grenades. Workshop Administrative office itself was used as an Armoury. There was a small Ordnance factory next to the Charbagh Shops.

13.23.6 Charbagh shops became a part of N. Rly. in the 1952 regrouping. This Railway did not have any loco POH shop. A major effort was mounted to develop the shops and increase its manufacturing as well as overhaul capabilities. Manufacturing activity continued and reached its peak in the 1960's giving ground in the 1970's when Indian industries developed and steam began to be slowly replaced by diesel locomotives. The shop was modified to undertake POH of diesel electric locomotives in 1975 beginning with one or two locomotives and gradually increasing to ten locomotives per month. The shops have POHed over 1000 Diesel locomotives. POH of Electric locomotives was also started in 1986.

13.24.0 CIVIL ENGINEERING WORKSHOPS & BRIDGE WORKSHOPS

13.24.1 To meet the urgent requirements of steel structures for new constructions and other maintenance needs, Engineering workshops were set up over the years at different locations on the railways. These workshops were to manufacture foot over bridges, roof trusses for workshops and sheds, bridge girders of different spans, flood lighting towers, christ church cribs, other steel structures, and do upkeep of tools, plants and machinery etc. The workshops were set up at: Manmad on the Central Railway, Mugalsarai on the Eastern Railway, Lucknow and Jallundhar on the Northern Railway, Gorakhpur on the North Eastern Railway, Bongaingaon on the North East Frontier Railway, Sini on the South Eastern Railway, Arkonam, on the Southern Railway, Lallaguda, on South Central Railway and Sabarmati on the Western Railway

13.24.2 The earliest workshops were at Manmad, Sabarmati and Mugalsarai. Such workshops had capacity to fabricate up to 1800 tons of steelwork in a year.

13.24.3 The number of persons engaged varied from 300 to 1200. An output of 0.5 tons per man per month was kept as a yardstick of monthly production. Initially, only small span bridge girders were manufactured, major spans being imported from U. K. Gradually, longer spans were manufactured, up to 30m spans. These were riveted structures. The manufacture of riveted structures required first making a full-size drawing on the shop floor, then cutting individual pieces as per measurement and joining them by riveting. The steel used was conforming to present IS2601, and was not of weldable quality as welding was not intended. Welding was gradually introduced in these workshops. Some workshops had a foundry. Manufacture of track items such as Switch Expansion Joints (SED, Tie Bars, Concrete items such as Bridge Slabs etc were added to the workload. Most workshops also keep reserve of bridge girders and erecting equipment like CC Cribs, stanchions etc. to be used if required in case of accidents, breaches, to speedily restore through rail communications.

13.25.0 ENGINEERING WORKSHOP MANMAD (CENTRAL RAILWAY)

13.25.1 Manmad Engineering Workshop came into existence in the year 1906 as a small unit for assembly of imported bridge components for the then Great Indian Peninsula Railway (GIPR) and was initially known as Girder Shop. After 1929 the Workshop started modification and reconditioning of released girders from major bridges.

13.25.2 Subsequently, Smithy, Carpentry, Mechanical, Foundry and Bolts,Nuts,Rivets shops were also added to Girder Shop. From the year

1939 during Second World War, the Workshop was engaged in production of war materials. After the war, normal activities were restarted. Due to massive regirdering programme on Central Railway in the year 1958, some remodeling of the. Workshop was undertaken. A new Template Shop for fabrication of 76.2 m span Open Web Girders and a Points & Crossing shop were added. The Workshop was functioning in a very small shed till 1993. New covered accommodation was provided during the year 1994. The total covered area of the Workshop is now about 21,000 sq. m.

13.25.3 In the year 1981-82, the fabrication of welded plate girders of 12.2 m span was started. The Workshop is now engaged in the regular production of welded girders up to 24.4m spans. Modernization of Workshop was started in 1989 and completed in 1994 during which the entire handling system of the Workshop was switched over from ordinary rail mounted cranes to electric overhead cranes.

13.25.4 The workshop obtained ISO-9002 Certification in December 2000. The Workshop has facilities for metallising the steel bridge components & Girders which provide much greater protection against corrosion .

13.26.0 BRIDGE WORKSHOP LUCKNOW (NORTHERN RAILWAY)

13.26.1 This workshop was set up during the year 1955 as a field workshop for fabrication & erection of workshop sheds for the Mechanical Workshop at Charbagh, Lucknow. After the completion of the mechanical workshop, this workshop switched over to other fabrication works. In 1963, the workshop was converted into a regular Bridge Workshop.This workshop is continuously engaged in fabrication of riveted and welded steel structure as per requirement of railways. In course of time, this workshop gained expertise in manufacture of track items such as SEJs, Crossings, Tie Bars, Cotters, M&P equipments, Thermit welding equipments, steel channel sleepers etc.

13.26.2 In 2001, this workshop got ISO-9000 certification. The workshop has manufactured girders for rehabilitation of old bridges and is this work is continuing.

13.27.0 ENGINEERING WORK SHOPS ARAKKONAM (SOUTHERN RAILWAY)

13.27.1 The present Engineering Workshop, Southern Railway originally started as a Points and Crossings repair shop at Royapuram near Chennai by the earstwhile Mysore and South Maratha (MSM) Railway in 1885. Subsequently, it was shifted to more spacious surroundings in Arakkonam. This Workshop is mainly intended to cater to the needs of Civil

Engineering department of Southern Railway. The important items manufactured are standard and specific crossings, curved switches, switch expansion joints, steel bridge girders - welded & riveted, foot over-bridges, passenger platform shelters, lifting barrier gates, motor trolleys, dip lorrys, track Jacks, push trolleys, glued insulated rail joints, flash butt welded rail panels and miscellaneous components like Joggled fish plate & Hand signal lamps. IS0-9002 certification was awarded in July 2000.

13.27.2 The first welded Girder was successfully fabricated in this Workshop in 1982. Glued joints are being manufactured since 1990. Steel channel sleepers, for replacing bridge timber, were manufactured from 2000. Curved switches, 60 kg. & 52 kg., both 1 in 12 and 1 in $8^1/2$ for fan shaped layout are being manufactured since 2000-01.

13.28.0 ENGINEERING WORKSHOP BONGAIGAON (NF RAILWAY)

13.28.1 The Bridge Workshop of N.F. Railway, also known as Engineering Workshop/ Bongaigaon (EWS/BNGN), is situated at Bongaigaon in Rangiya Division in the state of Assam. The workshop came into existence after Independence. Earlier, the requirement of Northeast Frontier Railway was met by Assam-Bengal Engineering Workshop at Saidpur, now in Bangladesh. A need was felt for fabrication of steel structures and bridge girder components within the Railway and it was decided to have a bridge workshop at Bongaigaon. The workshop commenced in the year 1950-51 in a few temporary sheds erected for this purpose. Subsequently, in the year 1957-58, two sheds of light column were constructed.

Presently the items which are fabricated in the Engineering Workshop Bongaigaon are :

- Fabrication of riveted plate girders of upto 18.3 m span.
- Fabrication of light welded structures such as Foot Over Bridges, Road Over Bridges, Platform Shelters, sheds for heavy loads etc.
- Steel channel sleepers, Glued joints, RCC slabs, CC Crib and other ancillary works of bridge girder components, packing plates for bridge components, packing plates for bridge girders etc.

13.28.2 After closing of Foundry Shop in 1985, staff of Foundry Shop were re-engaged for fabrication of Glued Joints.

13.29.0 ENGINEERING WORKSHOP LALLAGUDA (SCR)

13.29.1 This workshop was initially a small reclamation depot wherein conversion of class III BG steel sleepers into M G & N G sleepers was being done. In 1964, due to heavy workload in the Bridge Workshop, Manmad on the C.

Railway, a part work was diverted to this workshop. Consequently it became a small-scale feeding depot to the Engineering workshop, Manmad to undertake light fabrication work such as platform shelters, trusses, 6.1m girders, water tanks etc. When South Central Railway was formed in 1966, this workshop got transformed into an Engineering Workshop, since the Engineering Workshop at Manmad was not able to cater to the requirements of South Central Railway. It was also felt necessary to repair and maintain various assets of the Railway like lorries, trucks, compressors, concrete mixers etc. in this workshop. With this plan, facility to carry out mechanical repairs was added.

13.29.2 The main activities being carried out presently in the Engineering Workshop are:-

- Fabrication of riveted /welded, standard and non-standard plate girders upto 30 m span
- Fabrication of FOBs
- Fabrication of Glued Joints
- Fabrication of steel channel sleepers, rail dollies, dip lorries, speed indicator boards, nuts and washers, saddle plates, packing plates, motor trolleys etc.

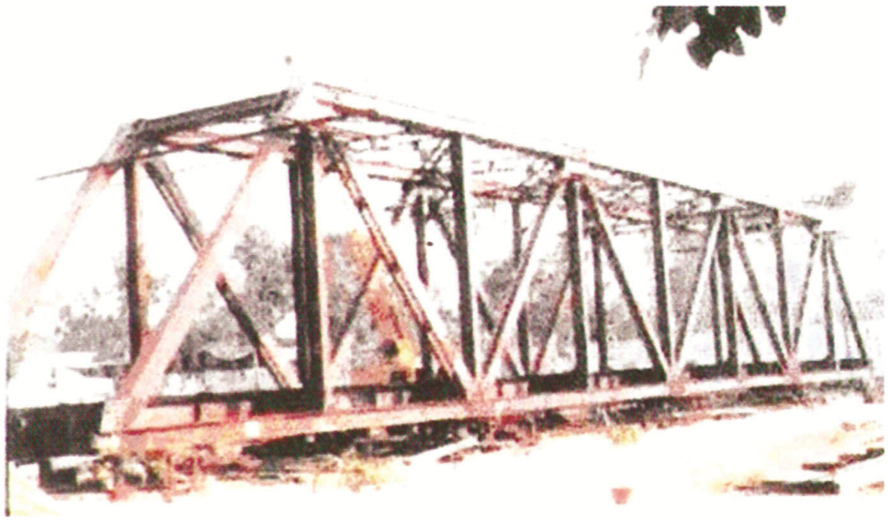
Bridge girder fabrication work is also undertaken departmentally. A target of 200 MTs per annum has been kept for production of girders.

13.30.0 BRIDGE WORKSHOP GORAKHPUR CANTT (NER)

13.30.1 Bridge Workshop Gorakhpur Cantt. was set up in the year 1954 with an initial investment of Rs. One lakh. Over a period of 50 years, it has evolved into a full-fledged steel fabrication & pre-cast concrete manufacturing workshop, catering to the requirement of the steel structures and pre-cast concrete items.The annual capacity of workshop is to fabricate 1400 MT steel structures and 1500 cum. pre-cast concrete items.

The workshop is broadly grouped into the following sub-units:-

i) Steel Fabrication unit	It has 7 Fabrication shops, one for light structures, three for heavy structures, a Machine shop, a Paint shop & a Cutting shop.
ii) Concrete Yard	It has a slab casting unit and a concrete sleeper casting unit.
iii) Plant unit	It is for maintenance and break-down repair of plant & machinery.



Prototype Erection of 150 Feet Girder

13.31.0 BRIDGE WORKSHOP JALANDHAR CANTT (NR)

13.31.1 Earlier a Bridge workshop existed at Jhelum in Pakistan, which was shifted to Ludhiana in 1947 after Independence. There was a problem of adequate space and electric power to accommodate this workshop in Ludhiana which necessitated its shifting to Jalandhar Cantt. in 1949. The workshop is having an area of 10.28 hectares.

13.31.2 The workshop was established to meet the requirements of fabrication of various types of girders, platform shelters, workshop sheds, foot over-bridges and road over-bridges. To meet the changed requirements/technology, casting of reinforced concrete and pre-stressed concrete bridge slabs was also started.

13.31.3 This workshop has been carrying out the fabrication work of 100' Open Web Girder (Riveted Type); 45 m Open Web Girder (Welded Type); Riveted plate girders of different spans from 6 m to 24m; Welded girders of 12.2 m & 18.3 m span.; Girders of Road Over Bridges and other miscellaneous works.

13.31.4 In addition, it also undertakes making of glued joints, Joggling of Fish Plates; Stress Benches & Moulds; Modification of BFRs for carrying long-welded rails; Metalising of vital components of Open Web Girder to increase their life; Casting of RCC Slabs for bridges and Casting of PSC Slabs of 20', 15,' 12' and 10' spans for bridges.

13.31.5 In the year 2005-06, the workshop achieved a total fabrication of 2950 MT.

Temporary bridge using Calendar - Hamilton griders

13.31.6 The Workshop launched 67 m Calendar - Hamilton (CH) span and 30.48 m CH Span on Bridge No. 7 on Sambalpur-Jharsuguda Section in Orissa. CH Span of 67 m was launched by assembling on embankment and pulling by 172.5 m over plate girders.

13.32.0 ENGINEERING WORKSHOP SABARMATI (WR)

13.32.1 The bridge workshop was originally set up before Independence at Vashi. It had a staff strength of about 500 with an annual production of Rs. 30 lakh. The workshop was shifted to Sabarmati in June 1958 to cater to the requirements of fabricating steelwork for both Broad Gauge and Meter Gauge. With increasing demands for more output, the capacity of existing shops had been increased over a period of time and new shops like foundry, flash-butt welding and smithy were added. At present the staff strength is 750 and the annual turnover is Rs. 26 cr. The workshop is spread over an area of 76 acres around 4 km from Sabarmati Railway station.

13.32.2 At present, the capacity is for fabricating 150 T of riveted bridge girders and 75 T of other steel work, totaling 225 T per month. The workshop started manufacturing open web girders in 1979. Open web under-slung type (30.5m span) was manufactured first and subsequently 45.7m spans were manufactured. The Metalising of plate girders and flooring system of open web girders to keep away corrosion has been out sourced.

13.32.3 Flash Butt welding plant was set up in 1964. The plant was supplied by A I welders of U K. It can weld 90 R and 52 kg UTS rails. Panels of 10 rails

(130 m) can be welded. The power supply to the plants was augmented in 2002 to permit parallel functioning of both the plants. Presently 6000 joints are being welded in a month.

13.33.0 INDIAN RAILWAYS SIGNAL WORKSHOPS

13.33.1 Post Independence while introduction of modern signalling was taking place on Indian Railways the need for its centralized overhauling and repair was felt. To meet with these requirements Indian Railways progressively established Signal Workshops in each zone .Over the years, some of these signal workshops graduated into departmental production units for modern signalling equipments and provided support to signalling maintenance and construction projects on Indian Railways .

13.33.2 The important Signal workshops on Indian Railways are :

- Podanoor Signal Workshop
- Gorakhpur Signal Workshop
- Byculla Signal Workshop
- Secunderabad Signal Workshop
- Ghaziabad Signal Workshop
- Howrah Signal Workshop

13.34.0 SIGNAL WORKSHOP PODANUR

13.34.1 It is the largest Signal Workshop of Indian Railways. During 1975 Railway Board brought in Transfer of Technology from Westinghouse UK to this workshop for indigenous manufacture of Q series Relays . Many items were indigenously developed by this workshop. As a result the out turn of the workshop reached Rs.30.95 Cr during 2005-06.

13.34.2 Important equipments manufactured in this workshop are Q series Relays, IRS Point Machines, TLB Instruments, Universal Axle Counters, Double line Block Instruments, Polarised Relays and Control Panels. This workshop has also developed High Thrust Point Machine 220 mm Stroke with clamp type locking and Special type Relays QTA2 and QT2.

13.34.3 Computerization And Networking has been introduced in this workshop in a big way. This Signal Workshop was awarded ISO 9002/1994 certification during 1998

13.35.0 SIGNAL WORKSHOP, GORAKHPUR

13.35.1 Signal Workshop, Gorakhpur, of North Eastern Railway, was established in 1958. It is the second largest Signal Workshop of Indian Railways .Besides providing overhauling and maintenance services since 1970, it is also engaged in the manufacture of Electric Points Machines-Rotary [EPM(R)], Relays, Lifting Barriers Gates, Apparatus cases etc

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CHAPTER 14

SIGNALLING & TRAIN CONTROL

14.1.0 Signalling was in use much before the railways came to India. Lighted '*mashals*' were used by Indian kingdoms for sending Signals from Fort to troops. For almost two decades after opening of railways in India hand / flag signal in the day and signal lantern at night were used for Train Control till 'Discs' followed by 'Semaphore Signals', Colour Light Signals and Communication based Signals arrived.

The Era of Signalling for Train Control in India can be classified into :

(i) Semaphore Signalling for train Control

(ii) Colour Light Signalling for Train Control

(iii) Computer based Signalling for Train Control

(iv) Communication based Signalling for Train Control

14.2.0 SEMAPHORE SIGNALLING FOR TRAIN CONTROL

List & Morse system of train control with Semaphore Signals was completed (1892-94) on Delhi (Ghaziabad)-Lahore section. GIPR introduced (1893) the technology of Cabin Interlocking with Semaphore signaling. The entire Delhi – Bombay section was equipped by 1912.

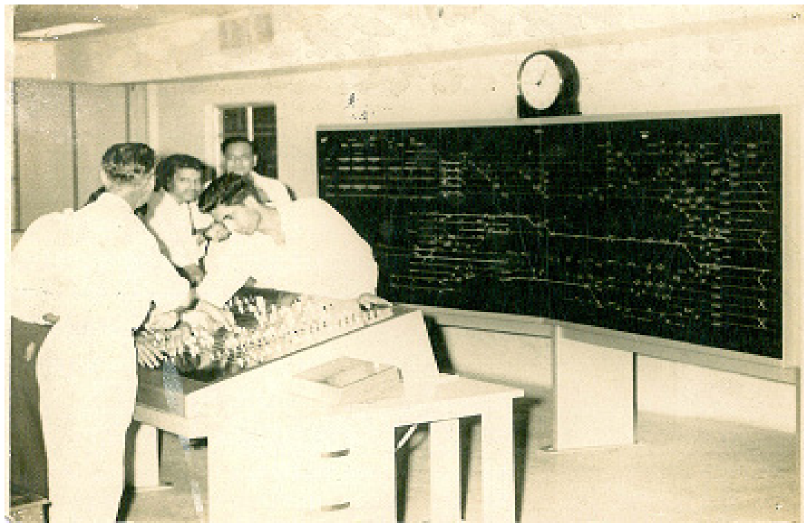
Semaphore Signal of Indian Railways

Initially the method of train working between stations was based on “space interval” till 1860 , when Telegraph system came in .The Block working was started by exchanging Morse messages between the stations The year 1910 marked the beginning of use of telephones for voice communication between stations in conjunction with block instruments for train control .

14.3.0 COLOUR LIGHT SIGNALLING FOR TRAIN CONTROL

The era of Colour Light Signaling for Train Control began after First World War .Track circuiting & electric lighting of signals were introduced (1920s)on Bombay suburban section. By 1923 Bombay VT –Kurla section was completely track circuited enabling GIPR to commission its first Automatic Colour Light Signaling on Bombay - Byculla section(1928). Power Signaling and Upper Quadrant Semaphore Signals came into being in 1930s followed by Neale’s Ball token instrument in 1940s .The first all Electric Interlocking was commissioned(1945) at Bandra station of Bombay suburban section.

Colour Light Signals on Indian Railways



Route Relay Interlocking Panel at Howrah (1966)

After independence, India set its ambitious Five Year Plans for industrialization which called for multifold increase in transportation capacity of Indian Railways. Signalling modernization have played an important role in it.

14.4.0 COMPUTER BASED SIGNALLING FOR TRAIN CONTROL

14.4.1 CTC (Centralized Traffic Control)

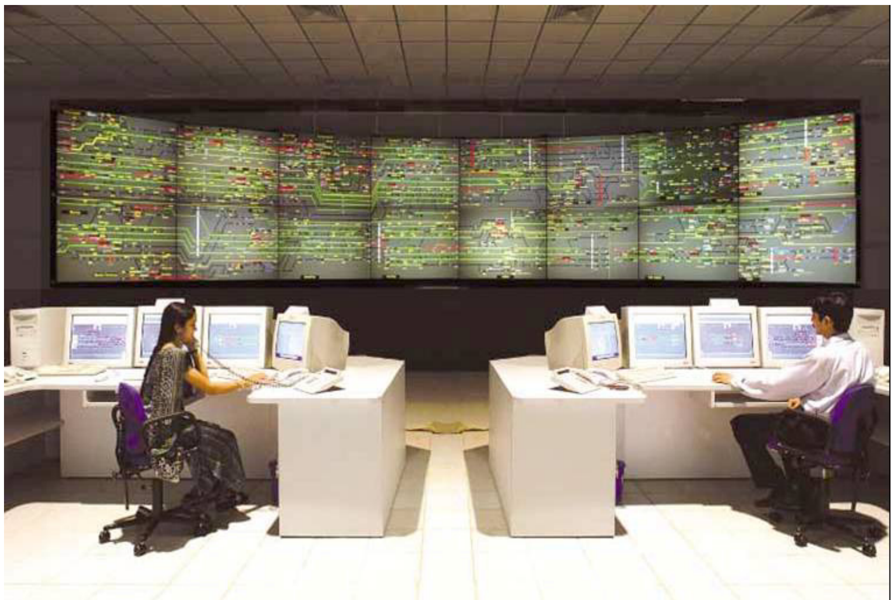
The GRS Expert Mr Finnie who visited Indian Railways in early 1960s recommended CTC for Siliguri- Alipurdwar MG section to improve line capacity. The first relay based CTC system was installed in 1966 on Gorakhpur - Chhapra MG section followed by Bongaigaon – Changsari section

14.4.2 Train Management System

Suburban trains form the lifeline of Mumbai – the commercial capital of India. Over 6 million passengers commute on the local trains, or locals, of Mumbai on a daily basis, making up almost half of the total daily passenger carrying capacity of the Indian Railways. For these commuters every minute counts. To meet their expectation for accurate train information **and train scheduling** Railway Ministry sanctioned a project of TMS (Train Management system) for Western Railway's Mumbai suburban section in 1998. This Software based TMS system, supplied by Bombardier Transportation was commissioned

(2003) and has proved to be extremely useful by commuters, control centre staff and management. A similar Train Management System has been introduced on the Suburban System of Central Railway.

Encouraged with the success of TMS at Mumbai, Railway Ministry have sanctioned new TMS projects for Sealdah, Howrah, Kharagpur and Chennai.



Train Management System at Mumbai

14.4.3 Automatic Train Control

Way back in 1968, RAEC (Railway Accident Enquiry Committee) recommended provision of AWS (Auxiliary Warning System) on trunk routes and suburban sections of Indian Railways. This was followed by subsequent recommendations, which resulted in installation of Siemens AWS system (ZUB 100) in 1982 on the Mumbai suburban sections, which is still working.

The search for a suitable ATC system meeting with Indian Railways needs & environments has been on for over 3 decades. A proven and world wide used ETCS L1 system called Train Protection & Warning System (TPWS) (=ETCS level 1) has been successfully introduced on the Chennai Central - Gummdipundi (45kms) suburban section.

With the experience gained, Railway Ministry has sanctioned new projects of Train Protection System (= ETCS level 1) for Sealdah- Howrah –Khanna, Tundla- Kanpur, Howrah – Kharagpur and Virar- Vadodara sections etc to provide Automatic Train Protection to trains in all automatic Signalling sections (3300 kms) on Indian Railways.

ETCS L1 when upgraded in future to ETCS L2 will be able to give appx 30 % increase in Line Capacity on that section .A Headway of upto 2.5 minutes have been achieved by ETCS L2 on Loteshchberg Project in Swizerland.

14.4.4 Computer Based Interlocking (EI)

In late 1980s, US&S offered a trial installation for SSI system on Indian Railways. Railway Ministry decided the trial to be undertaken by Southern Railway at Srirangam station. The SSI was put in parallel to the existing Mechanical Cabin Interlocking system (just like Lemington Spa in UK) and monitored for a long time. On 25th July 1987 CSTE Southern Railway took the historical decision to cut in the new SSI system, ushering the era of Computer based Signaling on Indian Railways. By 1996 there were 11 SSI installations on Indian Railways. Today it has over 800 Electronic Interlocking installations on its network providing flexibility in Train Control and it is growing.

14.4.5 Axle Counter

RDSO together with CEL, DCM and under guidance from IIT Delhi took up the indigenous development of axle counter. After extensive trial, in 1977 RDSO cleared the indigenous axle counter equipments for use on Indian Railway. CEL and Indian Railways Signal workshops at Podanur and Byculla took up production. Over 5000 of these analog axle counter equipments got installed for track circuit and automatic check of last vehicle over the next two decades.

In 1997, Railway Board sanctioned a pilot project of Digital Axle Counter on South Central Railway. The first set of Digital Axle counter (Alcatel) were put on trial on Maulali - Cherlapalli section. Since then there has been no looking back. Today block proving by Digital axle counters have become an integral part of Indian Railways Train Control improving capacity and enhancing Safety.

14.4.6 Metro Train Control

The honor to have the first metro in India goes to the "City of Joy". The Dumdum - Tollygung line was opened on 24th October 1984. Initial operation started with colour light signaling, which was followed by automatic signaling. In 1990 CTC and ATP was commissioned.

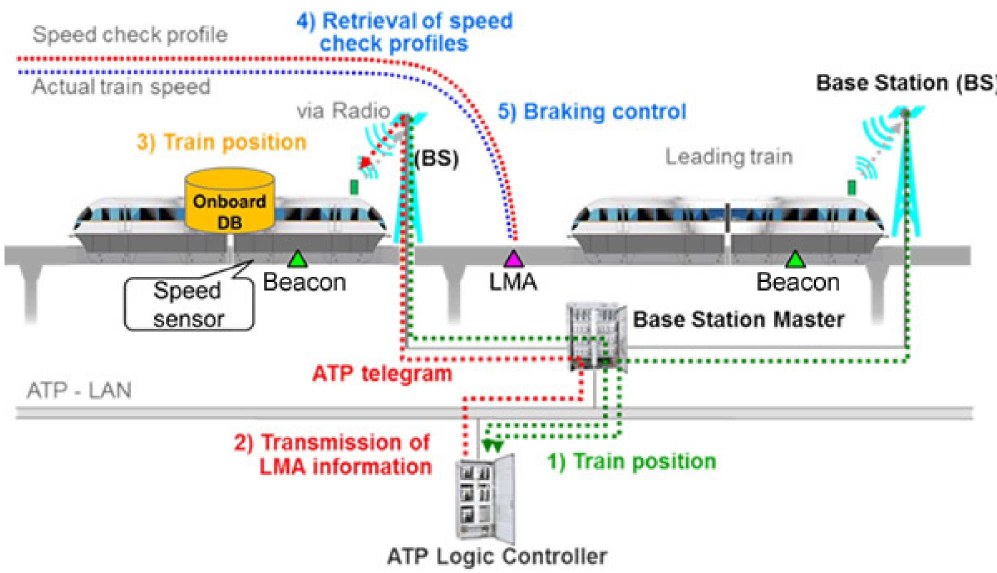
Delhi metro has introduced state of art S&T technologies on its network and is a show piece of most modern signaling & telecom technologies in India. It has introduced ATO/CATC, ATS, SSI, Train Radio on its metro network which is providing a 2 minutes practical headway.

Signal at Delhi Metro

Delhi Metro Train with CATC /ATO

14.5.0 COMMUNICATION BASED SIGNALLING FOR TRAIN CONTROL

The next stage of development in Train Control technology is Communication Based Signalling for Train Control.



Hyderabad Metro will be first metro in India to usher this technology of CBTC in India in 2015 to achieve 90 secs Headway. The CBTC system is also being installed by Delhi Metro in Phase III of their projects and on Kochi Metro.

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CHAPTER 15

TELECOMMUNICATIONS

15.1.0 HISTORICAL BACKGROUND

15.1.1 First trains in India were inaugurated from Bombay to Thane by GIP Railway on 16th April 1853 and on 15th August 1854 by EIR between Howrah and Hooghly. Regular train services, on these sections were started with two trains each way every day. These trains were operated on publicly announced fixed time table; with the arm of station staff providing basic control for train operation.

15.1.2 Railway network and traffic grew rapidly, as many guaranteed Railway companies were setup for development of Railways in all parts of India. Considering that Railways of different companies would be interconnected eventually, government recommended that uniform code of general regulations be adopted for all railways. Based on experience of running British Railways, general guidelines framed by EIR were adopted by all Railways. Uniform standards of Block working were laid down to ensure safety and increased line capacity.

15.1.3 As the railway network and traffic grew rapidly, Telecommunications played a key role in Railway Operations and Safety by providing safety systems for Block working, leading to large improvements in line capacity.

15.1.4 For Safe and Efficient management of Railways Operations on geographically widespread network with continuously increasing traffic, need was felt to establish Operation control centers to monitor and control trains. Telecommunication links between these control offices to all stations and other O&M facilities provided the basic infrastructure for efficient and safe train operations.

15. 2.0 TELECOMMUNICATIONS – BASIC NEED OF TRAIN OPERATION AND CONTROL

15.2.1 Globally Railways were the pioneers in adopting every Telecom Technology from Morse Telegraph to Mobile Wireless, Teleprinters to Data Terminals and overhead line wires to Optical Fiber for improving their Safety and Operations

15.2.2 Invention of telegraph by Samuel Morse in 1837 provided revolutionary change for transmission of messages and information exchange. First Telegraph line was laid from Euston to Camden for London - Birmingham Railway. It was used for public Telegraph and Railways train operation and control. Thereafter most of telegraph systems developed alongside British Railways with railway stations also providing telegraph services to public. British Telegraph industry had 1874 telegraph offices at Railway Stations and only 1058 other telegraph offices in 1869.

15.2.3 Telegraph systems were well developed on British Railways before railway lines were laid in India. Telegraph act of India 1854 made telegraph in India under Govt control. This Act later revised as Indian telegraph Act provided telegraph lines to be laid along the railway Lines. By 1857, 500 Km of telegraph lines had been laid along EIR. Railways had to hire telegraph services from Department of Telegraph.

15.2.4 Railways started leasing telegraph lines for their exclusive use. Three types of telegraph circuits were used based on operational requirements. Train wire was used between two stations for train movement authorization through telegraph. Inter wire services were provided on separate common line connecting all important stations on time share basis. Dedicated point to point circuits were leased to interconnect central telegraph offices setup at Major administrative control centers. As teleprinters became available by 1870 these were introduced along with punched tape transmitters at all central telegraph offices of railways for large information exchange between control office and administrative centers. As telegraph became the primary means of communication on Railways, all station operating staff and large number of telegraph operators had to be trained in Morse telegraphy. Training manuals and regular training courses were introduced by all company railways to meet this demand.

15.2.5 Block system of train working was used in one form or other from the very beginning. Under this, station master will obtain line clear for a train through train wire telegraph and hand over a written Memo to the train driver as authority to proceed to the next station.

15.2.6 Depot for repair and maintenance of Locomotives, Coaches and Wagons were set up initially near terminal stations, at Howrah by EIR and at Byculla by GIPR. As the network spread, more such depots were setup close to major junction stations or close to major cantonments. Bhusawal was setup by GIPR at junction of line towards Nagpur and Jabbalpore; Danapur and Allahabad by EIR, Baroda by BB&CI and Jhansi by Indian Midland Railway (later merged with GIPR) close to army cantonments. Train operation and control centers were also established at these points and provided with telegraph offices for intercommunication with other important Operation and Maintenance centers. These later developed as full-fledged control centers manned by staff from operating, loco, carriage and wagon departments.

15.2.7 Invention of Telephone by Alexander Graham bell in 1876 and its magneto ringer in 1878, were adopted by Railways world over as well by Railways in

India to provide communication in local area, between station and all important O&M centers.

15.2.8 Manual Telephone Exchanges evolved with multi-drop party line in 1878 and automatic strowger exchange in 1892. Based on principles of multi-drop party line and electromagnetic step control, Standard Telephone Company of UK developed selective calling for railway control communication, to link central control centers to all stations on a common line all along Railway Track. From 1895 this control communication were widely used on British Railway and by year 1900 these were introduced by Railways in India. For this separate line wires called Section control were laid by Telegraph department for Railways which linked Railway control Centers to each Station for monitoring and control of train operation. As these section controls were established, train charting by section controllers round the clock was started. In addition, Separate Deputy Control circuits were set up to linking all important traffic handling stations and O&M centers. These control systems became standard and are continuing to be used even today with some technology up gradations.

15.2.9 Train Crew were provided with portable control phones (PCP) and guide rods which could be hooked to control wires to provide communication between train crew and section controller all along the Railway Line. Provision of PCP, which provides means of communication between train crew and control office in any emergency, is statutory obligation under Indian Railway Act as an essential Safety requirement.

15.2.10 Reorganization of Indian Railways on Zonal and Divisional basis was carried out in1951 -52. Divisional control offices became the nerve centre of train operations. For intra and inter divisional co-ordination, extensive nation - wide telecom networks were provided to meet requirements of essential operations and administrative functions.

15.2.11 All telecom services requirements of Indian Railways were, initially, leased from Department of Post and Telegraph (DOPT) as laid down in Indian Telegraph Act.

15.3.0 GROWTH OF IR TELECOM

15.3.1 At the beginning of First Five Year Plan (1950), entire telecom network of IR was based on overhead line wire alignments running along-side the railway track provided by DOPT. The DOPT could not provide reliable communication services to meet Railways demand for 24X7 availability. Frequent failures, including total failure of communication between stations, became a serious bottleneck for safe and efficient operation of trains; which created serious limitation in meeting the rising demand of traffic movement of growing economy. Government authorized IR to plan, construct, operate and maintain telecom network for their internal use.

15.3.2 Railways took over one DOPT alignment where there were two alignments on either side of track and laid its own alignments with Aluminum Conductor Steel Reinforced (ACSR) wires. These alignments, being maintained by Railways, provided far superior service reliability for safe and efficient train operations.

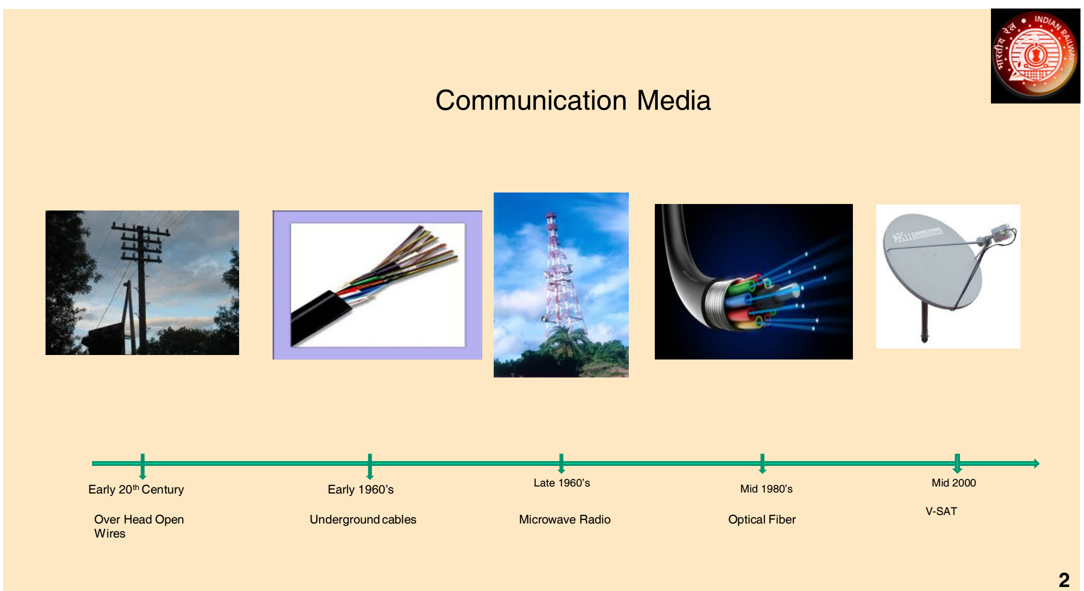
15.3.3 With introduction of AC electrification, Over Head (OH) alignments were converted to Paper Insulated Aluminum Sheathed Quad Cables on considerations of Electro Magnetic Induction (EMI). As EMI affected all OH alignments laid along the railway track DOPT, also, had to convert their network to underground Quad cables. Initially DOPT laid and maintained these Quad cables for common use of DOPT and Railways, but in subsequent years Railways laid their own Quad cables along the track while DOPT separately laid coaxial cables along roads. This led to total separation of Railways telecom network from that of DOPT.

15.3.4 Provision of under-ground Quad Cables in RE areas lead to remarkable improvement in service quality with availability better than 99% and clear noise free speech. However, reliability of OH alignments continued to suffer with frequent failures primarily due to theft and vandalism.

15.3.5 Indian Railways provided Microwave (MW) and UHF Radio Systems which provided radio-patch to the OH alignments at frequent interval of about 50 Km. This led to improved availability of telecom network for railway operations. MW/UHF Radio systems provided highly reliable communication between Divisional and Zonal Head Quarters and also between different administrative and O&M centers.

15.3.6 By mid eighties Optical Fiber Cables (OFC) had been developed and used as reliable cost effective communication system. IR also adopted this technology initially for all new RE routes and later for all trunk and mainline routes. OFC has transmission capacity far in excess of Railways' requirements. RAILTEL has been setup to market this excess capacity for public use and earn revenue.

15.3.7 As part of FOIS project IR installed a Satellite Communication System to link many remote freight loading sidings where OFC or other reliable communication was not available. All modern telecom technologies have been adopted on IR.



15.3.8 Following Table shows the growth of IR Telecom:

Year	OH Line	QUAD Cable	MW	UHF	OFC
	Rkm	**Rkm**	**Rkm**	**Rkm**	**Rkm**
1960	2173	-	-	-	-
1970	2669	-	909	-	-
1980	10416	-	11995	-	-
1990	23822	9536	23822	5353	495
2000	24944	13279	24944	5580	2737
2005	9644	20687	16328	4747	22423
2010	4026	39495	16037	3882	35268
2014	1850	55978	12629	3035	46850

15.4.0 COMMUNICATION FOR ADMINISTRATION, OPERATION AND MAINTENANCE

15.4.1 **Telephone Network** : For efficient administration, operations and maintenance a large network of railway telephone exchanges were set up at all Divisional and Zonal headquarters as well as at all important O&M centers throughout Indian Railways. All these exchanges were interconnected on trunk circuits on railways MW and OFC links. From small base 4000 railway telephone subscribers in March 1960, the subscriber base has grown to 3,83,000 by March 2014 with Zonal Railways wise STD facilities. Zonal Railways wise uniform numbering scheme has also been implemented

15.4.2 More than 20,000 manned **LC gates** have been provided with gate-phones connected to nearest station as an important Safety Measure.

15.4.3 **VHF Sets** were provided to stations as means of communication during failure of OH or cable links. These Sets provided means for safe operation of trains during total failure of land line communications. Drivers and guards have been provided with hand held **Walkie Talkie** sets for easy communication as the length of trains increased and exchange of signals between train crew by hand signals became increasingly difficult. By March 2014 more than 1,35,000 wireless sets have been provided on IR.

15.4.4 **Mobile Train Radio** to provide direct communication between train crew and control office with provision for priority calling during any emergency has been provided over 2200 Rkm.

15.4.5 All officers and senior supervisors have been provided with modern **Mobile Phones with Common User Group (CUG)** facilities permitting unlimited calls within the user group. By March 2014 more than 1,85,000 CUG SIMS have been activated.

15.5.0 COMMUNICATION FOR FOIS & PRS

15.5.1 After a detailed study, World Bank had recommended implementation of Freight **Operations Information System (FOIS)** on IR with a view to improve wagon turn round by more than 15%. FOIS project costing Rs 1050 crore, with computer segment of Rs 300 crore and telecom segment of 750 Crore, was sanctioned under which computer terminals, provided at all locations dealing with freight operations, were to be connected on line to a central computer. Dual connectivity was planned with diverse routes for each terminal. Centre for Railway Information Systems **(CRIS)** was established for planning and implementing Computer segment and Indian Railways Central Organization for Telecom **(IRCOT)** for the Telecom segment. Being a critical network for control and operation of freight traffic on entire Indian Railways, telecom network had to be designed for very high reliability. This was achieved by linking each terminal on two diverse routed on IR OFC and MW systems. At some locations leased DOT circuits were hired for link diversity. Railways installed a dedicated VSAT network to link many remote FOIS terminals to the central computer. FOIS project commissioned in year 2001-02 fully met its planned objective as the robust telecom network provided highly reliable communication backbone.

15.5.2 Computerized Passenger Reservation System **(PRS)** was sanctioned to improve the quality and reliability of reservation system on IR. While the basic software development work was in progress IRCOT carried out a detailed study for its communication network. Three system configurations were considered. Fully distributed configuration, in which each location will have its own processor linked to all other locations in mesh network, required a very complex communication network that would not be feasible and reliable. Fully centralized system at single location with PRS terminals at all locations on IR linked to one central computer was considered, but the system with five regional computers fully networked with high speed digital links was found superior on considerations of reliability, availability, maintainability and security. **PRS system of IR is one of the largest on line reservation system in the world** in which very large number of PRS terminals at more than 1000 locations have been networked through highly reliable communication links. IRCTC has provided interface and link for internet connectivity through which PRS is now accessible globally.

15.6.0 IR TELECOM – SERVING THE NATION

15.6.1 Under National Telecom Policy (NTP), National Long Distance Telecom segment was opened to license to spread network across India including rural areas. In September 2000, RAILTEL was formed as a Railway PSU with a mandate to modernize Railways communication network and to significantly contribute to the realization of goals and objectives of NTP-1999.

15.6.2 It was decided that Railway's existing telecom assets and Right of Way (RoW) shall be transferred to RailTel for commercial exploitation. RailTel initiated rollout of OFC across the country using exclusive RoW along Railway tracks by 2001 and created over 25,000 Rkm of OFC network equipped with modern SDH based systems by year 2005. After fully meeting the communication requirements of IR, additional capacity was marketed to meet the rising demand of National Long Distance communication links by all telecom service providers. OFC network of RailTel grew rapidly form 25,000 Rkm covering 2407 Points of Presence (PoP) in year 2005-06 to more than 42,000 Rkm serving more than 4200 towns and cities by year 2013-14.

15.6.3 RailTel now offers wide range of managed telecom services to Indian Telecom market. Services include managed leased lines, Tower collocation, MPLS based IP-VPN, Internet and Data center services, Next Generation Network (NGN) based voice carriage services to Telecom Operators, Data links to Internet Service Providers, MSOs, Enterprises, Banks, Govt, Institutions/Depts, Educational Institutions/Universities, etc.

15.6.4 By setting up of RailTel, IR Telecom has been transformed from a cost center to profit center. Its income of Rs 60 crore in years 2005-06 has grown to Rs. 538 crore in 2013-14 with a Profit after Tax of Rs.138 crore.

15.6.5 Some Important milestones of **RailTel** are listed below :

- 2000 - Formed as 'Schedule A' PSU, under Ministry of Railways.
- 2002 - Obtained NLD license from DOT.
- 2005 - Commissioned first STM-16 network with higher capacity.

- 2006- Commissioned MPLS-IP network at 36 locations enabling integrated Data, Voice & Video services to the customers

- 2007 - Turned into profit making enterprise after wiping off accumulated losses.

- 2008 - Commissioned first DWDM based network in Southern India capable to carry multiple 10G (Gigabit) capacities.

- 2009 – Commissioned Next Generation Network (NGN) based softswitch to carry voice calls over Internet.

- 2010 - Signed agreement with National Informatics Center (NIC) for providing high capacity links under National Knowledge Network (NKN) project.

- 2011- Signed agreement with Universal Service Obligation Fund (USOF) under DOT for laying OFC in 6 States of North East connecting all District and Block HQs.

- 2012 – Selected for implementing National Optical Fiber Network (NOFN) for reaching up to 2.5 lac gram panchayats (GPs). Railtel allotted 11 states/UTs covering 36,000 GPs

- 2013 – Commissioned its first as well as IR's first Tier- III Data Center at Secunderabad.

- 2014 – Launched "RAILwire" for broadband service delivery to SMEs and households effectively making entry into retail segment for the first time.

15.6.6 Setting up of RailTel has enabled IR to utilize spare capacity of its OFC network for growth of telecom services in the country and earn profit on the basic investments required for its operations. RailTel has inducted modern cutting edge technologies to serve wide spectrum organizations in Govt, Public and Private sectors. This has helped IR also to avail these advanced communication services for its operations and administration.

15.7.0 IR TELECOM – BASIC INFRASTRUCTURE FOR TRAIN OPERATIONS & SAFETY

15.7.1 Right from the inception of Railways, Telecommunication provided the basic infrastructure for safe and efficient train operations. As the telecom technologies advanced from basic telegraph on overhead wires to advanced high speed data communication on Optical Fiber Cables (OFC), Indian Railways have adopted these for improving the train operations, efficient administration and improved customer services.

15.7.2 To utilize the spare capacity of OFC cables and provide telecom services to other users RailTel has been set up by IR. RailTel has upgraded the network by inducting modern technology and provide multiple value added services for benefit of IR and other govt, public and private sector customers. Railways telecom network, besides fulfilling its essential communication needs, has been turned in to an independent profit center.

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CHAPTER 16

OPERATIONS / OPERATIONAL PRACTICES

16.1.0 SUSTAINED GROWTH IN OUTPUT

In 2012-13 Indian Railways joined the 'Billion Tonne Club' when it transported over a billion tonnes of originating freight traffic in a single year. It joined the small distinguished league of China, U.S.A. and Russia as a leading freight railway of the world. Indian Railways was already the leading passenger transporting rail system in the world with the highest passenger kilometers in the world. The achievement is singularly remarkable in view of the fact that unlike several European and other advanced rail networks, in India both passenger and freight traffic share the same tracks without segregation of rail corridors for each type of traffic. The role of operational practices in sustaining growth may be highlighted by the fact that in the 61 years between 1950-51 and 2011-12 whereas the Index for growth of various inputs e.g. Route Kilometres increased from 100 to 121, Wagon Capacity from 100 to 311, Passenger Coaches from 100 to 356, Tractive Effort of Locomotives from 100 to 372, the actual Traffic Output grew from 100 to 1516 in terms of Net Tonne Kilometres and 100 to 1505 in terms on Non-Suburban Passenger Kilometres. This phenomenal growth in output against relatively modest investment based inputs could only be achieved by steady induction of new technology and adopting innovative operational strategies.

16.2.0 INDIAN RAILWAYS AT TIME OF INDEPENDENCE

At the time of Independence in 1947 India had inherited a Railway System that was considerably run down as a result of the debilitating impact of World War II and was in urgent need of rehabilitation. It was a system that was dominated by steam traction, low capacity freight rolling stock, mostly four wheeler with plain bearings, semaphore signalling with a number of sections with rudimentary standard of interlocking between point and signal and a track structure that consisted of much lighter rails than today, sleepers were mostly wooden or cast iron and most arterial routes were still single line. Productivity of the system was low, reliability and safety performance was also poor by modern standards. Moreover, there were a large number of Railway systems and they came in different shapes and sizes. Railway reorganization and greater Central control had started in 1905 with the creation of the Railway Board, Railway Finances were separated in 1925 following the Acworth Committee and some structural changes had been introduced in 1935. At the time of

Independence, although the organization was well managed there was need for organizational change particularly, as some Zones were divided between India and Pakistan, some were directly managed by the State, a few were controlled by princely states and still others had strong Company traditions. Therefore the Re-organization of Zones in 1951 along Geographical lines was an important step taken by Independent India's new Government to ensure efficient management of assets. The Railways at the time were the leading mode of transport carrying 80% of freight and over 60% of passenger transport in the country. It played a crucial role in national integration, economic development and was a leading industrial enterprise in the country.

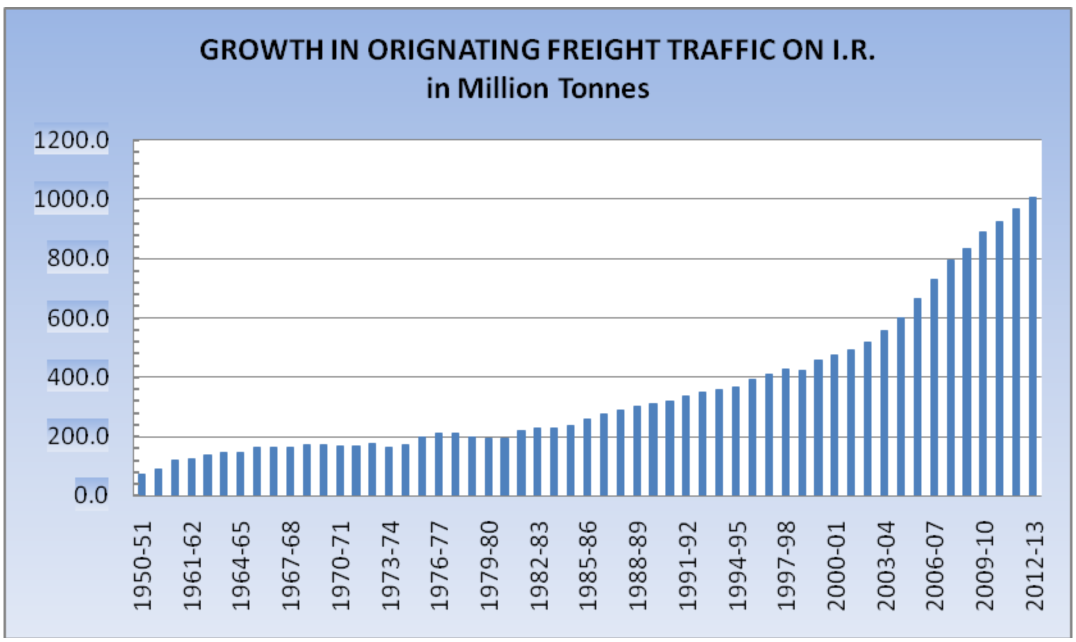

Chart 16.1

16.3.0 CREATION OF FACILITIES FOR NEW INDUSTRY

In the last 65 years operational practices, aided by new technology have undergone a sea change without which the growth in freight and passenger volumes being transported on the rail system could not have been achieved. The growth as depicted in Chart 16.1 has accelerated in the last decade with the increase in GDP growth of the Indian economy. During the first three decades up to the early eighties the focus of Railway development in India was catering to the new Heavy Industries that were created in the country such as the Steel plants at Durgapur, Bhilai, Rourkela and Bokaro or the new Fertilizer and Cement industries that came up in different parts of the country as well as the new oil refineries that came up in Mumbai area, the North East and later at Mathura and Panipat in Northern India. In order to cater to the new industrial complexes during this period new Marshalling Yards and siding complexes were built to serve the industries.

16.4.0 MARSHALLING YARDS

Traditionally the world over the basic unit of rail transport in case of freight was the wagon. All the wagons for a particular direction were coupled together to form a freight train. These trains were broken up and resorted in marshalling yards. The Freight train ran from one marshalling yard to the next marshalling yard which may be 300 to 400 Kilometres away where the train was again broken up and after combining with other wagons towards its final destination was reformed in a new train and dispatched. Thus a wagon would move by several different goods trains between its originating point and final destination. Marshalling yards therefore played a key role in operations. These were huge complexes with distinct components of a reception yard, marshalling yard and dispatch yard with auxiliary facilities like a grid yard for local and sick wagons. There were usually separate yards for up and down directions. Indian Railways had very large marshalling yards on all Zonal Railways these included Mughal Sarai and Andal on erstwhile Eastern Railway, Khanalampura on Northern Railway, Ajni and Katni on erstwhile Central Railway, Bandra, Vadodara and Gangapur City on Western Railway to name a few. Yard design and modernization was a focus area during the first six Five Year Plan periods. As most large yards were 'Hump' yards wagons were rolled from a hump so that they travelled by gravity into various sorting lines. New technology was inducted for controlling the speed of a wagon rolling down from the hump by introducing 'retarders' which would apply appropriate brake pressure on the wheels as the wagons rolled down from the hump depending on the weight of each wagon and number of wagons in one hook. In addition automatic computerized switching of points was introduced as it was possible to feed the line on which each 'cut' of a train being broken up was to be sent in advance. The Hump Operations were controlled from a centralized Tower cabin in the yard.

16.5.0 TRANSITION FROM WAGON LOAD TO TRAIN LOAD

During the late 1970's and early 1980's there were severe capacity constraints on the Railway system. The Railways found it difficult to meet demand of the core sectors of the economy such as coal for power houses, cement, fertilizer etc. This was because the productivity of wagons was relatively poor. The large number of marshalling yards a wagon had to go through in its journey resulted in delay and marshalling yards were sometimes were described as 'graveyard' for wagons as a major portion of the time a wagon was in a marshalling yard instead of on the move. As a result a momentous decision was taken by Railway Management in the late 1980's when they decided that instead of the single wagon being the unit of transport for which a trader or industry could indent the minimum size of consignment for booking would be a train load. The advantage was significant as a consignment could meet directly between its originating point and the destination. This would greatly improve the mobility and availability of wagons. **There was a negative aspect also in that Railways lost the wagon load and less than wagon load traffic and would in future be confined to bulk commodities or traffic that moved in very large volumes.** This decision also was the death knell of Marshalling Yards. However the operating strategy ensured that the growth would be sustained.

16.6.0 THROUGHPUT IMPROVEMENT – WAGON DESIGN

In the 1970's induction had begun of the new BOX Wagon which greatly helped in improving IR's transportation capacity. The wagons were bogie wagons and had a number of superior features compared to earlier stock. It had roller bearing axle boxes, fabricated bogie, centre buffer couplers. The wagons were capable of higher speed, required less frequent attention and heavier trains could be formed. A train load consisted of 40 BOX wagons. Later by the late 1980's a BOX'N' wagon was introduced which had cartridge roller bearing, cast steel bogie, helical spring suspension, Central Buffer Coupler air brakes. As the length of the BOXN was much less than a conventional BOX and carrying capacity was higher. A BOXN train with 58 wagons can at present carry a pay load of 4000 tonnes per train. The wagons require very little maintenance and are capable of long runs at higher speeds. There are covered versions of the BOX known as BCX and the BCN/BCNHL. Improvements in wagon design have helped in increasing throughput capacity by transporting much higher tonnages per train than was previously possible. **Further improvement is envisaged by improving the pay load to tare ratio by using lighter materials for wagon construction, this includes steel and aluminum.**

16.7.0 THROUGHPUT IMPROVEMENT – TRAIN EXAMINATION POLICY

In the days of the marshalling yards, the yard was also a point where wagons were given an 'Intensive' or 'safe to run' examination by examination staff. Whereas the marshalling yards were getting redundant the 'safe to run' examination continued based on a policy that every freight train must be examined every 500 kilometres. Every examination takes time, usually the locomotive has to be detached and the train has to be freshly ordered. The practice continued for several years, however, as a productivity enhancement policy it was progressively discontinued. Thus it became possible to for a train to go from end to end without any intervening examination. Now as an operational practice to improve wagon productivity a freight train can undergo several loading and unloading operations between a C&W examination as current policy is that (i) in case of Closed Circuit (CC) Rakes examination is done at interval of 6000 Km or 35 days whichever is earlier, (ii) In case of a ‘Premium Examination’ after 12 days and may be relaxed for a further 3 days to enable a loaded rake to reach its destination and (iii) in case of ‘Intensive Examination’ it may proceed from originating point to destination. Indian Railways has come a long way from the time of the plain bearing four wheeler wagons which had to be oiled every month, repacked once in six months and required constant ‘nursing’ and when trains had to undergo several safe to run examinations between the originating and destination station. The technological inputs, operating policies and rationalizing of Train Examination procedures have resulted in significant improvement in Wagon mobility and productivity as shown in the Charts 16.2 to 16.5.

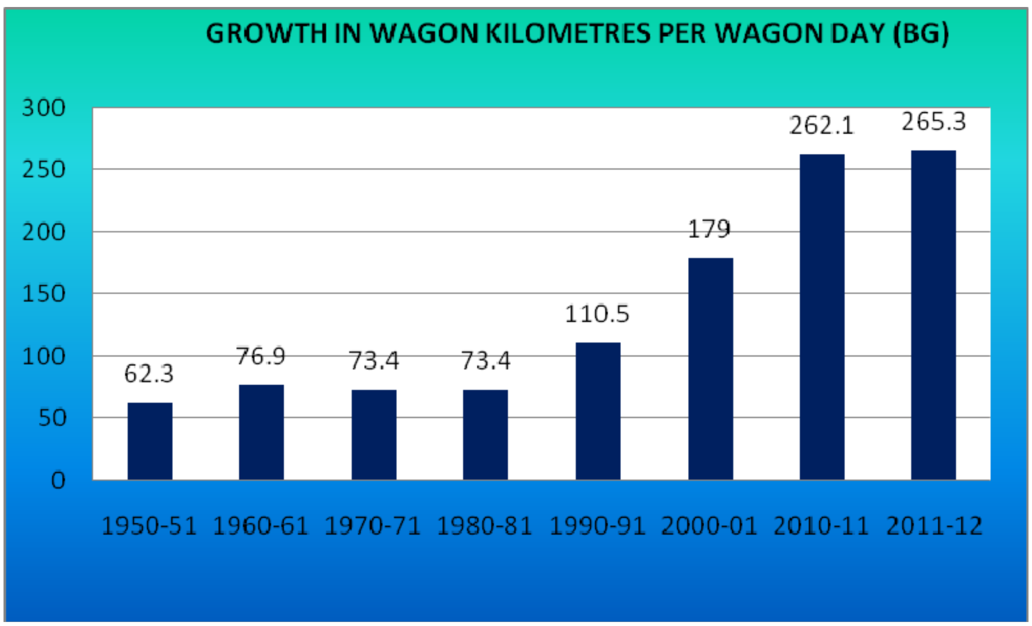

Chart 16.2 Wagon Kilometres per Wagon Day (Broad Gauge)
Reflects improvement in wagon mobility

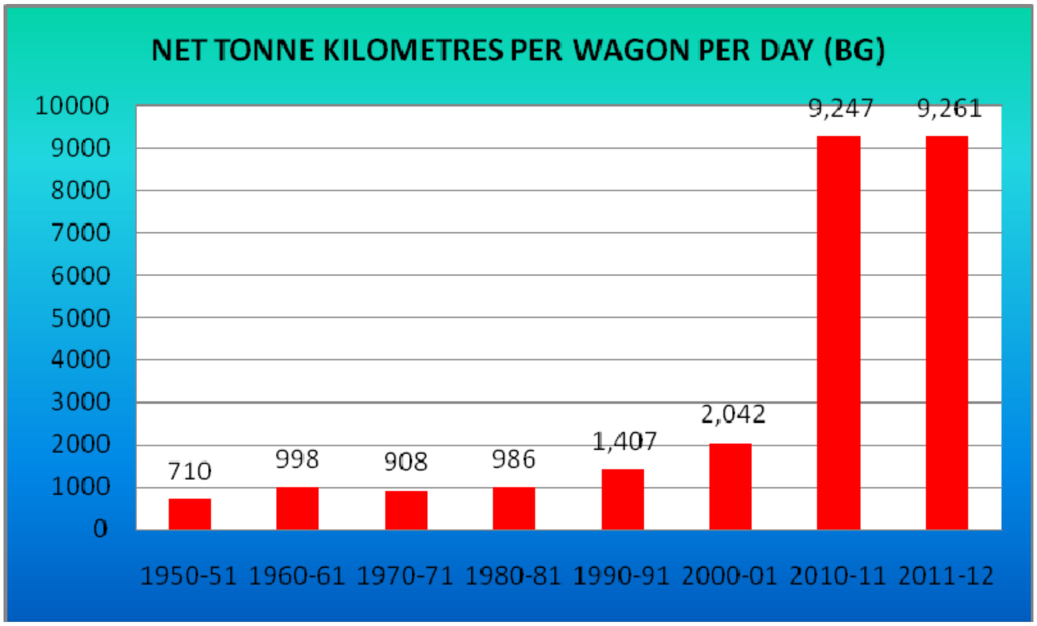

Chart 16.3 Net Tonne Kilometres per Wagon per Day (Broad gauge)
Displays the phenomenal improvement in Wagon productivity

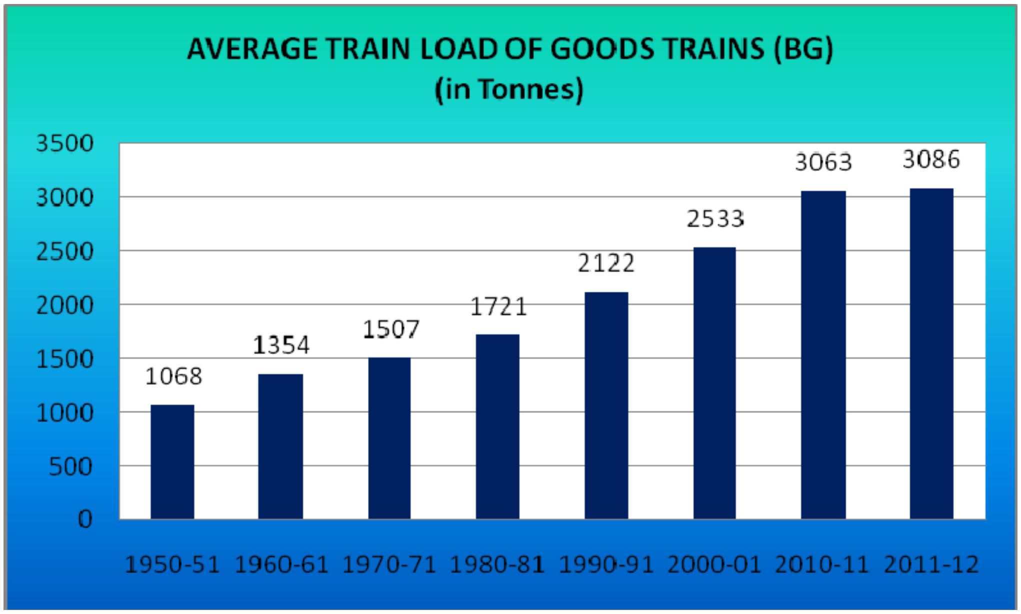

Chart 16.4 Average Gross Load of Goods Trains (BG) including weight of Engine
The Graph displays the increase in load of freight trains

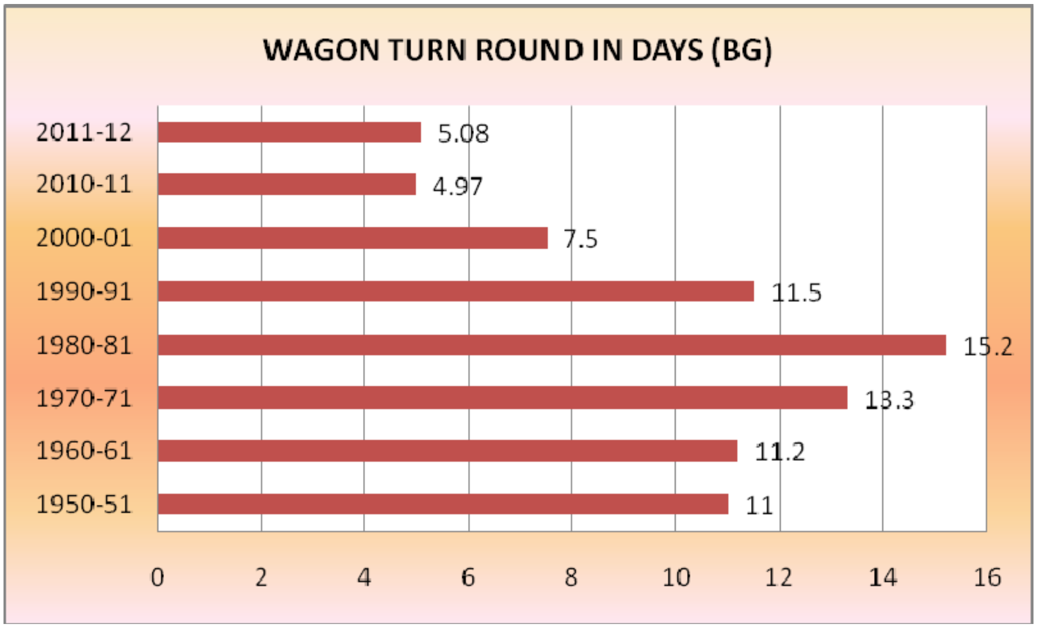

Chart 16.5 Wagon Turn Round (BG) – Period between successive Loading
The chart shows improvement in Wagon usage

16.8.0 TRACTION

16.8.1 Traction – Steam

At the time of Independence, Indian Railways had more than 10,000 steam locomotives and they were the primary means of traction. With a view to develop indigenous capacity for the manufacture of Steam Locomotives a new Production Unit was set up at Chittaranjan. Production at Chittaranjan started on 26th January 1950 and up to 1972 the Chittaranjan Locomotive Works manufactured 2351 Steam Locomotives. The Tata's at their TELCO unit also had capacity for the manufacture of steam locomotives. Steam locomotive design had evolved in India over a century since the first lines were built. Initially each private company had its own design of locomotives. The first stage of standardization took place when a sub-committee of the British Engineering Standards Committee was set up for the purpose. Its first report came out in 1903. Their designs that came out at the time came to be known as the BESA (British Engineering Standards Association) designs and they were in use on Indian Railways till the 1970's. These BESA classes are listed below:

	Type	Grate Area	Engine Weight	Class Code
Standard Passenger	4-4-0	25.3	52	SP
Standard Goods	0-6-0	25.3	49	SG
Passenger Tank	2-6-4T	25.3	76.5	PT
Heavy Passenger	4-6-0	32	69	HP
Heavy Goods	2-8-0	32	71.5	HG
Heavy Tank	2-8-2T	37	90.5	HT

After World War I there was again a need for updating existing BESA designs and developing more powerful locomotive designs that could use inferior grades of coal. As a result in 1924 the Government set up a Locomotive Standards Committee. The committee after extensive consultation developed three passenger and two goods locomotive apart from shunting engine designs which were manufactured during 1927 to 1929. The main features was a larger grate area to cater to higher percentage of non-combustible content in coal and a larger number of axles to bring down axle loads. All the locomotives came to belong to the Indian Railway Standard (IRS) Class and were in use up to the 1980's:

	Class Code	Wheel Arrangement	Grate Area Sq.ft.	Axle Load Tons	No. Built
Branch Passenger	XA	4-6-2	32	14	113
Light Passenger	XB	4-6-2	45	17	99
Heavy Passenger	XC	4-6-2	51	19.8	72
Light Goods	XD	2-8-2	45	17	194
Heavy Goods	XE	2-8-2	60	22.5	93
Light Shunter	XF	0-8-0	30.25	17	6
Hump Shunter	XG	0-8-0	41	22.5	3
Light Shuttle	XT	0-4-2	14	14	77

During World War II traffic volumes grew and India turned to the North American continent to meet its Goods locomotive requirements. The different types imported were the AWC (2-8-0), AWE (2-8-2), AWD (2-8-2) and the CWD (2-8-2). The only difference between the AWD & CWD was that the former was built in the USA and the latter in Canada. The AWD/CWD was an American 'austerity' version of the IRS 'XD' class. About 800 of the AWD / CWDs were inducted on the Indian Railway system. The AWE was similar to the IRS 'XE' class. The AWD/CWD class was used in extremely large numbers over IR. Basic characteristics are given below:

	Class Code	**Wheel Arrangement**	**Grate Area Sq.ft.**	**Axle Load Tons**
Medium Goods	AWD/CWD	2-8-2	47	16.1
Heavy Goods	AWE	2-8-2	63.2	22.2
Medium Goods	AWC	2-8-0	41	15.7

There was also a 'W' series of new locomotives that were inducted in order to cater to heavier loads and incorporating features based on the experience of the IRS 'X' classes of locomotives including improved valve gear and better riding qualities. Of these the 'WM', 'WL' and 'WW' are important as these types were homed at various sheds on the system. Basic characteristics are indicated below:

	Class Code	**Wheel Arrangement**	**Grate Area Sq.ft.**	**Axle Load Tons**
Medium Passenger	WL	4-6-2	38	16
Medium Shuttle	WM	2-6-4T	24	16.25
Passenger Shunting	WW	0-6-2	14	16.5

In the years after Independence steam locomotive design culminated in a new standard design based on war time experience of running larger American locomotives. For passenger services which took into account the latest developments in boiler efficiency, the sleek 'WP' 4-6-2 was developed and manufactured on a very large scale at the newly established Chittaranjan Locomotive Works. Similarly for Freight traffic the 'WG' 2-8-2 design was adopted and they became the 'work horses' of Indian Railways for over three decades.

	Class Code	Wheel Arrangement	Grate Area Sq.ft.	Axle Load Tons
Standard Passenger	WP	4-6-2	46	18.5
Standard Goods	WG	2-8-2	46	18.5

Although traditionally steam locomotive runs were relatively short and in early days a locomotive was also assigned to a single set of crew this practice was later discontinued in order ensure greater usage of locomotives and the interval between engine changing stations was also increased.

16.8.2 Traction – Diesel

Although steam traction had its romance and steam locomotives were simple in design, easy to maintain and highly reliable equipment they had their drawbacks such as the need for good quality coal which had to be transported to different corners of the country, they had low hauling capacity, were highly polluting, frequent stoppages were needed for watering and output was low in terms of Kilometres per day. Most of the shortcomings were overcome with diesel traction. India standardized on the American ALCO diesel design. The on-set of the nineteen sixties witnessed the start of the transition from steam hauled trains to diesel locomotives on the main lines. After 1963-64, when production of indigenous locomotives started at Diesel Locomotive Works, Varanasi the process of dieselization gained momentum and a large number of diesel sheds were set up in all parts of the country with each shed homing over 100 locomotives. The ALCO WDM2 soon became the work horse on the Broad Gauge. The WDM2 is a multipurpose AC/DC type Diesel Electric locomotive which is powered by a 16 Cylinder, single acting turbo supercharged engine, capable of producing 2600 HP. It has conventional cast tri-mount CO-CO bogies and an axle load of 18.8 tonnes. This model was a dual–purpose loco designed for both freight and passenger services. Over time the diesel locomotive has been progressively upgraded, for example the WDG 3A Freight Locomotive is a 3100 Horse Power Locomotive with high adhesion Co-Co tri-mount bogies, a gear ratio of 18:74, capable of a maximum speed of 105 Kmph and is equipped with Air and Dynamic brakes. In recent years India has started manufacturing a much more powerful High Horse Power Freight locomotive based on the EMD design which has a Horse Power in the range of 4000 to 5500 HP. These locomotives are being used over the steeply graded sections of the Western Ghats on South Western Railway.

16.8.3 Traction – Electric

Although the suburban sections of Western Railway had been electrified as early as 1924 in Mumbai Area, mainline electrification was also started with 1500 volt D.C. in Central Railway from Bombay VT to Igatpuri and Pune in 1925. Subsequently, A.C. electrification was started on Howrah-Delhi route in the 1960s based on the French 25 KV AC overhead traction system. The electric traction in Mumbai area was on the DC system and has only been changed over to the AC system in recent years. A wide range of Electric Locomotives with both Bo-Bo and Co-Co wheel configuration have been used on the system. For combined Freight and Passenger service there was the WAM series of locomotives, for Goods the WAG series and for passenger WAP series of locomotives. The locomotive in use at present are for example the WAP 5 which is a light passenger locomotive weighing 78 tonnes with 5400 HP engine, a maximum tractive effort 26.2 tonnes and is capable of a maximum speed of 160 kmph. It has a 3 phase Drive with GTO Thyristors and microprocessor based Control. Then there is WAP 7 which is a 123 tonne Locomotive of the latest class with 6000 Horse Power, three phase squirrel cage induction motors, three phase drive with GTO Thyristors and microprocessor based controls. It has air, regenerative and parking brakes and is used on Shatabadi and Rajdhani Express trains with a maximum service speed of 140 kmph. On the freight front is the WAG7 which has a 5000 HP engine with a Tractive effort of 44 tonnes, weighs 123 tonnes and is capable of a maximum speed of 100 kmph. It uses DC series motors, controlled by a tap changer and has a high capacity transformer, rectifier, traction motor, compressor and other matching associated equipment. The most powerful freight locomotive is the 6000 HP WAG9, which is a 3 phase GTO thyristor and micro processor controlled 6 axle locomotive with an axle load of 20.5 tonnes and a maximum speed of 100 Kmph. The induction of new technology has helped in augmenting trailing loads and ensuring smooth operation with fewer instances of stalling on grades.

16.8.4 Traction - Operating Strategies To Improve Usage

With improvements in traction and introduction of more powerful locomotives, trailing loads have increased, sectional speeds have gone up and locomotive reliability has improved substantially. Various operational measures have also helped productivity. In the case of Diesel and Electric traction, locomotives are also required to undergo regular inspection and maintenance schedules. Locomotives undergo a weekly, fortnightly, monthly inspections / schedules. Initially these schedules were being done in the Home Shed, however, progressively over time some of these inspections are being done at sheds other than the home shed where the locomotive is available. This has improved locomotive availability and provided greater flexibility in operations. Earlier also loco runs were confined by and large to Zonal boundaries, this also has changed and locomotives if not due higher maintenance schedules are free to move over the system and run end to end. Railway operations have also focused on minimizing time spend on avoidable detentions such as a conscious effort to reduce time taken for change of crew. Effort is that crews change over in less than 10 minutes. Similarly in case of diesel locomotives time spent on fuelling the locomotive has also been reduced. For this fuelling points were provided on ‘run through lines’ where required. Drivers are also encouraged to run their trains at maximum speed and from time to time awards are given by individual Divisions to drivers who perform well in terms of maintaining maximum permissible speeds thus ensuring maximum throughput. With more powerful locomotives being inducted and better speeds as an operating policy it has been the endeavor to increase crew runs and close down intermediate crew change points. This requires willingness of the running staff and where it has been successfully implemented the returns are significant.

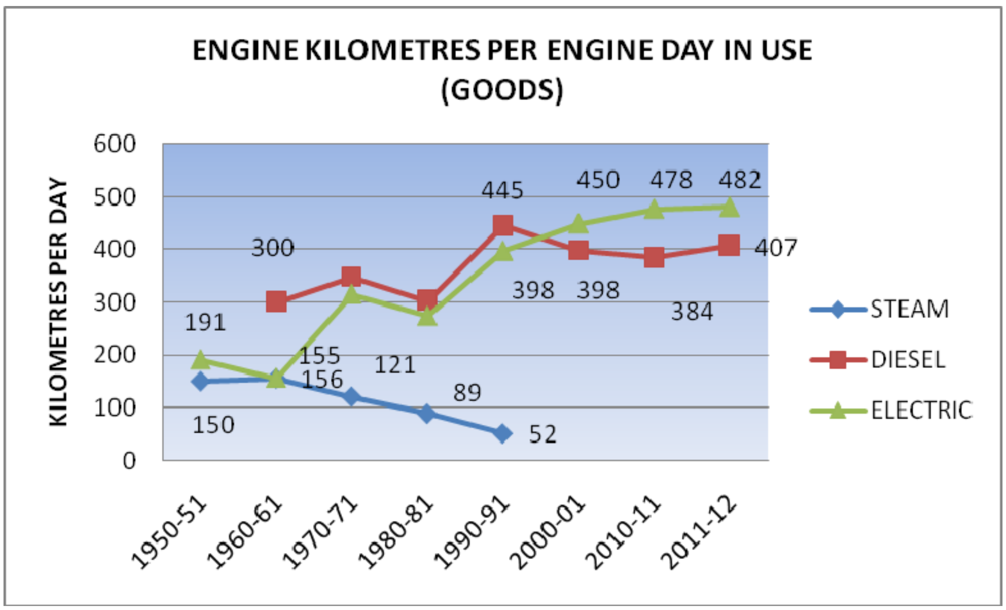

Chart 16.6: Engine Kilometres per Engine Day in Use for Goods Traffic
Chart depicts improvement in Engine Usage in case of Diesel & Electric

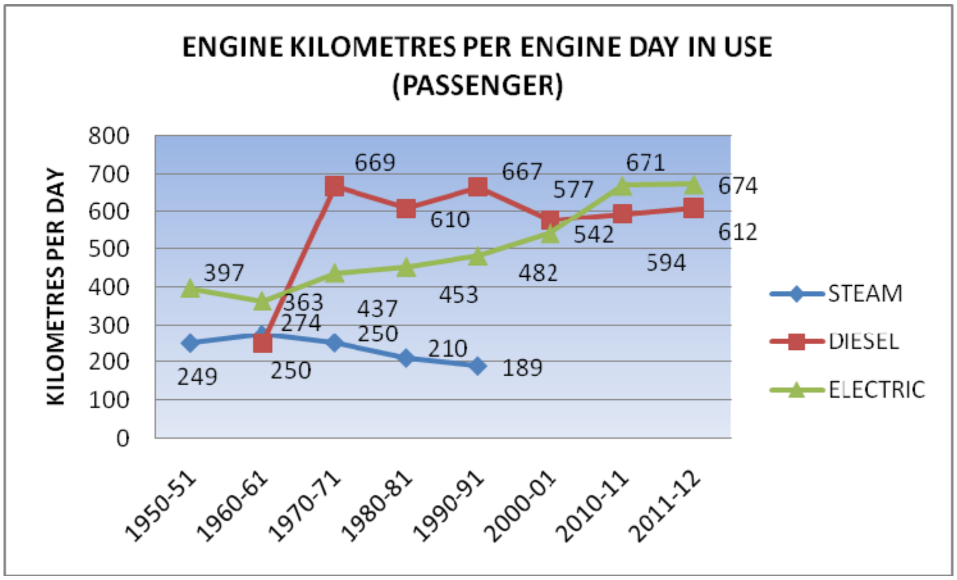

Chart 16.7: Engine Kilometres per Engine Day in Use for Passenger Traffic Passenger Locomotives are scheduled to work to a fixed link.

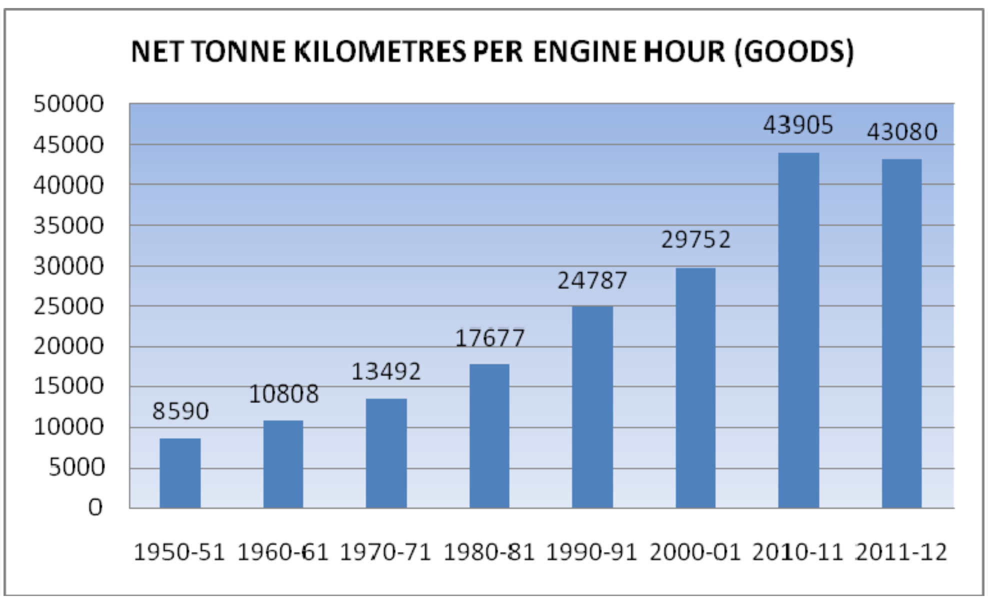

Chart 16.8: The productive work done by a Locomotive is measured in terms of Net Tonne Kilometres per Engine Hour which has improved very significantly.

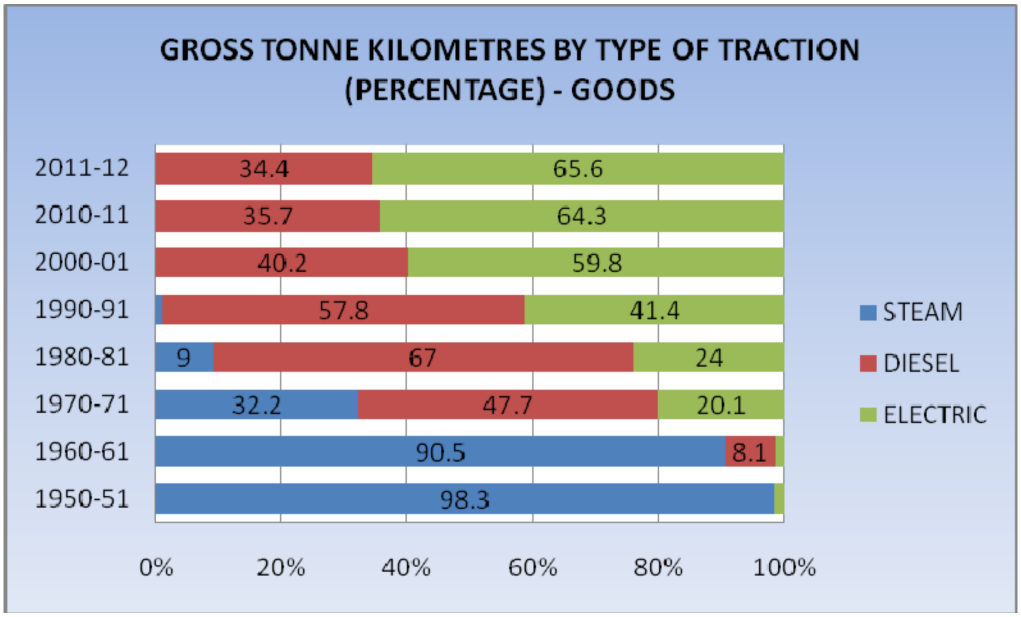

Chart 16.9: Gross Tonne Kilometres by Type of Traction – Goods
The graph shows the growing volumes of freight traffic moved on Electric Traction

16.9.0 ROLE OF TRACK STRUCTURE IN RAILWAY OPERATIONS

Over the last 65 years there have been tremendous improvements in the track Structure on the IR network. Progressively PRC Sleepers have replaced Wooden, CST 9 and ST sleepers; whereas earlier 90 lb rails were being used all Main Lines today have 60 Kg UTS or 52 Kg rails. Elastic fastenings are being used, and today rails are either continuously welded with switch expansion joints or long welded rail panels are used. While constructing new track a layer of blanketing material is used over the earthwork. Similarly both inspection systems for measuring track geometry as well as maintenance procedures have improved with the use of tie tamping machines, ballast cleaning machines, use of ultrasonic flaw detectors and oscillograph cars for identifying deficiencies. This steady up-gradation of the permanent way has enabled major improvements in Gross Tonne Kilometres per Running track kilometre carried over the system is shown in the chart below:

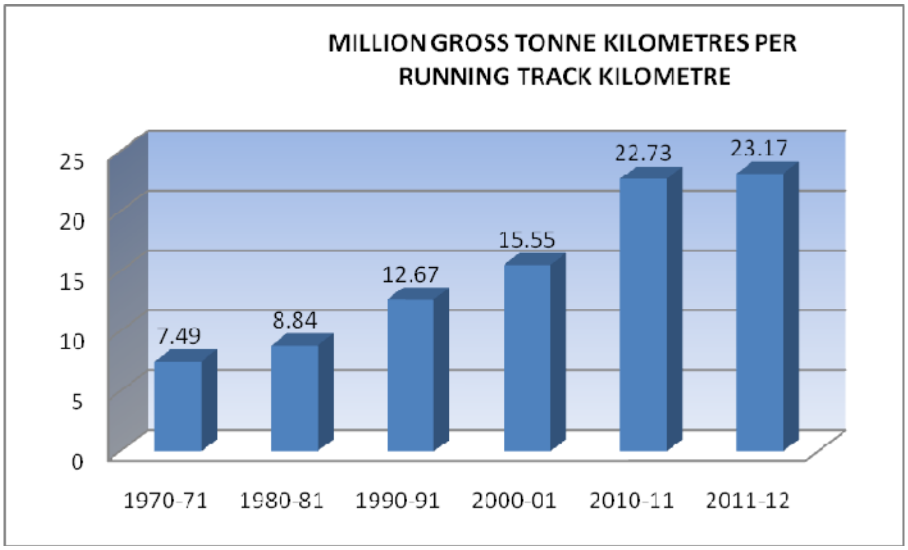

Chart 16.10: Million GTKM per Running Track Kilometre indicates how intensively the IR track is being utilized. This has enabled multifold growth in volume of traffic with much lower increase in network size.

The up-gradation of track has also facilitated the increase in axle loads permitted on various routes. In 2005-06 when economic growth was peaking and demand for Rail movement of freight was growing a solution had to be found to meet the demand. As a result of an operating necessity it was decided to authorize loading of wagons beyond their carrying Capacity and beyond the permissible axle loads. Today wagons are permitted to be loaded to the extent of 9 tonnes beyond their carrying capacity. This would not have been possible unless operating and engineering management of the Railways had agreed to permit such a relaxation. Much of the growth in the last seven years may be attributed to this policy. Despite fears that this would impact safety, the system has worked satisfactorily though there will be requirement of additional maintenance on track and rolling stock.

16.10.0 SIGNALLING WORKS AUGMENT CAPACITY

Railway operations have also benefited by careful operational planning and implementation of a range of Signalling works. Such works have ranged from up-gradation of interlocking standards to permit higher speeds over facing points, provision of Multiple Aspect Color Light Signalling so that drivers have better visibility and can maintain higher speeds and on arterial routes provision of double distant signals for high speed trains such as the Rajdhani Express. Introduction of Automatic Signals on many busy routes has also helped create capacity. For example on Western Railway there is today Automatic Signalling on the entire 500 Km stretch from Mumbai Central to Ahmedabad, the longest in the world, which has enabled capacity creation before additional third line proposals or the Dedicated Corridor become functional. Signalling works also aid safety and extensive panel interlocking, Solid State Interlocking, track circuiting at stations and use of axle counters have enhanced safety levels. Today over 4000 stations have panel interlocking, 5400 stations have color light signals, 250 stations have Route Relay Interlocking, 3400 Block sections have last vehicle verification by axle counters and 2300 Route kilometres have automatic signalling all of which aid operations, improve safety and have helped augment line capacity.

16.11.0 PASSENGER OPERATIONS

Operational Policies have also helped Indian Railways to meet rapidly growing passenger volumes. A number of steps have been initiated to augment passenger capacity. Firstly, train lengths have been increased. In steam days the typical train length was 14 coaches or less. Today 22 to 24 coaches in Express trains is the norm. In few cases 26 coach trains have been introduced. This is only possible with CBC couplers as beyond 24 coaches the screw coupler becomes the weak link. Increasing train length has meant that platform lengths have had to be increased in a systematic manner a major task in itself. Secondly, Hauling 24 and 26 coaches would not have been possible without the induction of both Diesel and Electric locomotives with the appropriate characteristics. Thirdly, from an operational perspective the drive to rationalize Rake links to optimize coach utilization has been an ongoing effort. This requires standardization of rake composition. Fourthly, initiatives have also been taken to ensure quick turn round of rakes without a visit to the pit line for examination with only cleaning and watering of coaches. This helps improve coaching train availability. The future will probably see significant changes in terms of introduction of train sets on the European pattern, increasing interval between train examination, increasing seating capacity, **and more double deck coach trains**.

16.12.0 INFORMATION TECHNOLOGY

Railway Operations have benefited from Information Technology in a big way. This includes both Commercial and Operating Applications. The Passenger Reservation System (PRS) is the largest one of its kind in the world. Tickets are available on the net and counters have been provided at remote locations including non rail head locations and e-tickets may be purchased from the comfort of your home. There are about 3000 different locations where PRS counters are available. In addition, a networked, computerized Unreserved Ticket System is functional which provides facility to the passenger and reliable accountal and analytical mechanism to the Railways. On the Freight side the

Freight Operating Information System tracks every rake on the systems monitors demand for rakes, and through the Terminal Management System arranges issue of Electronic Railway Receipts and receives payment through a payment gateway. A range of analysis such as sectional speeds, detention at various points, wagon holding etc can be compiled by the system. The daily position, which was for over a century manually compiled, is today generated automatically by the system. It provides management with more time for analysis and planning. A host of other operating IT applications are operational which include the following:

- Crew Management System – to optimize crew utilization
- Integrated Coaching Management System – Tracking of Coaches & Analysis
- Control Office Application – Electronic Charting of Trains
- Parcel Management System
- Real time Train Information System
- Freight Maintenance Management System

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CHAPTER 17

RESEARCH & TECHNOLOGY DEVELOPMENT – RDSO

17.1 Research and development is of great importance in any organization so that it can carry out its assigned functions in the most efficient and economic manner. Even in those sectors where not much competition exists, research plays an important role to provide the services to the users in a most efficient way with the least cost.

17.1.1 In the earlier years, the Indian Railways developed as a conglomerate of independent units owned by different Companies and States. There was not much coordination between them especially in technical fields. As the traffic grew, need for interchange of rolling stock at various meeting points was felt which highlighted the importance of standardisation of both track and rolling stock. The first step in this direction was creation of Indian Railways Conference Association (IRCA) in the year 1903. This followed setting up of a Central Standards Office (CSO) at Shimla in the year 1930 to standardise designs and specifications for track, bridges, signaling and rolling stock. Initially the CSO was assigned a very important job of determining the maximum loads which could be hauled with the available locomotives and speeds which could be achieved under different service conditions. With the reorganisation of the Railways after Independence, need for developing standard designs for track, rolling stock and signaling systems became more obvious and important to achieve economy and to make best use of the local talent. The research section of CSO was reorganised and established on 1st September 1952 as a separate directorate of the Railway Board with headquarters at Lucknow as "Railway Testing and Reasearch Centre (RTRC) with two sub centers at Lonavala near Mumbai and at Chittaranjan near Asansol. The Lucknow centre carried out research on fuel, dynamic effects of vehicles on track and bridges, riding quality and performance tests on locomotives and rolling stock assemblies and components. The Lonavala centre dealt with research in connection with buildings, foundations and concrete engineering as applicable to Indian Railways. The Chittaranjan centre conducted chemical and metallurgical studies on paints, water softeners, lubricants and metals. As the time passed, activities of both the CSO at Shimla and RTRC at Lucknow, Lonavala and Chittaranjan spread many folds. Coordination between research work and standardisation became difficult due to these centers located at different and far off places. Soon, the necessity of locating the facilities at one central place was felt. Accordingly, the Central Standard Office and the Railway Testing and Research Centre were merged in to one unit known as Research, Designs, and Standard Organisation (RDSO) at Lucknow on 7th March, 1957. The CSO at Shimla however continued till early sixties.

17.2 MAIN FUNCTIONS OF RDSO

- Development of new and improved designs related to Railways.
- Development, adoption and absorption of new technology for use on Indian Railways.
- Development of standards for materials and products especially needed by Indian Railways.
- Technical investigations, statutory sanctions, testing and providing consultancy services.
- Inspection of critical and safety items of rolling stock, locomotives, signaling and telecommunication equipment and track components.

Manak Bhawan (Annexe I)

Abhikalp Bhawan (Annexe II)

17.2.1 The RDSO serves the above functions through a number of well equipped laboratories with research and testing facilities spread over 160 hectare campus. Some of the laboratories are listed below:

- Air Brake Laboratory
- Brake Dynamometer Laboratory
- Bridges and Structures Laboratory
- Diesel Engine Development Laboratory
- Fatigue Testing Laboratory
- Geo-technical Engineering Laboratory
- Metallurgical and Chemical Laboratory
- Psycho-Technical and Ergonomics Laboratory
- Signal Testing Laboratory

- Telecom Laboratory
- Track Laboratory
- Traction Installation Laboratory
- Vehicle Characteristic Laboratory

17.2.2 In addition to above mentioned static facilities, a number of mobile Testing Cars are also available. Important ones are:

- Oscillograph Car- for measurement of track and vehicle parameters under dynamic conditions
- Rail profile measurement car- for measurement of rail cross section in the running track
- Self Propelled Ultrasonic Rail Testing (SPURT) car- for detection of hidden defects in rails in motion.
- Brake Dynamometer Car – for measurement of braking effect and coupler forces
- NETRA Car – for measurement of parameters of overhead electrical equipment

17.3 INTERNATIONAL COLLABORATION

17.3.1 In a number of research programmes, the RDSO is collaborating with UIC (Union of International Railways), Paris as indicated below:

- UIC project on Rail defect Management (JRP-1) for rail defects inspection and rail failure prediction technologies
- UIC Project on Rail Wheel Interaction (JRP-2) for defining/ describing/ cataloguing the rail-wheel interaction phenomenon and mechanism with respect to vertical and lateral discontinuities at joints.
- UIC Project on Automated Health Condition Monitoring and Predictive Rolling Stock Maintenance (JRP-3) for automatic monitoring of rolling stock conditions.

17.4 CAPACITY AUGMENTATION ON INDIAN RAILWAYS

17.4.1 Three important parameters decide carrying capacity of any railway system. These are:

- maximum allowed load of a single train,

- average speed,
- reliability of assets.

Various directorates of RDSO have worked and continue to work towards these targets with an overall objective of achieving higher output of the System. Contributions by various Directorates to the capacity growth are described briefly in the following paragraphs.

17.4.1.1 Bridges and Structures Directorate

- Revising the axle loads gradually from 22.5 tonnes (BGML) in 1926 to 25 tonnes (MBG loading of 1987) and then to 32.5 tonnes for 'Dedicated Freight Corridor (DFC of 2008). There was substantial increase in tractive effort from 36.8 tonnes in 1926 (BGML) to 75 tonnes in 1975 (RBGML), and then to 100 tonnes in 1987 (MBG) and further to 126 tonnes for DFC loading in 2008.
- Assessment of strength of old masonry arch bridges for running of heavier trains.
- Study of dynamic effect (Impact) and dispersion of tractive and braking forces
- Assessment of residual life of old steel bridges.
- Development of PTFE bearings
- Development of all welded bridge girders and use of special steel.

17.4.1.2 Track Directorate

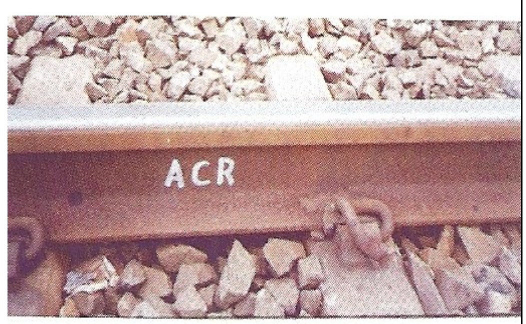
- Development of modern track structure having elastic fastenings, concrete sleepers and heavier rails. The rail section was revised from 75 / 90 lbs per yard run to 52 kg per meter run and then to 60 kg per meter run. The steel used was also upgraded from 72 N/mm sq UTS to 90 N/mm sq UTS. The sleeper which were mostly cast iron and wooden were replaced by high strength concrete sleepers which could carry heavier axle and lateral loads.

Steel channel bridge sleepers

Turnout with concrete sleepers

- Development of special concrete sleepers for turnouts, level crossings and switch expansion joints.
- Development of monolithic cast manganese steel crossings to replace medium manganese built-up crossings.
- Introduction of long welded rail panels to one km length replacing single, 3/5 rail panels reducing the number of rail joints drastically. Rail welding technology was also upgraded in the meantime.

Ordinary 90 UTS Rail



Corrosion Resistant Rail

- Development of ultrasonic testing technology for rails and joints for identification of inherent and hidden defects-reducing the failures.
- Development of steel bridge sleepers in replacement of wooden sleeper in view of dwindling forest produce.
- Introduction of machine maintenance and mechanised laying of track including mechanised deep screening of track.

	
Track tamping machine	Turnout tamping machine

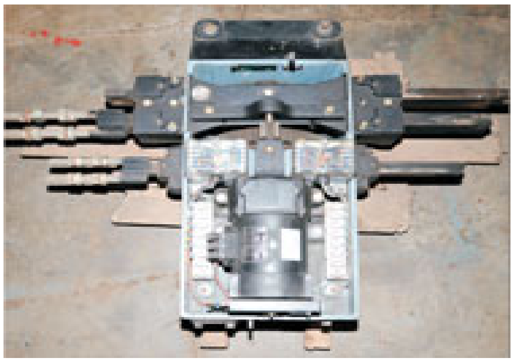
- Introduction of rail grinding and rail profiling resulting into longer life of rails.
- Introduction of small machines for rail cutting and drilling of holes resulting into quicker restoration of track in cases of accidents.
- Introduction of Track Management system for planning of maintenance activities.

17.4.1.3 Geo-technical Engineering Directorate

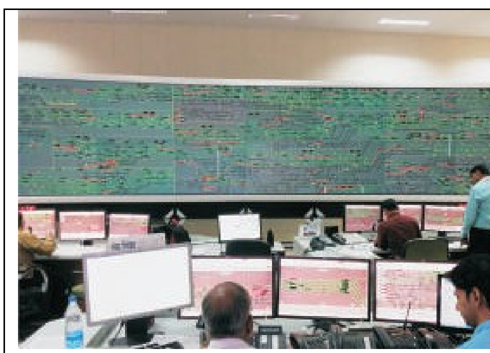
- Designing of high embankments over soft and marine soils.
- Stablisation of black cotton soil embankment

17.4.1.4 Signal Directorate

- Development of Electrical Point Machine.
- Development of LED signals which are more reliable, consume less power and last longer.

	
Electric point machine	LED based signals

- Development of Integrated Power Supply (IPS) system.
- Development of Train Actuated Warning Device (TAWD).
- Development of electric lifting barriers, low maintenance lead acid secondary cells, "Q" series metal to carbon relays, metal to metal relays, fail safe electronic timer, electronic flasher device etc.

	
Train management system Mumbai	RRI panel at Allahabad

- Development of Indigenous Block Instrument for operation on single and double lines

- Development of Analogue Axle Counter, Multy Entry Axle Counter, Universal Axle Counter, Digital Axle Counter, Multiple Section Digital Axle Counter.

- Development of Electronic Interlocking in collaboration with Industry.

17.4.1.5 Telecom Directorate

- Extensive development of Microwave Communication Network.

- Development of 50 volt, 50 Hz signaling board control circuit and way station selector and headquarter equipment for AC electrified areas.

- Development of VHF and UHF equipment.

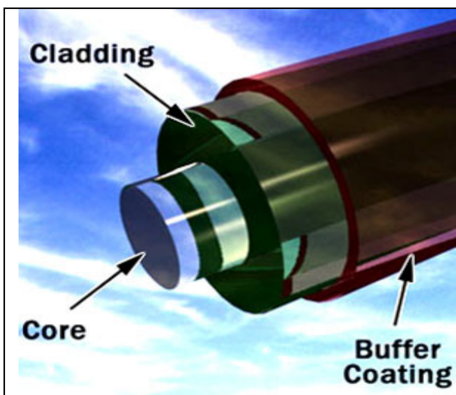
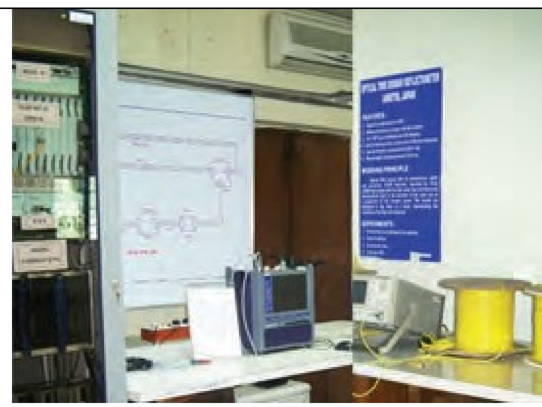
- Design and development of Solid State equipment

- Development of Hot box detector.

- Guard driver VHF communication system.

- Last vehicle checking device.

- Optic Fiber Cable (OFC) system along with OFC accessories in electrified and non-electrified areas.

	
Optic fibre for communication	Transmission system laboratory

- Development of DTMF HQ equipment and way station equipment for control communication.

- Development of Quad cable and cable based communication.

- Satellite Imaging for Rail Navigation (SIMRAN).
- Mobile Train Radio Communication.
- Voice Data Logger/ Monitor for control circuit

17.4.1.6 Motive Power Directorate

- Development of WDP4. (4000 hp), WDP3A (3100hp), WDM3A (3100 hp), WDG3A (3100 hp), WDG4 (4000hp) locos.

	
WDP2	WDP4
	
WDG4	WDG3

- Development of DEMU (Diesel Electric Multiple Units 700 and 1400 hp) and 350 hp MG DEMU.

A view of DEMU

- Development of self propelled 3 coach Accident Relief Train.
- Development of IGBT based invertors for 4000 hp GM locos.

Diesel Engine Development Laboratory

GM Locomotive bogie

- Development of high heat capacity “S” shaped wheel for BG locos.
- Development of 75 t MG diesel hydraulic brake down crane.
- Development of 15kj high capacity buffer.
- Development of Bio diesel (alternate fuel).
- Development of locotrol.
- Development of cab simulator.

17.4.1.7 Carriage Directorate

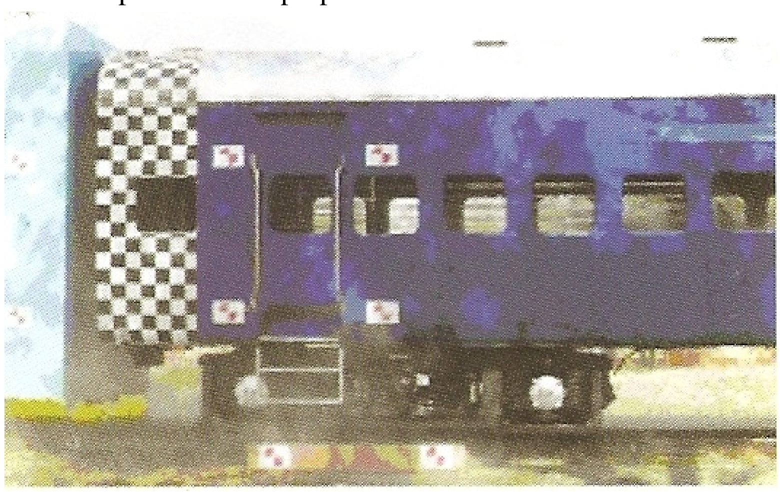
- Development of all coil suspension for coaches.
- Introduction of Rajdhani/ Shatabdi Express trains.
- Development of double decker coach.

Fatigue Testing of Bogie Frame and its components in Fatigue Laboratory

- Introduction of air brakes on coaching stock.
- Development of air springs for suburban stock.
- Development of AC coaches.




- Development of CBC (Central Buffer Couplings) with anti climbing features for coaching stock.
- Development of bogie mounted brake cylinders.
- Development of solid wheels.
- Development of fire retardant furnishing material.
- Development of self propelled ultra sonic rail test car.



Crash test being conducted on a full size coach

- Development of crash worthy coaches.

17.4.1.8 Wagon Directorate

- Development of BOXN wagons with CBC, air brakes system and CASNUB bogies.
- Development of BCN covered wagon with features of BOXN wagons for carriage of cement, food grains etc.
- Development of BTPN/BTPGLN wagons for carriage of petroleum products and LPG.
- Development of BRNA flat wagons for carriage of rails, steel coils etc.

- Development of BOBRN hopper wagons for carriage of ballast, iron ore etc.
- Development of BOCNHA/BOXNCR wagons with higher axle load.
- Development of BOXNHS wagons for higher speed running of goods trains.
- Development of composite brake blocks in replacement of conventional cast iron brake blocks.

- Development of higher payload wagons BOXNLW with stainless steel body and BOXNAL/ BOBRNAL with aluminum body for further increasing the carrying capacity.

17.4.1.9 Traction Installation Directorate

The Directorate is involved in the following main activities: -

- Design, development and introduction of appropriate technology for equipment related to Electric Traction Power Supply and Overhead Equipment (OHE) of electric traction.
- Evolving designs & standards to improve the reliability & availability of Traction Distribution System.
- Standardization of equipment used for 25 kV Traction System & 2x25 kV AT System.
- Providing technical consultancy in the field of Traction Power Distribution and Railway Electrification to Indian Railways and other agencies like - Rail Vikas Nigam Ltd, Dedicated Freight Corridor Corporation of India Ltd and Metro Rail Systems.
- Design and development of high rise OHE, Light weight insulators, Thermo Vision system for condition monitoring of current carrying joints of jumpers, feeder wires, earthing etc, Power Factor Compensation to improve power factor, Harmonic Filter- Active Harmonic Filters & Tuned Harmonic Filters, Supervisory Control and Data Acquisition (SCADA) system to exercise remote control of traction power supply and Data Logging.
- Vendor development of important and critical items.

17.4.1.10 Electrical Loco Directorate

Electrical Loco Directorate is responsible for design and development of all types of Electric Locomotives including their sub-systems and has been in forefront in modernization of technology for electric locomotives from time to time and staying abreast with evolving technologies the world over. It also deals with service related technical problems, including standardization, indigenisation of technology/sub-systems through industry and quality control/vendor base of vital components of Electric Locomotives. The Directorate is totally involved in evaluation of new technologies and up gradation of product for higher performance, reliability and economies in operation including Design and Development of IGBT based 3-phase propulsion equipment for 6000 HP passenger and freight locomotives

This Directorate is now actively associated with design & development of specifications of 9000 HP locomotives with 25 T axle load (CO-CO) and 100 KMPH maximum operational speed(upgradeable to 120 kmph with changing software) for heavy haulage in western DFC as well as 12000 HP locomotives with 22.5 T axle load (BO-BO+BO-BO) and 100 KMPH maximum operational speed(upgradeable to 120 kmph with changing software) for heavy haulage in eastern DFC.

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<tr><td>WAP 5 electric loco</td><td>WAG 9 electric loco</td></tr>
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Some of major land marks of this Directorate can be listed as under: -

- Indigenous manufacturing of high horse power locos having three phase drive system (WAP5, WAP7 and WAG9).
- Introduction of Rockwell technology for casting of Co-Co bogies.
- Design and development of indigenous VCB, High Capacity Transformer, Micro processor based speed-cum-energy monitoring system with data recording facility for 60 days, Roof Mounted DBR, Insulation System for Hitachi Traction Motors, Microprocessor Based Control & Diagnostic System (MPCS).
- Up gradation of WAP5 locomotive for a Service Speed of 200 kmph.
- Design improvements in 3-ph traction motor including re-design of rotor and stator to reduce its failure. The design is cost effective and has improved reliability of traction motor.

- Design & development of Head On Generation (HOG) supply arrangement-A move towards green technology, Metalized carbon strip for pantograph to enhance life of contact wire of 25 KV OHE system, Oil free compressor and Air bellow raised high speed pantograph.

17.4.1.11 Power supply & EMU Directorate

Power Supply & EMU Directorate is engaged in developing design and standardization of electrical equipment and systems for Electric Multiple Units, Metro Rolling Stock, Train Lighting, Air Conditioning and Power Supply related items of coaches and development of initial vendors for these items, with a view to achieve the Quality Objectives for improved suburban and main line services to Railway Passengers in terms of better comfort, safety, reliability, efficiency and maintainability of equipment. Following are the major activities of this organisation: -

- Design, development, testing and commissioning of microprocessor control IGBT based 25 kV AC 3-phase propulsion system.
- Development of energy efficient Head On Generation (HOG) scheme for mainline passengers.
- Design and development of EMU type train set for main line operations.
- Development of roof mounted air conditioning package unit for EMUs operating in Mumbai area
- Development of Integrated passenger information system (PIS) for mainline and EMU coaches
- Development of V-Belt Driven permanent magnet alternator for LHB and conventional coaches

17.4.1.12 Energy Management Directorate

Recently set up Energy Management Directorate is responsible for design and development of energy efficient electrical systems to be used on Indian Railways including harnessing of the renewable sources of energy and use of energy efficient products. It also deals with service related technical problems, standardization, quality control/vendor base of vital items relating to the subject, evaluation of new technologies & its absorption and up gradation of product for higher performance, reliability and economies in operation. Some important projects in hand are as under: -

- Grid Connect Solar Generating System of capacity 10 KW to 500 KW.
- Stand-Alone Solar Photovoltaic LED based street lighting system.
- Specifications for standalone wind + solar photovoltaic hybrid generating system for level crossing gates.
- Specification for Power saver in lighting system.
- Technical Specification for T-5 Fluorescent lamps, luminaries & Electronic ballast.
- Technical Specification for Passenger Escalators to be installed at various railway stations of Indian Railways.

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