ज्ञान ज्योति से मार्गदर्शन

To Beam As A Beacon of Knowledge

CONSTRUCTION AND MAINTENANCE OF HIGH SPEED RAILWAY

October 2015

Indian Railways Institute of Civil Engineering
Pune 411001

First Edition : December 2008

Second Edition : October 2015
Revised Edition

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PREFACE (Second Edition)

High Speed Rail is the most anticipated Railway Project in the country apart from dedicated freight corridor. Population of India is only a shade lower than china. The population density is ideally suited for high speed rail. High speed rail will bring speedy travel as well as large augmentation in line capacity for passenger transport.

Since the publication of first edition of this book the scenario of High Speed Railways in the world has undergone shift. In last 7-8 years China has commissioned close to 19,000 kms of high speed rail network which is now more than the combined lengths of high speed network of rest of the world. Lot of action is going around in India also leading to definitive steps in starting the work on High Speed Corridor.

The second edition of this book has incorporated updated information of various high speed networks in the world with updated and latest photos. The name of book has also been changed to reflect the change from vision to action.

A new chapter no. 13 has been added compiling current scenario in High Speed Rail sector in India. Various Budget speeches of the year have been referenced which capture the wishes and desire of people of India. The prefeasibility study report on Pune-Mumbai-Ahmedabad HSR corridor has been submitted by consultants in April 2010. Extract of the report has been included in the chapter for appreciation of readers including projected cost. Updated happening under HSRC (PSU entrusted with development and implementation of High Speed Rail Projects in India) has been incorporated in the book.

The book will be of immense use for Railway Engineers who are yet to see work and or travel on High Speed Rail and will be able to update their knowledge.

9th October 2015

Vishwesh Chaubey
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ACKNOWLEDGEMENT (Second Edition)

Since publication of first edition of this book lot of events have taken place. High speed Rail project has moved on from being a fancy project pursued by Indian Railways to the most sought after project persued by whole country. MOUs have been signed with other countries at Government level and studies on various routes has started.

In this scenario the second edition of the book is being published. To capture the mood the name of book has been changed from 'Vision Of High Speed Rail Corridors in India' to a more action oriented 'Construction and Maintenance of High Speed Railway'.

Since inception of Human travel speed and travel time has been the most prominent feature. Readers may be surprised to note that only in 1804 i.e 210 years ago Trains travelling at 4 kmph were making world record. Today we are looking at 350 kmph travel. Very interesting information on evolution of speed on Railways, Highways and air has been presented in Ch 2 (from UIC).

Elsewhere all chapters have been reviewed and updated duly elimination typo errors (if any). A new chapter no. 13 has been added for presenting the current happenings on the subject in India. Useful information from Pre Feasibility Study report of Pune – Mumbai – Ahmedabad High Speed Route has been compiled. Salient features of recommendations of the report has been included in the chapter.

We would like to acknowledge sincere gratitude to Sh Vishwesh Chaubey, Director, IRICEN, Pune for regular guidance and direction.

Valuable suggestions from the readers are welcome for further improvement in the next edition. (mail at mail@iricen.gov.in)

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PREFACE (First Edition)

High Speed Rails are attracting attention, for almost half a century, throughout the world especially in the economically advanced nations. Japan was the first to have started the 'Shinkansen' and the Bullet trains in 1963 followed by other Countries v.i.z. France, Germany, Italy etc. The high speed Rail has been generally considered to be competing with air journey and an attempt by the Private Railways of the countries to retain rider ship which otherwise prefer to travel by air or cars. The last but a formidable country joining the elite club has been China, probably for different reasons. The passengers in India traditionally, had been largely traveling by trains for short as well as long distances, thanks to monopoly of Government operated airlines with very high fares and poor road and vehicle conditions. With improvement of roads, latest technology cars/ buses and private airlines entering the transport scene in last few years the traditional assumptions are bound to get upset. Some private airlines are openly claiming that they are competing with upper class railway travel, as far as fares are considered. This appears to be paying dividends also to the airline sector which is seeing a growth of about 30% annually for last few years. Simultaneously the rapid growth in Economy has not only increased the need to travel more frequently but also increased the paying capacity of the travelers. These factors qualitatively, strengthen the case for High Speed trains in our country, also.

High Speed Rail is completely a new field for Indian Railway Engineers and requires understanding and adopting much different specifications and standards rather a completely new technology for construction and maintenance. This book is primarily a study of the available literature and information available on the high speed railway systems in the world, the technology adopted by them, and identifying the appropriate parameters, adoptable for high speed corridors in India. The experience of High speed Rail on the existing systems is with standard gauge, so are the guidelines issued by UIC (International Union of Railway Sector) for High speed Rail, whereas the National Gauge of India is Broad gauge. Effort has been made to consider this difference and suggest parameters suitable for adoption, for Indian Railways.

The history and the development of high speed rails in the world, chronologically is covered in chapters 1 to 4. The experience of other Nations can tell us a lot and the pitfalls to avoid. The focus of the book however, is on track, formation, tunnels and Bridges. Chapters 6, 7, 8 and 9 give detailed coverage along with analysis and attempts to answer the questions as to what, why and how? This will be of great interest to all Railway Engineers in regard to the issues involved in High Speed Rails and will also give the direction for taking up further study and research for finalizing the parameters for construction and maintenance. Salient aspects of electrical overhead Traction and signaling have been introduced in Chapter 10, which will give the needed preliminary information to the reader. Chapter 11 deals with the rolling stock including tilting coaches and Operation of High Speed corridors.

Indian Railway had appointed, RITES Limited for 'Feasibility Study for introduction of High Speed railway from Ahmedabad to Mumbai' in 2003-04. Relevant information from the report including financial appraisal, has also been covered in Chapter 5. This is though 5 years old and several changes in the scene have taken place but is an useful document and will be of interest to planners and Engineers alike. Chapter 12 deals with the required parameters for maintenance for track as well as OHE equipment. This is very important in as much as the design of infrastructure has to be such that it is maintainable and safe for operations and has to be kept in mind while assigning parameters for any and every element of the system.

Overall the book presents information on all the aspects involved in construction and maintenance of High speed Railways, and fills the gap of non-availability of a single source for information on Technology of High Speed Rail Corridors. A large amount of facts and figures from all over the world, colourful pictures taken from the Public domain material will surely make this book worth reading for every Railway Engineer.

A.K.GOEL
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ACKNOWLEDGEMENT (FIRST EDITION)

The subject of “High Speed” is gaining lot of importance in the recent past. In addition to Europe and Japan, several Asian countries including our neighbor China has started high speed operation and is having several projects on the anvil.

In India, thought has started as back as in 1988 but without any headway. However in recent times, thought has again been revived.

After realizing the benefit of Uni-gauge policy in India, it will be needless to mention that high speed corridors should be built with Broad Gauge only.

Keeping this aspect in mind, I realized the difficulty of finding the technical information on the subject, as there is neither such experience available in our country nor in any part of the world. High speed corridors, historically has started with 1064mm gauge in Japan and spread worldwide with 1435 mm standard gauge. Almost all the high speed corridor in the world are with standard gauge only.

The inspiration for writing this book on “Vision of High Speed Rail Corridors in India” has come from Shri A.K. Goel, Director, IRICEN, Pune.

The subject has demanded lot of time for digging out information by referring to various books in IRICEN Library, several high speed related web sites, international presentations, technical information made available by U.I.C., international codes and manuals, monthly and quarterly journals on high speed and RITES reports on feasibility of Mumbai-Ahmedabad high speed corridor.

It was too difficult to get useful technical information, as most of the world railway sites, journals, magazines, etc. provides predominantly commercial and operating information. Despite all

the odds the useful information not only have been collected, edited and transformed, but also converted for Broad Gauge corridor, as available information were only for standard gauge.

After gathering large amount of information, difficulty was felt to make it concise and brief which could finally be achieved.

The effort has been to investigate what track standards could be allowed in order to achieve high speed performance with use of latest known train technology in the world.

I sincerely acknowledge my gratitude for the time to time guidance, support and inspiration, extended by Shri A.K. Goel, Director, IRICEN.

I am thankful to my wife and children for giving support and allowing me to spend more time for making this book more concise, informative and useful.

I further thank to the concerned staff of IRICEN associated with typing and editing work and also to the staff of IRICEN's Computer Section for their computer related assistance.

This book is expected to be quite helpful in giving an overall idea about how to proceed in the direction of construction of "High Speed Rail Corridors' in India.

Valuable suggestions from the readers are welcome for further improvement in the next edition.

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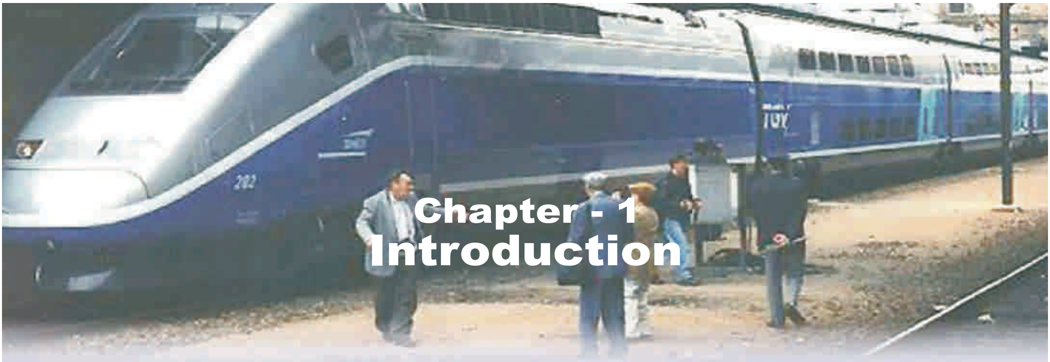

Chapter - 1
Introduction

1.1 Objective:

Concept of High Speed train has started developing throughout the world after the world war-II. Japan has taken a lead in this field followed by several European Countries viz France, Germany, Sweden etc.

The importance and advantages of High Speed train has been understood globally viz a viz areoplane and road transport.

During last 50 years enormous advancement has taken place in this field. Several historical milestones have been achieved by various countries. However India is lagging behind in this field. The vast size of the country, population and economic growth strengthen the justification for High Speed train in our country.

A thought for High Speed Corridors in our country has started in the year 1987 but without any desirable progress.

However recently Indian Railways has taken definitive steps to identify potential corridors and has commissioned reputed agencies for feasibility studies which are underway. “High Speed Corridor” is completely a new field for railway engineers and practical experience is not available in this field in India.

Most of the countries of the world having major Railway transport system are having all the four system i.e. running of convention mail/express train, freight train, suburban system and also the High Speed Corridors. It is only India, where though one of the largest railway network system is existing, but without High Speed Corridor. In the recent part Asian countries like China, Korea etc have also gone for High Speed Corridor in a big way leaving India for behind. It is high time now to think and proceed in this direction so as to enable to keep pace with other countries.

1.2 Preliminary remark :

The high-speed train is a means of transport between cities of commercial and administrative importance. With 8-9% economic growth of the country, the transport needs are increasing day by day, specially between centre of production, trade and commerce. The development of the networks of high speed must be based on effective modes of financing, associating all the factors that profit from this type of transport.

The construction of new high speed railway lines is currently being undertaken in a large number of countries, in particular on the continent of Europe, Japan and china.

The development of these new lines has been done over a period of more than fifty years, between the middle of the 1950s and the current decade. During this period the design criteria have been modified as experience has been gained with the different aspects of high speed running.

From the point of view of commercial operation, the experience available is in the range from 250 to 320 km/h. However, recently lines have been opened for speeds of 360km/h in a few countries.

1.3 Role of UIC:

UIC, normally brings all its support to its members wishing to develop high speed, in particular through its activities in the field of the technical harmonization and interworking, but also by facilitating the exchanges on the aspects operational, commercial, economic and financial.

The remit of the **UIC High Speed group** is to coordinate the activities of the different countries in the field of high speed and thereby play a part in helping create a true high speed network and promoting high speed worldwide.

1.4 High Speed Railway Components:

High Speed Railway is a complex system, comprised by state of the art of all the following components:

- Infrastructure
- Rolling Stock
- Operation rules
- Signalling systems

- Marketing
- Maintenance systems
- Financing
- Management
- Legal aspects

1.5 Performance support for High Speed :

The performance which supports high speed for customers are

- Commercial speed, travel with a high level of speed
- Total time of travel, a short travel time from door to door
- Frequency, a high level of available transports
- Reliability, a reliable system of transport, which works independent in nearly each case of weather
- Accessibility, you can enter a train spontaneous without long check in times, which supports high level of flexibility
- Price, one does not pay more than, any comparable means of travel.
- Comfort, there is a higher level of comfort (in terms of space, accelerations, noise, light, etc.) than in the plane, bus, or a average car
- Safety, High speed trains are the safest transport medium.
- "Freedom", during trip, one can go everywhere and every time one wants, else in the restaurant, to the lavatory, or only for promenade, seatbelts are not necessary, electronic devices aren't limited, etc.

1.6 High Speed Advantages for Society:

1.6.1 Social Benefits (Economic externalities):

Externalities are in economic terms costs or benefits which are not covered by market forces. For example, if you drive to your place of work, you are producing harmful emissions and adding to congestion which other people are forced to consume. Left up to a free market economy situation these costs would never be compensated for, an example of market failure. The government is left to step in and indeed majority of the price of petrol is tax, to make people pay for the cost of causing emissions and congestion. This is similar across most of the countries.

1.6.2 Reduced CO_2 Emission:

The USA has the highest CO2 emission rates in the whole world. Why what is crucial different between the USA and Europe/Japan? Is there more industry in the USA well even if there is it wouldn't account for all the extra CO_2? Perhaps the rate of car ownership is slightly higher in the USA. Well even that isn't significant. People must use their cars very much more in the USA accounting for the extra emissions. But why there is one crucial difference the USA has very little by the way of railways, both high speed and local. It would seem reasonable to conclude that the more trains you have, the lower your countries CO2 emissions. Admittedly it's a bit simplistic but if definitely does seem to be related.

All countries of the world are targeting to curb green house-gas emissions caused by the transport sector. While in the other sectors, CO2 emission has been stabilizing or even decreasing over the last 15 years. CO2 emissions caused by transport sector is increasing by 2% per annum. Overall 20% reduction target by 2020 can only be achieved if transport sector can be organized in a less polluting way.

1.6.3 Respect for the environment:

Train system gave very efficient use of land. For same amount of traffic, road may normally need 3 times land as compared to trains.

1.6.4 Economic development:

It helps economic development. High speed rail promotes logical territory structure and helps contain urban sprawl.

1.6.5 Huge Capacity:

High speed railways have by far the highest capacity per unit land they use. A high speed rail needs just a double track railway, one rail for trains in each direction. These have a capacity for 16 trains per hour, each train with a capacity of 800 passengers. This means a high speed rail has a maximum capacity of 12,800 passengers per hour and more than 3,00,000 passengers per day, which clearly is enough to satisfy the highest of demand, only one railway line is needed. This is unlike motorways which take up a very large amount of space and often cannot satisfy demand fully at peak times.

1.6.6 Reduced Traffic Congestion:

Imagine you have two cities about 500km apart, by car the journey time will be about 10 hours. The motorways will be jammed full. If you can provide new rail service of 300km/h between two cities the Journey time by rail will be about 2 hours. Provided the rail service is well priced, very few people are likely to drive any more between the cities, causing a massive decrease in traffic. Of course with a decrease in traffic pollution decreases too.

1.6.7 Energy Efficiency:

The train offers per passenger energy efficiency that no other form of transport can achieve. The reason is because steel wheels on steel rails, because they are hard smooth surfaces, provide very little friction. Also because the wheels are held by steel ball bearings friction too is very low even at high speed. Air resistance of a train is not really a problem because it is thin and long. On the other hand aircraft must burn huge amount of fuel to even move at all, and in flight the engines have to continue to burn just to keep the plane in the sky. Once a train is moving even if the engines are switched off the trains does not even decelerate noticeably even at very high speeds. Cars as everyone knows are by far the least efficient form of transport. Journey by plane consumes 9 times and journey by car consumes 4 times energy as compared to journey by train.

1.6.8 Efficient Land Use:

A three lane motorway will have a capacity of 2 x 7650 passengers per hour compared to 2 x 8000 passengers per hour for a double track high speed railway. However, the land width required for a double track will be only 25 m compared to 75 m for a comparative motorway.

1.6.9 Reduced Pollution:

Because of their efficiency, the pollution that a train makes is very low, and if the electricity being used for the train is generated by a green source then there may well be no pollution at all as a result of running the train. Reduced traffic also reduces pollution, no more cars pumping out gases in huge amounts, and of course compared to aeroplanes which need to burn fuel at an astonishing rate just to get thrust. In fact, it has been calculated that a Eurostar train with a capacity of 800 causes pollution level through power stations about equivalent to 20 cars. Now most cars carry one person.

1.6.10 Speed:

300km/h is very fast. Imagine the 100 metres running race. Now imagine doing that in just one second. That is the speed at which these trains fly along. No time is wasted in getting people to their destinations. There is no worry about waiting in traffic, or having a long stressful drive. Also it means that flying can be avoided, which is particularly welcome for the more ecological people (or people who don't like flying).

1.6.11 Convenience :

While airports are often out of town and hard to access, railway stations are usually located in the heart of the city. Also with some services you can just buy a ticket and get straight on the train. Aircraft have drawbacks such as long check-in times and constant moving around.

1.6.12 Safety :

What is perhaps not known about is that high speed trains are in fact the safest form of transport. High speed trains are perhaps surprisingly safer than normal trains. Most use very advanced computer signaling systems meaning risk of collision is very low, and apart from that there is not a lot that can go wrong. It is a myth that at high speed trains just fly off the tracks. They don't, France had tested trains going at 574.8 km/h in the year 2007, which shows that dangerous, experimental speeds are a long way off commercial everyday speeds.

1.6.13 Comfort:

With the possible exception of cruise ships, trains are the most comfortable form of transport. Even at these very high speeds the train remains about as smooth as an aircraft, and of course very much quieter. Also there are no limitations, the seats are not cramp like in an aircraft, and unlike in a car you can get up, walk around, or buy a snack from the buffet car or have a proper meal in the restaurant car.

1.7 Limitations of High Speed :

1.7.1 Social Drawback (Externalities):

It is only suitable for densely populated areas. Thus medium and small size towns do not get the benefit of fast connectivity. However, Japan's Bullet train timetable shows that there are slower services stopping at smaller stations and there are nonstop services.

1.7.2 Economic Drawbacks:

The primary objection is always the cost. High speed railways are very expensive.

1.7.3 Is high speed rail the most cost-effective way to gain lower pollution?

High initial costs often mean public money has to be used because the private sector is usually unwilling to engage in such large projects. As a result many would argue that the money used to build such rail systems would be more effectively spent in other projects if the primary objectives were to reduce traffic congestion / pollution.

1.7.4 Limitation of high speed rail :

High speed rail is only applicable to intercity services in high density corridors. Having said that connecting trains /metro rail services can deliver people door to door. This means something very important, in order to work effectively high speed rail must be backed up by a decent urban/light rail transit system.

1.7.5 Limitations of Geography :

High speed railway lines need to be as straight and level as possible. Therefore, often the railways are carried over dips and hills in the countryside by embankments, viaducts cuttings and tunnels. (Tunnels are sometimes unsuitable due to wind turbulence problems). However these greatly increase the cost of the railway, and of course if the landscape is mountainous then it becomes very difficult to built straight and level. Naturally railways cannot be built over water for long distances. So railways across water are likely to remain very much a rarity.

1.7.6 Limiting speed :

High speed rail system can be of two types. Steel wheel running on steel rail system and Maglev system running with electromagnetic system by keeping rail wheel just above the rail. In the first system commercial speed is normally limited to 360 kmph with an upper limit of 400 kmph. Beyond which, it is likely to be uneconomical by giving due consideration to the increased input required for maintenance of infrastructure and rolling stock. On the other hand Maglev system can offer commercial speed beyond 500 kmph but its exorbitant construction cost, huge energy consumption and sound produced during operation make it economically and environmentally prohibitive. That's why it is not becoming popular. In other words, a maximum commercial speed of 400 kmph for steel to steel contact high speed system is considered to be economically viable by most of the leading countries of the world.

Presently only two Maglev lines are in commercial operation.

1. SMT high speed airport link in Shanghai for a length of 30 km, with journey time of 8 minutes and maximum commercial speed of 430 kmph.
2. Low speed Limino line in Nagoya running since 2005.
3. Incheon Maglev will also be a medium to low speed line with maximum speed of 110 kmph in Korea, second country to adopt Low Speed Maglev train.

1.8. High Speed Trains Versus Aeroplanes :

1.8.1 Speed:

Modern Jet aircraft can travel at of about 1,000km/h. However, in commercial use aircraft usually travel in the region of 500 km/h to 800 km/h. The speed at which it flies is calculated based on how much fuel it will consume at the various speeds.

Trains however travel at a maximum of 360 km/h. This is considerably less than the aircraft, only about one third of the speed. So how can they still compete?

Aircraft have crucial disadvantages. Although once cruising up in the air they may reach very high speeds, it takes a long time to arrange everything.

1.8.2 What makes aircraft slow?

First of all Airport exist out of town. This is because they take up a large amount of room, often several square kilometers as with major airport. To get to the airport people face a journey, often in the region of 60 minutes. Train stations on the other hand usually exist in the centre of cities, for historical reasons. Even if there is no room for a train station, it can be built underground, so there would be no reason for a major station not to be at the heart of the city. Hence journey time to and from stations is considerably less than to airports.

Secondly there is bureaucracy. Airports require people to check in, leaving baggage behind, and provide their tickets all the time. People are usually requested by the airline to arrive early. There is no such thing in trains, you just find out the platform and walk straight onto it. With aircraft once you get to the other end you have to hang around and wait for the baggage at the reclaim facility.

Thirdly there is boarding time. Trains have doors down the length of them. The eurostar with an 800 capacity has 18 doors, that's 45 passengers per door. A Boeing 747 (capacity 400) has at best 3 doors. (Front, middle rear), that is 133 passenger per door. Since the rear door is often not used this goes up to 200 passengers per door. While it is possible to board TGVs in 2 minutes (the general time spent at stations) it can take as long as 15 minutes to board an aircraft because of the few entry/exit points. (Note: Peak capacity stations have a platform both sides of the train, effectively doubling the number of entry/exit points). Another thing is that before the aircraft can leave the terminal everyone has to be sitting with all their luggage put away (safety reasons). However, its perfectly acceptable for a train to start leaving the station while everyone is still standing up and stowing their bags.

The fourth reason is that aircraft cannot leave immediately. Once everyone is on board and ready to go the aircraft still has to spend a long time getting to the runway (taxing). And at busy airports they then have to wait for clearance to take off, and queues of planes often build up, meaning you have to wait for aircraft in front to take off. This is the same with landing, aircraft spend a long time circling around the airport and then there is the usual time taken to get to the gate. At busy airports sometimes aircraft have to wait on the tarmac until a gate becomes free.

All of this means that in fact the door to door Journey time for distance upto 400 km is faster by high speed train than it is for the aircraft. This usually means bankruptcy for any airline serving to cities connected with high speed rail.

1.8.3 Well, Why not compete on price?

If aircraft cannot compete with trains on journey time you might think they could try price. This is very difficult. Aircraft are very expensive to build and maintain, much more than trains. The most expensive train in the world is the Eurostar at Rs 16 lacs a seat. Most aircraft by comparison are Rs.80 lacs per seat! Trains do have costs such as paying for the railway lines which are expensive, then again, so are airports, and airlines have to pay airports a lot of money. (Landing charges). Also there is energy, aircraft consume a hideous amount of fuel when compared to trains, which has to be paid for. As a result operating costs for airlines two to three times higher than for trains. Offering a cheap and cheerful service is not possible. In India, aero planes are competing with present train fares of Air condition second class.

1.8.4 Examples of Aircraft being displaced by trains:

The Paris to Lyon line is the famous example. France's two biggest cities, about 450 km apart. This was the most obvious section for high speed rail, and in 1981 the first TGV services on new high speed line started. The journey time from Paris to Lyon reduced to only 2 hours. This crippled the airlines, a 40% drop in air travel between the two cities occurred.

Paris to Brussels high speed line has been completed in January 1998, a distance of 340 km. By taking a Thalys between the two cities direct, journey time is a staggering 1 hour 30 minutes! This has crippled air services too.

Eurostar, London to Paris and Brussels also has stolen large percentage of the market after construction of channel tunnel rail link by reducing journey time from London to Paris to 2 hours 30 minutes. The flight time is 45 minutes, although surveys find, point to point time using airlines is 3 hours.

1.8.5 Supersonic Aircraft :

They have a top speed of 2316 km/h, roughly twice as fast as the speed of sound. While technically these are marvelous machines, commercially they are a complete failure. They are not allowed to travel at supersonic speeds over land because of the sonic boom they create (they will never compete with trains!) and use so much fuel and need so much maintenance prices are very high.

1.8.6 The Environment:

So is it a good thing the aircraft are being replaced by fast trains? From an environmental point of view it certainly. High speed train produces only 3.2mg of CO_2 per passenger, whereas aircraft produces 225mg of CO_2 per passenger.

1.8.7 Energy Consumption:

Trains do have air resistance, but the faster you go the more air resistance you face. As a result the faster you travel the more energy you consume between two points since energy=force x distance. Now one advantage of aircraft is they climb to where the air is thinner, so air resistance is 40% less. But because they go 300% faster than trains, its not a benefit. Also the design of aircraft makes them more prone to air resistance. They rely on air resistance to stay in the air. Aircraft use a lot of fuel to climb about 10km into the air.

The Jet engine is always going to be inefficient too, because it relies on blasting burnet fuel out of the rear. This means that the vast majority of energy goes speeding up the air. It does not divide 50/50 because kinetic energy is a function of the square of velocity (double speed quadruple energy). So most of the energy is used to make a huge hurricane with a little left for the actual aircraft. Another reason why it is inefficient is because it releases heat, so you get a hot hurricane! Not only that but because there are so many moving parts there is a huge amount of noise. In short, noise, heat, wind come out of the jet engine as wasted energy, meaning only about 10% left goes into making the aircraft go.

1.8.8 Emissions:

Electric trains by definition don't produce emissions, although the electricity has to be generated. Even if it is through oil powered stations as opposed to cleaner electricity generation because energy efficiency is so high. Assuming electricity is generated by oil powered stations, aircraft will produce about 5 times more carbon dioxide than trains, plus producing toxic nitrous oxides.

1.8.9 Noise:

High speed trains do produce noise, however not that much noise. A high speed train passing at full speed (360km/h) is still slightly quitter than a busy motorway. Aircraft are extremely noisy, this occurs because they have to shoot air out of the back at beyond supersonic speeds. However, this is only a problem for those living around an airport. Once at altitude noise on the ground is not noticeable. A high speed railway is noise all along. However air craft are flying at low altitudes for a considerable distance around the airport itself, usually over cities. A high speed railway only affects those near the railway, but more importantly 98% of the noise from a high speed line can be cut out by building a sound barrier next to the line.

1.8.10 Capacity:

The largest aircraft is the Boeing 747 series 400. Now this has a capacity of 400 and if all the first class were replaced with standard this could be increased to 500. The largest train is in Japan with a capacity of 1,400 passengers. Clearly even if every aircraft was this size and was taking off and landing every 2 minutes it still couldn't match the capacity offered by rail. New terminals and runways could be built, but this would increase noise to residents of the city and increase congestion along airport-city routes. A double decked E4 series shinkansen can carry 1634 passengers, double than of an Airbus A 380 in all economy class.

1.8.11 Is this good for the consumer?

Well it finally means that we no longer have to rely on people's environmental conscience to choose the train instead of the aircraft/car because the high speed train will provide most of the benefits of competing forms of travel, and more. It will also mean airlines tightening up procedures to get people through airports faster and will encourage airports to have better city links so high speed trains will means improved quality of service for those still traveling by air.

For longer flights, where the aircraft gets to spend longer at its full speed, the high speed train loses its edge and building a high speed railway line for exclusive distances much more than 600km would be a mistake seeing as such a long distance would be incredibly expensive, and air could probably beat it for time, meaning profits would not be that good. Having said that, if there were a major city half way down then it would be an excellent idea since services could stop in the major city and go on. Even if we do get 500km/h trains, it will not completely mean the end of aircraft because trains cannot cross oceans obviously, although the channel tunnel does indicate trains can cross small seas. It is likely as the high speed rail grows in Europe, flying around will become a way of the past.

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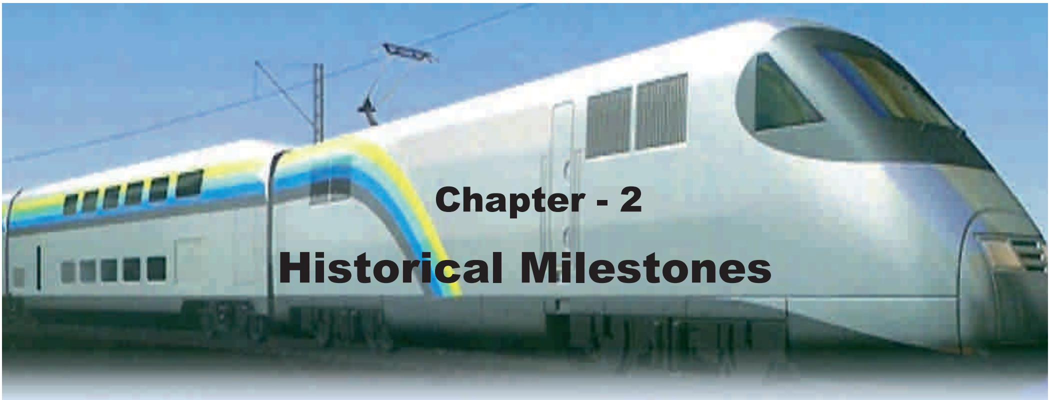


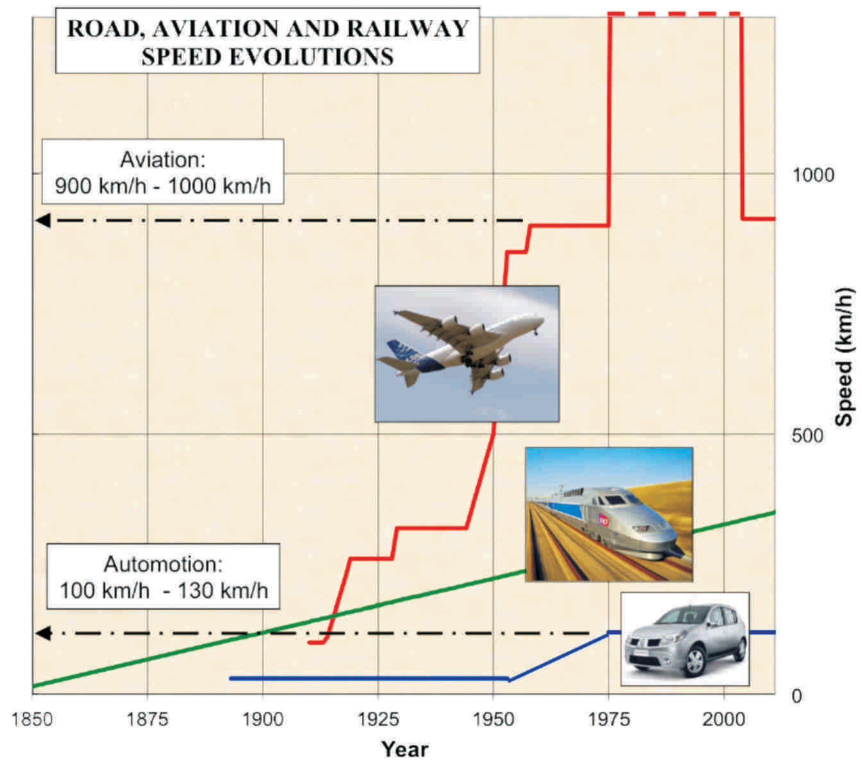
Chapter - 2

Historical Milestones

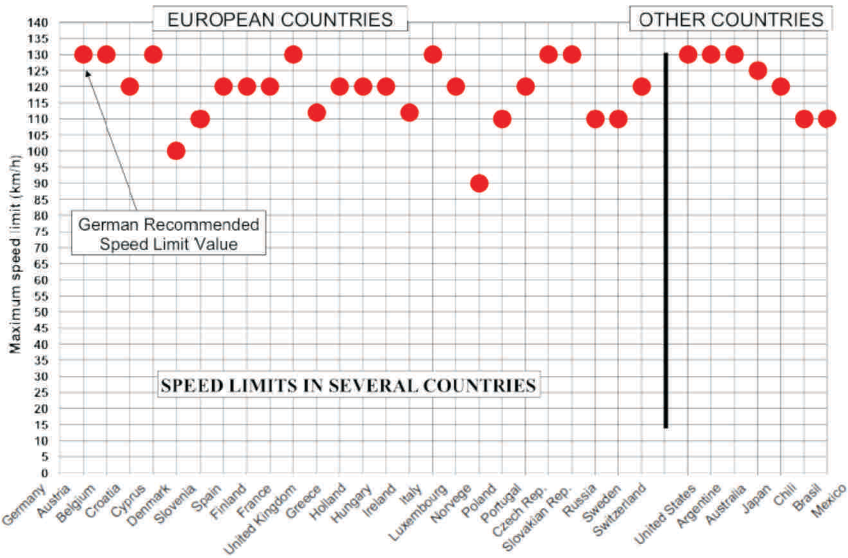
2.1 Historical Evolution of Speed

Speed / travel time is an inseparable feature of human travel. There is constant desire to reach early at destination and reduce travel time. Technology has helped us to achieve faster speed of travel in every mode of transport.

The historical evolution of speed for each mode of transport is very well captured in following graph (UIC).



The current speed limit on road in various countries is shown below (from UIC).



Thus it can be seen that the road speeds have stabilized in the range of 90 to 130 kmph across the globe. It will be interesting to see the evolution of speed record in Railways since its inception.

YEAR	SPEED (km/h)	TRACTION	LOCOMOTIVE / TRAIN
1804	8	Steam	Trevithick's Locomotive
1825	24	Steam	Stephenson's Locomotive no. 1
1830	48	Steam	Stephenson's Rocket
1848	96.5	Steam	Boston & Maine "Antelope"
1901	162	Electric	Seimens & Halske Railcar
1903	206.7	Electric	Seimens & Halske Railcar
1903	210.2	Electric	AEG Railcar
1938	202.8	Steam	A4#4468 "Mallard"
1955	326	Electric	Alstom Electric Loco CC7107
1955	331	Electric	Alstom Electric Loco BB9004
1981	371	Electric	TGV-PSE 16
1981	380.4	Electric	TGV-PSE 16
1988	387	Electric	ICE-V BR-410-001
1988	406.9	Electric	ICE-V BR-410-001
1988	408.4	Electric	TGV-PSE 88
1990	515.3	Electric	TGV-A (Atlantique) 325
2007	574.8	Electric	TGV V150 (LGV Est) 4402

Thus Railways are still testing the limits of speed.

2.2 Introduction of High Speed Railways :

High speed railway has started from Japan and has spread through out the world. A chronological sequence of important events in the field of development of High Speed Railway in different countries of the world is given in the following paras

2.3 Chronological sequence of events in JAPAN:-

1930 - The popular English name bullet train is a literal translation of the Japanese term **dangan ressha**, a nickname given to the project while it was initially being discussed. The name stuck due to the Shinkansen locomotive's resemblance to a bullet and its high speed.

1940 - The "Shinkansen" name was first formally used for a proposedstandard gauge passenger/freight line between Tokyo andShimonoseki, using steam and electric locomotives with a topspeed of 200 km/h.

1956 - Following the end of World War II, high speed rail wasforgotten for several years. Passengers of conventionalMain Line increased and by the mid-1950s, the linewas operating at full capacity.

Japan began considering the options for reconstruction, withhigh speed rail already very much part of the plans. 1956 sawthe first feasibility studies conducted for a new line linkingTokyo to Osaka. It was decided to design the line for a speed of250 km/h, setting a new record for that era and representing aremarkable technological leap for a country equipped with aconventional, 1064 mm gauge network on which, up until then,trains had been worked at speeds of around 80 km/h.

1958 - Japan Ministry of Railways decided to revisit the Shinkansenproject. Government approval came, and construction of the first segment of the Tokaido Shinkansen between Tokyo and Osaka started in April 1959.

1963 - Shinkansen – Trail run at 256 km/h

1964 - The Shinkansen is a network of high-speed railway lines in Japan operated by four Japan Railways Group companies. Tokaido Shinkansen opened in 1964 running at 210 km/h, in time for the Tokyo Olympics.

Tôkaidô Shinkansen is the world's busiest high-speed rail line and carries 375,000 passengers a day, and has transported more passengers (4.5 billion) than all other high speed lines in the world combined. Though largely a long-distance transport system, the Shinkansen also serves commuters who travel to work in metropolitan areas from cities beyond the metropolitan areas.

The first Japanese high speed train

1965 - Japan was the first country to build dedicated railway lines for high speed travel. Because of the mountainous terrain, the existing network consisted of 3 ft 6 in (1,067 mm)

Construction of the Sanyo Shinkansen between Shin-Osaka and Okayama was authorized on September 9, 1965 and commenced on March 16, 1967. Construction between Okayama and Hakata commenced on February 10, 1970.

1972 - Shinkansen - Trial run at 286 km/h

The Shin-Osaka to Okayama segment opened on March 15, 1972; with an increase in maximum speed to 220 km/h.

1975 - Launch of revenue-earning services on the Sanyo Shinkansen line between Okayama and Hakata.

1977 - Launch of revenue-earning services between Hakata and Kokura in Japan.

1978 - HSST-01 - Trial run at 307.8 km/h(Auxiliary rocket propulsion)

1978 - HSST-02 – Trial run at 310 km/h

1979 - Shinkansen – Trial run at 319 km/h

1979 - 500R(unmanned)- Trail run at 504 km/h

1979 - ML- 500R(unmanned) – Trial run at 517 km/h

1982 - Launch of the Tohoku Shinkansen line between Omiya and Morioka, followed by the Joetsu Shinkansen line between Omiya and Niigata.

1985 - Launch of Tohoku Shinkansen services between Omiya and Ueno.

1987 - MLU001 (manned) – Trial run at 400.8 km/h

1989 - 100 Series Shinkansen trains, introduced in 1989, boosted maximum speed to 230 km/h

1992 - Shinkansen – Trial run at 350 km/h

1993 - Shinkansen - Trial run at 425 km/h Tokyo-Hakata Nozomi services began on March 18, 1993, using 300 Series Shinkansen equipment.

1994 - Japan celebrated the 30th anniversary of high speed rail with close to 3 billion passengers carried and no fatalities.

1995 - A major earthquake hit the Kobe region, wrecking part of the Sanyo Shinkansen line. Three months later, normal service resumed on the route.

1996 - Shinkansen – Trial run at 446 km/h

1997 - MLX01 - Trial run at 550 km/h

1997 - In Japan, the new line between Akita and Morioka opened in March, served by Komachi trains, followed in October by the launch of the Nagano Shinkansen line and its Asama trains. A new service was launched on the Joetsu Shinkansen line between Tokyo and Takasaki/Yusawa. In December of the same year, magnetic levitation tests began, with a world speed record of 531 km/h set on the Yamanashi test line.

1997 - On March 22, 1997, the 500 Series Shinkansen entered service on Nozomi services between Shin-Osaka and Hakata, at a maximum speed of 300 km/h.

1999 - MLX01 – Trial run at 552 km/h

On 14 April, the Maglev beat its own record by notching up a speed of 552 km/h on the Yamanashi test line.

Japanese train MAGLEV

2003 - MLX01 – Trial run at 581 km/h

2007 - The N700 Series Shinkansen was launched on **Nozomi** services on July 1, 2007, with a top speed of 300 km/h (compared to 285 km/h for the 700 series).

Fastec 360 became operational at a commercial speed of 360 kmph with potential upto 400 kmph.

2014 - Japan celebrates 50 years of high speed rail service with zero fatality and punctuality loss of less than one minute per train.

2.4 Chronological sequence of events in GERMANY:-

1965 - DB offered daily high speed services at 200 kmph between Munich and Augsburg.

1974 - EET-01 - Trial run at 230 km/h

1975 - Comet – Trial run at 401.3 km/h

1985 - ICE – Trial run at 300 km/h

1988 - ICE – Trial run at 406 km/h

1988 - TR-06 – Trial run at 412.6 km/h

1989 - TR-07 – Trial run at 436 km/h 0

1991 - Germany launched the first ICE trains on lines between Hanover and Würzburg (327 km) and Mannheim and Stuttgart (100 km), shaving two hours off journey times and taking the country into the high speed rail era.

ICE 1 the first German high speed train

1993 - TR-07 - Trial run at 450 km/h

1999 - ICE has become capable of commercial operation at 330 kmph.

2003 - ICE3

Transrapid – Trial run at 501 km/h

2.5 Chronological sequence of events in FRANCE:-

1967 - TGV – Trial run at 318 km/h (gas turbine type)

1974 - Aérotrain – Trial run at 430.2 km/h (high speed monorail train)

1976 - In response to the popularity of high speed rail in Japan, SNCF had begun investigating options for France in 1966. In 1976, the planned new 410 km line between Paris and Lyons was declared to be of public interest.

1981 - TGV – Trial run at 380 km/h

Inauguration of the South-East TGV line in September by French President François Mitterand, heralding a reduction in journey times between Paris and Lyons from 4 to 2 hours. The line quickly proved to be a success, with annual ridership figures of 15 million, soon rising to 20 million.

TGV Sud Est, the first French High Speed Train

1986 - Launch of the Atlantic TGV line spanning 280 km, with two branches serving Paris-Tours and Paris-Le Mans. All regions to the west of the country can now be served by high speed train.

1989 - Launch of the Atlantic TGV line spanning 280 km, with two branches serving Paris-Tours and Paris-Le Mans. All regions to the west of the country can now be served by high speed train.

TGV Atlantique

1990 - TGV – Trial run at 515.3 km/h

1992 - France inaugurated its Rhône-Alps TGV line, by passing Lyons

1993 - for onward services to Valence.Opening of 332 km North Europe TGV Line, bringing 1 hour journey times between Paris and Lille. The lines run onwards into Belgium, laying cornerstone for a veritable Europe wide high speed network.

Thalys train which link Paris, Brussels, Amsterdam, and Cologne/Düsseldorf

2007 - TGV – Trial run at 574.8 km/h **(Still not broken)**

Current rail speed record run of 2007

2.6 Chronological sequence of events in ITALY:-

1970 - Start of construction work in Italy on the Rome-Florence Direttissima (trunk line). The project took 20 years to complete, with line sections opened progressively between 1976 and 1992. Journey times on the new line were slashed from three hours to one.

1976 - The first section of the Rome-Florence Diretissima was opened in Italy, with further stretched opening at intervals through until 1992.

1978 - Italy - Pendolino – Trial run at 250 km/h

1996 - Work got under way on the Bologna-Florence line in Italy. The new route would cut across the Appenines and stretch for 79 km, 72 km of it in tunnels, making it the one of the world's most expensive lines. Two launch dates are scheduled: 2003 and 2007.

2006 - In 2006, two new high speed lines were inaugurated in Italy, Rome - Naples and Torino - Novara. Also DB inaugurates the new high speed line Ingolstadt-Nuremberg bringing 1 hour journey times between Munich and Nuremberg.

2.7 Chronological sequence of events in KOREA :

1989 - Government decided to construct HSR between Seoul and Pusan

1991 - Call for tenders TGV (Alstom), Shinkasen (Mitsubishi), ICE (Siemens)

First High Speed Train in Korea

1992 - Civil construction started

1993 - Selection of TGV technology

1994 - Core system contract for rolling stock, electrification & signaling between Eukorail & Korean authorities

1996 - Problems in construction

1999 - First run of the KTX train in Korea

2000 - 12 train sets arrived in Korea. First run at 300 kmph

2004 - Commercial operation began on 1st April

2015 - A new line from Wonju to Gangneung is under construction to serve the 2018 Winter Olympics in PYEONGCHANG.

2.8 Chronological sequence of events in OTHER COUNTRIES:

SPAIN

Spain launched its new Madrid-Seville line and the 1st Eurailspeed World Congress on High Speed Rail was held in Brussels.

Swedish tilting train X2000

2004 - In 2004, the "classic - new high speed line between Hamburg and Berlin was opened to the public admitting maximum speeds of 230 km/h.

SWEDEN

1998 - Since its population density did not warrant major investment in new lines, Sweden decided to upgrade existing lines to accommodate speeds of around 200 km/h at a reasonable cost using tilt-body technology. Journey times on the Stockholm-Gothenburg line (455 km) came down to three hours, with four hours for Stockholm-Malmö (610 km).

Spanish AVE on the line Madrid-Séville

CHINA

China has become the powerhouse of high speed rail in last decade. China has the world's longest HSR network with over 19,000 km of track in service as of December 2014 which is more than the rest of the world's high speed rail tracks combined. China's high speed rail system also includes the world's longest line, the 2,298 km (1,428 mi) Beijing–Guangzhou High-Speed Railway. There are more than 16,000 km line further planned and under construction.

2007 – **China –** Maglev train for 30 km length became operational at maximum commercial speed of 430 kmph.

2008 – **China** – Beijing to Tianin 115 km opened for commercial operation at 300 kmph on 01.08.08 just before Olympic Games with potential upto 360 kmph.

TAIWAN

2007 – **Taiwan –** 345 km corridor opened for commercial operation at 300 kmph with potential upto 360 kmph.

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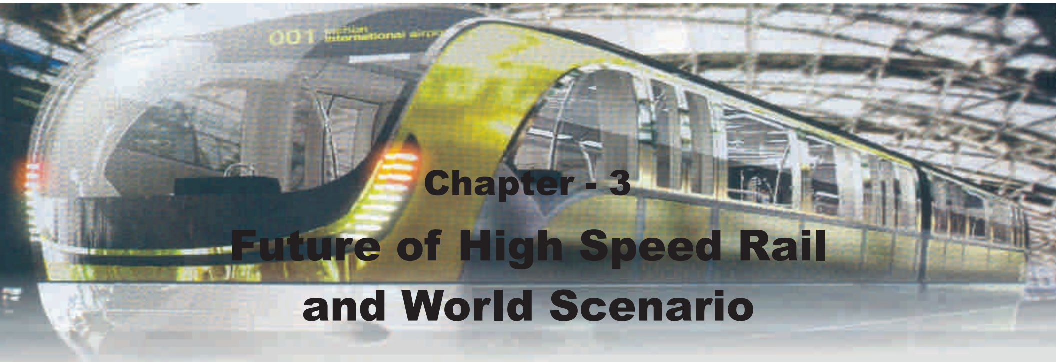

Chapter - 3
Future of High Speed Rail and World Scenario

3.1 High speed lines in operation at 250 km/h or more:

The speed of construction of High Speed lines is increasing day by day and several new countries are joining the high speed club. Length of high speed rail routes and their speeds in various countries is given in the following table.

(as on Dec 2014)

Country	Total Network Length In kms	Test run speed record in kmph	Average Speed Of Fastest Scheduled Train in kmph
Belgium	214	347	237
China	19369	394	313
France	2036	574	272
Germany	1334	406	226
Italy	923	368	178
Japan	2664	443	256
Netherlands	1200	336	140
South Korea	819	355	200
Spain	3100	404	236
Switzerland	79	280	140
Taiwan	336	315	245
Turkey	1420	303	140
United Kingdom	1377	335	219
Total	**34871**		

3.2 New high speed lines under construction:

Majority of High Speed Railway lines under construction are in China France, Germany and Japan. In recent past USA and UK and India have taken definitive steps to create high speed rail corridors. Thus in future more corridors of high speed rail are expected from these countries apart from China and Japan.

Following is the length of high speed line under construction in various counties.

Country	Length under Operation (km)	Length under construction (km)
Austria	292	210
Belgium	209	0
China	19369.8	16280
Denmark	5	60
France	2036	757
Germany	1334	428
Italy	923	125
Japan	2664	782
Netherlands	120	0
Poland	85	322
Russia	1496	0
South Korea	819	585
Spain	3100	1800
Switzerland	80	57
Taiwan	339	9
Turkey	1420	1506
UK	1377	0
USA	362	483

Thus a total of 23,400 km of high speed rail length is under construction out of which 2/3rd is in China.

3.3 High speed route Km in the world

Since 1964, upto the end of 2014, total high speed kilometer is likely to touch 35,000 kms mark. However, it is envisaged that till the end of the year 2025, high speed route kilometer is expected to increase upto total of 50,000 – 55,000 route kms. Majority of new lines are expected from China which is annually adding 2000 kms on an average. The pattern of growth of high speed route kms in the world is shown in the fig. 3.3.

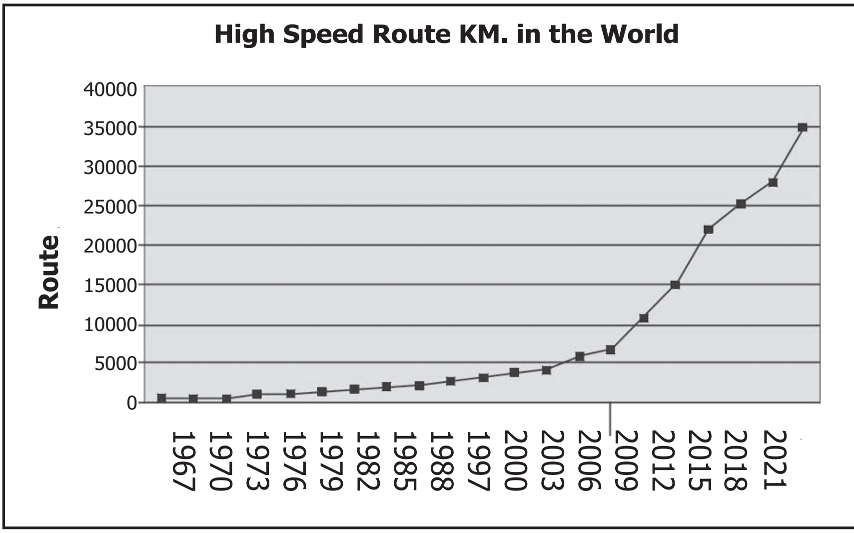

Fig. 3.3: High speed route Km. in the world

It can be seen that this projection is now vitiated by the fast paced construction done by China in last one decade and the progress envisaged in 2024 has been exceeded in 2015.

3.4 Improving the High Speed:

3.4.1 Speed Potential:

For the here and now speeds are being pushed up to 360km/h in different countries like Japan, France, Germany, China, Taiwan, Korea etc.

Despite the Speed Record by the French TGV of a whopping 574.8 km/h these speeds are not really viable commercially at the moment for a number of reasons. First of all, all pantographs have to make contact with an overhanging wire, when travelling at such speeds vibrations are immense. Also the dynamic pressures experienced by the track are overwhelming, and they would be worn out much faster, other than changing the physical size of the rails there is not a lot that could be done. Also there are a few other things, tracks and train wheels need to be absolutely perfect in order to run at such speeds. Already lasers are used in France to place sleepers millimeter by millimeter to ensure perfect straightness. However, wheels must be perfectly round too, and that is another problem. So going over 400 kmph commercially in the near future seems unrealistic.

People are starting to say that the upper limit for conventional steel on steel trains is 360 km/h.

Many people see the future in Magnetic levitation (maglev) trains. These are trains that float on a magnetic field, and are propelled by electromagnets. This would no longer need physical contact anywhere, so no wearing out would occur and there would be the capability of aircraft speeds. However there are drawbacks, a lot of energy would be required to float the train and one has to beg the question of why not just fly. The major drawback of course is the lack of infrastructure.

There is also the energy problem with maglev, it would take a lot of energy to float the trains and now that we are looking at having to conserve energy it might be the case that they just would not be commercially viable. Japan is the only country with plan for a commercial maglev service, for about 500 km track, planned to be completed by 2025.

3.4.2 Do we want trains to go any faster?

The problem is that the faster trains go, the greater the resistive force in terms of air resistance they face. Vast amounts of energy has to be used to counteract this force which at speeds over 360km/h can amount to several tons. To counter this force vast amounts of energy must be consumed. The whole environmental point about trains is that they use up a lot less energy (and therefore pollute a lot less) than the equivalent number of cars on the road. If they go faster than 360km/h they may start to loose this advantage and may even become more costly in terms of energy use than the car, like the aero plane. We should not really be pushing the top speed above 360 km/h. We should instead concentrate on bringing high speed train travel to more routes.

3.4.3 French Railway has advance from TGV to AGV:

While TGV is already running at 320km/h, AGV is the first train in the TGV family able to operate at 350 km/h. A standard TGV has two power cars and eight trailer coaches. AGV have a modular concept, grouping cars in threes, so that trains can be supplied in various lengths with a capacity ranging from 300 to 600 passengers. The train-maker ALSTOM \spent 10 years and €100 million ($147 million) to develop the AGV, which it compares with the Airbus's giant A380 jetliner in terms of innovation and its impact on the world of transportation. French Railway started AGV services in 2009.

3.4.4 JAPAN Railway has advanced to Fastech – 360:

Earlier in 2007 East Japan Railway's latest high speed test train took to the rails. Starting a programme of trial running on June 25, fastech 360 S is a key player in the evolution of the next generation of Shinkansen trainsets. Fastech 360 S is formed with six motored cars and two trailers. Although designed for a maximum commercial speed of 360 km/h, it is actually capable of running at 400 km/h. The two end vehicles both have to 16m long noses, but these are of very different shapes to test their respective aerodynamic shapes to test their respective aerodynamic performance.

From past experience of Japanese railway we know that current collection account for a significant proportion of the noise generated by a high speed train. The existing10-car seriesE2 has two pantographs. To minimize the aerodynamic noise Japanese are using a single low-noise pantograph with multi-segment sliders which closely adhere to the overhead.

Also contributing to better current collection at high speed are improvements to the overhead line fluctuation propagation speed through weight saving and increased tensile strength. A newly developed contact wire with a 10mm2 cross-section is supported at a tension of approximately 20 kN.

Running at 360 km/h increases vibration in the running gear, putting higher loadings on key elements such as bearings and final drives. For the load endurance test, we confirmed the reliability of the bogie by running consecutive 'trips' totaling 600 000 km at speeds of around 400 km/h. The existing combination of dynamic and mechanical brakes is suitable for operation at higher speeds.

In the event of an earthquake, the capability of the emergency brakes to bring a train to a stand as swiftly as, possible is of critical importance. As well as having upgraded conventional brakes, Fastech 360 S is fitted with aerodynamic brakes, intended to decelerate the train using 'resistance boards' that project from the roof of the train.

Using these brakes, we anticipate that the emergency stopping distance from 360 km/h will be the same as or even less than – required for Series E2 trains to stop from 275 km/h.

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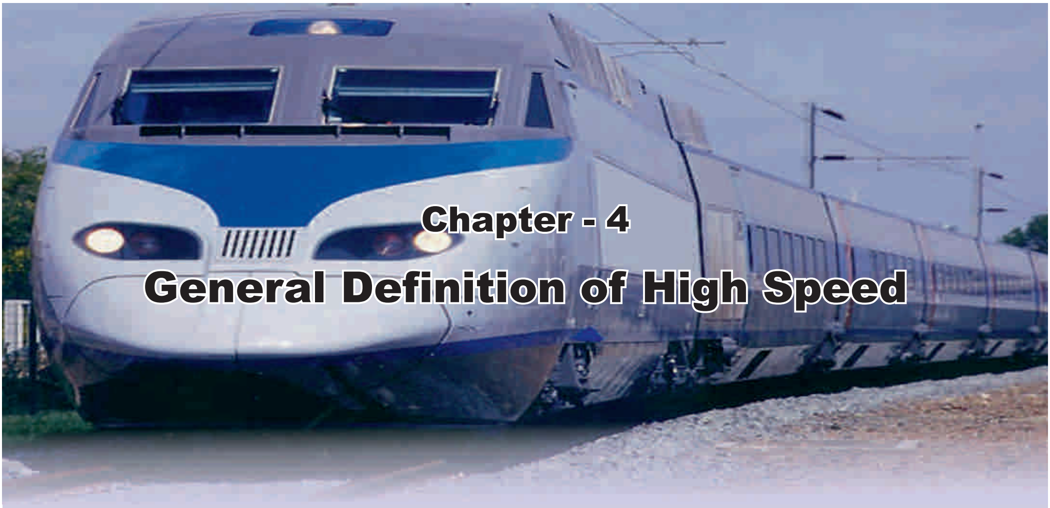


Chapter - 4

General Definition of High Speed

4.1 Definition :

The word "**definition**" has been used in the plural because there is no single standard definition of high speed rail (nor even a standard usage of the term: sometimes it is called "**high speed**" and sometimes "**very high speed**"). The definitions vary according to the criteria used since high speed rail corresponds to a complex reality.

At all events, high speed is a combination of all the elements which constitute the "**system**": infrastructure, rolling stock and operating conditions.

4.2 The high speed definition of U.I.C.:

4.2.1 Infrastructure:

a) Those built specially for High Speed travel, those specially upgraded for High Speed travel. They may include connecting lines, in particular junctions of new lines upgraded for High Speed with town centre stations located on them, on which speeds must take account of local conditions.

b) High Speed lines shall comprise specially built High Speed lines equipped for speeds generally equal to or greater than 250 km/h, specially upgraded High Speed lines equipped for speeds of the order of 200 km/h, and specially upgraded High Speed lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case.

4.2.2 Rolling stock:

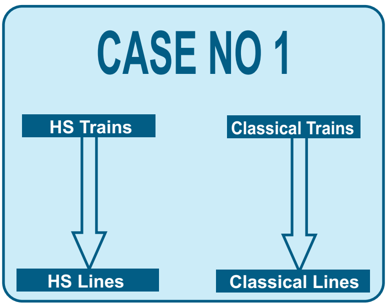
The High Speed advanced-technology trains shall be designed in such a way as to guarantee safe, uninterrupted travel, at a speed of at least 250 km/h on lines specially built for High Speed, while enabling speeds of over 300 km/h to be reached in appropriate circumstances, at a speed of the order of 200 km/h on existing lines which have been or are specially upgraded, at the highest possible speed on other lines.

4.3 Compatibility of infrastructure and rolling stock:

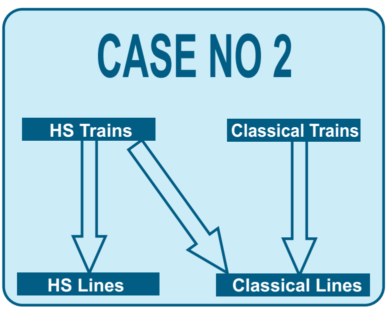
High Speed train services presuppose excellent compatibility between the characteristics of the infrastructure and those of the rolling stock. Performance levels, safety, quality of service and cost depend upon that compatibility.

4.4 Types of High Speed Systems:

It is possible to outline four types of high speed system:



Type 1 is the most classic and the "purest" high speed system. This constitutes a network of lines used exclusively by high speed trains which themselves do not operate on any other lines. The Japanese Shinkansen systems are such systems.



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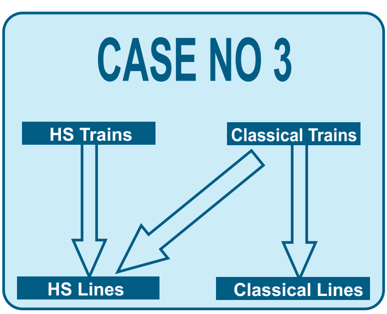
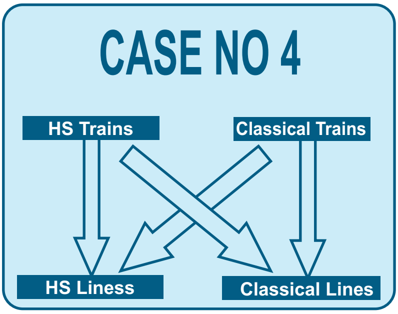


The Spanish system (AVE) constitutes type 3, i.e. a system of high speed lines which are used not only by high speed trains (> 250 km/h) but also by some conventional trains equipped of changing gauge systems, at lower speeds - which invariably involves capacity reductions. On the other hand, high speed trains do not run on conventional lines.



The German and Italian systems are examples of type 4 which permits all types of train run on the high speed lines and the high speed trains run on all types of lines.

4.5 Selection of High Speed System :

The decision on the type of traffic is very important, for it has immediate and basic consequences for the route of the track, the maximum, permissible axle loads, the conditions and the equipment for operation and maintenance. The co-existence of freight traffic and trains with speeds higher than 300 km/h can pose capacity problems, but also involve serious constraints of the geometry because of the limitation of cant deficiency.

This initial finding affects the comparative analysis of the parameters of the line. Such is the case with the maximum gradient, where there is a very large margin of variation, between 12.5 and 40%0 which clearly shows that it is impossible to fix a recommended value, because the traffic and the hills of the region that a new line passes through may play a major role in the decisions taken.

Heavy freight trains require modest gradients (10 a 12%0) if ordinary locomotives are to be used. This would cause a very rigid and non-flexible alignment, both horizontally and vertically. There would be substantial need for bridges, high embankments and tunnels, depending on the topography of the landscape. The cost may increase so much that the project would be unprofitable from the social-economics point of view. Due to the rigid alignment the project would also run the risk to cause excessively large infringements in nature and culture environments. The project could therefore be politically questioned.

Finally once the criteria for the maximum speed have been fixed, the parameter essential to determine the other geometric characteristic is the cant deficiency (in the absence of consideration that are sufficiently validated for the use of speeds greater than 300 km/h for vehicles fitted with tilting suspension systems).Tilting Trains are not very popular now a days.

However, it is conceivable, in principle, to design tilting trains in the future for speeds above 300 km/h which could operate on the high speed lines with larger cant deficiencies than are allowed for conventional high speed trains.

It would, therefore, be interesting to consider two questions in detail:

(1) What would be the characteristics of a high speed line for 350 km/h designed for operation WITHOUT TILT or with tilting trains.

(2) What should be the technical characteristics of high speed tilting trains.

The importance of these considerations comes from the fact that the construction of lines with low radii in plan is less expensive as far as the civil engineering structures are concerned, especially when the line is built in the context of a very limiting topographical system. However the tilting Technology is not something that the major high speed rail operation can agree upon.

4.6 Why a passenger corridor in India ?

While deciding about type of High Speed Corridor to be built in India ,four kinds of different conditions can be looked at:

1. Track for all types of trains, including heavy freight trains
2. Track for high-speed Passenger trains, conventional Mail/Express Trains and light freight Trains.
3. Track for high-speed passenger trains and conventional Mail/Express Trains only
4. Track for high-speed Passenger Trains only

High speed trains and heavy freight trains have different demands on track standards concerning horizontal alignment, cant, gradients and vertical curves.

The reasons for constructing entirely new lines for exclusive operation of high speed passenger trains are not far to seek. By segregating freight trains from such lines, increase in the capacity of the high speed line is achieved as follows:

(1) This would allow the speed conflict to be resolved, viz. a very high speed train would otherwise affect the path of 3 or more goods trains, if both types of trains were to run on the same track.

(2) Studies conducted in Europe, for rail failures and deterioration of Track geometry under both passenger and freight traffic suggested that it would be impossible to maintain the high standards needed for running at speeds above 200km/h on

tracks that were also carrying locos with axle load of 23 ton. (on the TGV, axle loads are restricted to 17tonne only).

There is only one speed for a particular curve for which super elevation would be correct. For example on a curve of radius 4000m on a Standard Gauge track, goods trains running at 80km/h would need an equilibrium cant of only 19mm, whereas high speed passenger trains running at 300 km/h would required an equilibrium cant of 265mm. Both these requirements cannot be met by providing an intermediate value of cant, without exceeding the permissible limits of both Cant deficiency and cant excess. For the above said reasons, the Japanese Railway decided to lay entirely new lines for their Shinkansen High Speed lines which were built on Standard Gauge. Similarly the SNCF also chose to lay a new line between Paris and Lyon for their TGV operations.

Separation of goods traffic from passenger traffic has been justified in above paragraphs.

Now the question arises whether to make an exclusive high speed passenger corridor in India, only for plying of very high speed passenger trains at a speed of 350 kmph or design the track geometry in such a way as to facilitate plying of present mail/express trains also on the same corridor. Mixing of any type of goods train light or heavy may not be desirable from the maintenance point of view.

As we know construction of high speed corridor will cost a huge sum for the Indian Railway. Initially in a first few years the traffic demand may be met only by running a couple of pairs of high speed train, thus leaving huge line capacity unutilized. It will be therefore desirable to divert most of present mail/express train running/ passing between the two stations on to the high speed passenger corridor and utilizing left over path on conventional routes by running more goods trains. This strategy will help in justifying the economics of more and more high speed corridors in India specially between the two major cities about 500 kms apart between which traffic on existing routes are oversaturated.

However this intermixing of high speed trains with present mail/express trains will compel to adopt more horizontal curve radii thus increasing the cost of construction. With the passage of time as the requirement of number of high speed trains increases, it can be introduced by re-diverting conventional mail/express trains to their old routs if capacity permit so.

In India, therefore, it is desirable to adopt a high speed passenger train corridor with maximum speed potential of 350kmph along with running of present mail/express train at a minimum speed of 140 kmph without freight trains.

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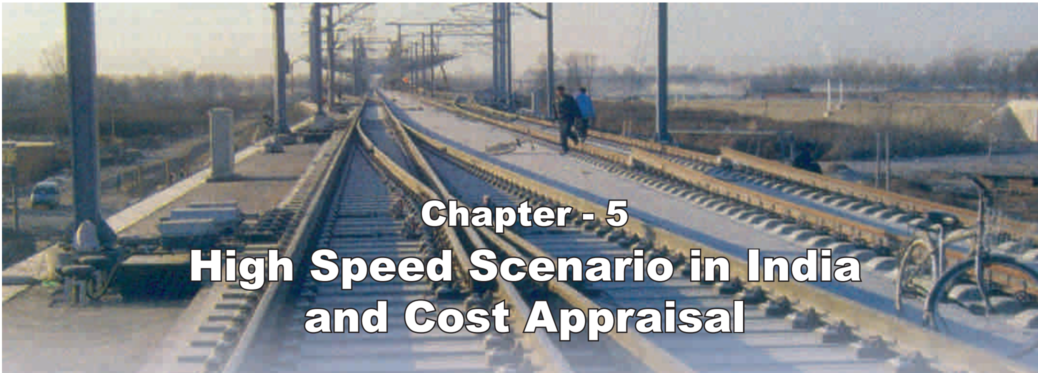

Chapter - 5
High Speed Scenario in India and Cost Appraisal

5.1 Introduction:

In India, a thought for high speed operation was given in the first Governing Council Meeting (GCM) of RDSO in 1988 when it was decided to develop technology for operation of passenger services at 160 kmph on specified mixed routes and at 200 kmph on dedicated routes. A Task Force was set up in RDSO to study all the aspects of introduction of high speed technology. In this connection, a feasibility study was conducted with the help of a Japanese Company (JICA) for Delhi-Kanpur section via Agra (448 kms) to run the trains at 250 kmph. Report was submitted in 1987. JICA recommended setting up a new corridor with terminal stations at Delhi, Agra and Kanpur with an anticipated cost of Rs.2200 crores at 1987 price indices. Two types of services as given under were suggested in the study report.

- Super express train at maximum speed to 250 kmph on new corridor of Delhi-Agra-Kanpur and
- Long distances express trains operating at 160 kmph to utilize dedicated track with facility of getting in and out of new corridor at Agra and Kanpur.

A detailed questionnaire requiring answers from manufacturers, maintenance teams and operators of high speed railway system was prepared by RDSO. Following three corridors were considered for the high speed services. :

i. Mumbai Vadodara-Ahmedabad (492 kms.)

ii. New Delhi – Kanpur – Lucknow (507 kms.)

iii. New Delhi – Agra (199 kms.)

Detailed studies for anticipated traffic on these routes were also done and based on these detailed studies. Mumbai-Ahmedabad section was found having the best potential. However, cost being very high (Rs.4.9 crores per km. in 1987); if upgraded to the present day cost. It would come out to be about

Rs.50 crores per km. Board closed the mission vide their letter no. 98/ER/3400/21/1 dated 28.03.01 addressed to RDSO.

Indian Railway is now again considering going for high speed. The Integrated Railway modernization plan Nov.2004 for the period 2005-2010 envisages high speed trains running at 250-330 kmph. Ahmedabad-Mumbai corridor was specifically identified for the feasibility study. In this regard, RITES Ltd., has carried out a feasibility study and financial appraisal for Mumbai-Ahmedabad corridor.

Hon'ble MR also envisaged development of high speed passenger corridor in his Budget speech in February,2007. The then CRB in his message to railway men after taking over has stated in the future strategy and plans for Indian Railways as -

"Pre-feasibility studies for construction of high speed Dedicated Passenger Corridors (one each in Northern, Western, Southern & Eastern regions of the country) to run high speed (300-350 km/h) passenger trains".

As quoted by Indian Express in January 2008, Indian Railways is buoyed over the fact that not only have nine state governments shown interest in it, they have even suggested as many as 16 routes, spread over 5,400 km, for constructing such corridors.

While Maharasthra, Karnataka, Tamil Nadu, Gujarat, Delhi, Haryana, Punjab, Andhra Pradesh and West Bengal are learnt to have formally expressed interest in the project, others like UP, Rajasthan, Gujarat, Kerala, Bihar and Jharkhand too are testing the water. Some of the routes suggested by the states include Mumbai-Ahmedabad (492 kms.), Bangalore-Mysore (140 kms.), Chennai-Coimbatore (497 kms.), Delhi-Chandigarh 240 kms.), Hyderabad-Bangalore (763 kms.), Vijayawada-Vishakhapatnam (351 kms.) and Howrah-Haldia (80 kms.).

The states formally expressing interest have also accorded "in principle' approval for the pre-feasibility studies needed. From the beginning, the Railways was keen that State Governments share the cost of pre-feasibility studies on the project, which is expected to take a minimum of two years.

5.2 Need for High Speed Rail Corridors:

1) It is seen that high-speed rail corridors are competitive to air traffic up to a distance of 600 km.
2) It is a safer mode of transport in comparison to road and air transport.

3) It is environment friendly.

4) Comfort level is much higher

5) It has been accepted as an intercity mode of transport in highly industrialized regions in Europe and Japan. Many other countries have also taken lead in this field. These are Taiwan, Korea and China.

6) Being the fastest growing economy after China and being projected as a financially very strong economy by 2020, India can not afford to fall back in developing HIGH SPEED DEDICATED CORRIDOR.

7) A recent McKinsey report suggest that by 2025, India will be the world's fifth largest economy after the USA, Japan, China and the U.K. By then the number of house holds earnings Rs.2 lakhs to Rs.10 lakhs a year (at the price level of year 2008) will increase from 5 crores to 58 crores.

8) Union cabinet has approved development of DELHI-MUMBAI INDUSTRIAL CORRIDOR along Dedicated Freight Corridor in the next 7 to 8 years where in investment of about 100 billion $ is expected.

By constructing these corridors, the Railways hope to win back clientele that has migrated to low-cost airlines in recent times. A rough surveys done on the Mumbai-Ahmedabad and Delhi-Amritsar routes indicate that a high-speed train would attract enough ridership. Further, the Railways are keen to market the idea as an important instrument in the battle against carbon emissions. The Indian Railway's preliminary estimates suggest that a High-speed Rail consumes 0.933 litres per passenger of fuel per 100 km travelled, in comparison to the 4.04 litres consumed by an airplane and 5.69 litres consumed by an economy car.

The estimates further indicate that if one were to commission Mumbai-Ahmedabad High-Speed Passenger Corridor in 2008, it would result in taking, 2,36,000 cars and 74,000 buses off the roads by the year 2013.

However, the exorbitant costs involved in setting up the infrastructure for the project has many worried in the Ministry. Rough estimates suggest an expense of Rs.30,000 crores (excluding the cost of land) for every 500 kms. at the 2008 price level.

5.3 The challenge for the transportation sector in India:

- Reduce consumption of oil.
- Reduce congestion and air and noise pollution in urban areas.
- Provide fast passenger travel at fares affordable to the mass of the users.
- Reduced journey time to minimise use of working/business hrs for journey
- 30% Urban population can afford to travel by high speed trains.
- Fast inter-city travel (in less than 3 hr))for distances up to 500kms.
- Transportation capacity is likely to increase by about 5 times in the next 25 years.

To meet these challenges, the option for increasing speed and capacity is dedicated high speed passenger corridors, (300 to 350 km/h) and also the option is to upgrade the existing lines for speed upto 200km/h with conventional stock and 250 km/hr with tilting trains.

The high speed project is a very high techno economic project requiring huge financial resources. Therefore, Indian Railway has to go for a balanced approach. However, going for high speed is a demand of the time specially when India is going through an era of high economic growth. Hence, Indian Railway cannot lag much behind the other advanced world railways. Such a project would also give excellent exposure to Railway engineers of higher technology. It would also benefit in upgrading the maintenance standards of the existing conventional track. Therefore, it would require a very close interaction amongst civil engineers in particular and with other departments of the railways and the rail users in general.

Major challenges for civil engineers would be in laying, maintaining and monitoring the high speed track. Construction of embankment would require special attention. Planning and designing the high-speed corridor would require very detailed and in-depth study. However, it is hoped that with desired will, determination and cooperation of all concerned, Railway engineers would rise to the occasion to deliver the required results.

5.4 Cost of Constructing New High Speed Corridor (300-350 kmph)

For 8000 km of high speed rails have been laid in the world till the middle of year 2008, the cost of the same updated to 2008 is approximately 170 billion Euros and the rolling stock 36 Billion Euros. As per the international standards the approximate cost of constructing new H.S. corridor is as under:

Item	Cost (Million Euros)/km	Cost in Crore Rs./km
Infrastructure (Stns., maint. Facilities etc.	12	60
Track (Formation incl. Ballastless)	3.5	17.5
Electrification	2.0	10.0
Safety & Signalling	2.5	12.5
Total	20	100
Rolling Stock	2 per coach or 40,000 Euro per seat	10 per coach or Rs.20 lakh per seat

The cost depends on several factors, like topography, extent of built up area through which the lines traverse, the standard of access provided at the stations/terminus etc. and can be reduced to about 60% by judicious selection of infrastructure and standard of specifications. It may be in the range of Rs.60-100 Crores per km and additional for special coaches @ Rs.10 Cr. Per coach.

The cost of HSR line between Beijing Shanghai is Rs 90 to 100 crores per km (due to major portion constructed as elevated track).

The cost of making High Speed line for a speed of 350 kmph is much higher vis-à-vis cost of upgrading lines for a speed of 200kmph. However since existing railway lines are saturated and traffic is going to increase many fold. Construction of many new railway lines is inevitable. It is therefore better to have some of them as High Speed Corridor in India.

5.5 Feasibility study of Mumbai-Ahmedabad high speed corridor:

RITES have conducted the feasibility study for Introduction of High Speed Railway from Ahmedabad to Mumbai (492 km) and submitted its report to Railway Board in October 2005.

Cost Estimates and financial appraisal of the Project has been incorporated in the RITES's report. A brief of the same is reproduced below. For more detailed information RITES's report may be referred to.

5.6 Construction and rolling stock cost:

The estimate of initial cost of construction excluding maintenance cost, replacement cost and cost of addition of rolling stock after commissioning is summarized in Table below:

The estimate of initial cost of construction excluding maintenance cost, replacement cost and cost of addition of rolling stock after commissioning is summarized in Table below:

5.6.1 Capital Cost:

		(Rs.Cr) at 2005 price level
Sr.No.	**Items of Cost**	**Cost**
1	DPR & Tender Documents	218.30
2	Land	7532.38
3	Civil	6485.50
4	S&T	2722.89
5	Electrical	1990.34
6	Taxes	109.15
7	Contingencies	592.72
8	Initial year's Rolling Stock Procurement	700.47
	Total:	**20351.75**

5.6.2 Rolling stock Cost:

Number of trains has been worked on the assumption of 766 passengers per train and it is further assumed that each rake would make 3 trips each way per day.

Number of rakes alongwith the cost as and when required to haul the projected traffic over the project life have been interpolated between the horizon years and to avoid the overloading. Cost of one rake is 91.8 crore.

5.7 Maintenance and Replacement Costs:

5.7.1 Infrastructure (Civil Engineering):

Annual maintenance cost of civil engineering works beyond Defect Liability Period was estimated at Rs.100 Crores based on mechanised maintenance being proposed for new lines on Indian Railways.

5.7.2 Signalling and Telecommunication:

Annual maintenance cost of beyond Defect Liability Period was estimated as Rs. 0.21 crores based on mechanised maintenance being proposed for new lines on Indian Railways.

Replacement cost for signalling works was computed based on asset life of 25 years, as Rs. 1998 Crores in year 2035-36. The replacement cost for telecommunication works based on life of 13 years is Rs. 208 Crores by year 2023-24 and Rs. 208 Crores by year 2036-37.

5.7.3 Electrical works and Rolling Stock:

Annual maintenance cost of beyond Defect Liability Period was estimated as Rs.44.27 Crores for electrical works and Rs.22 Crores for rolling stock.

5.7.4 Residual and replacement cost of Rolling Stock:

For estimating the residual life at the terminal year (2040-41), the straight-line depreciation method has been followed.

In addition to the residual value the salvage value @10% for civil, S&T, electrical and 20% for rolling stock has been considered. Likewise, the replacement cost has been worked out only for such of the assets whose economic life is less than the project life of 30 years and the same have been duly accounted for in the appraisal.

5.8 Financial Appraisal of Ahmedabad – Mumbai high speed corridor:

5.8.1 The financial appraisal of High Speed Rail corridor between Mumbai and Ahmedabad has been carried out by RITES from the implementing agency's point of view viz., Indian Railways. Because the proposed High Speed Corridor is dedicated to passenger traffic, capacity released on the existing corridor has also been taken into consideration in the financial appraisal.

5.8.2 All the costs and benefits that would accrue to the Railways viz. the implementing agency have been identified, and their values have been quantified as per base year prices (2004-05).

The project period considered for financial appraisal is 36 years (2005-06 to 2040-41) comprising five and a half years of high speed corridor construction and 30 years of operation period.

The cost to be incurred on the project comprise the cost of construction of the high speed rail link (including its S&T and Electrification components), Rolling stock and Operation & Maintenance costs.

The project benefits would be earnings that would accrue from running of the projected passenger traffic on high speed corridor as direct revenues. However, because of surplus capacity created on the high speed corridor, it would be possible to divert certain passenger trains running on congested existing route onto this corridor, thereby releasing capacity on the existing route to cater to the running of additional freight trains resulting in the increase in the freight earnings to Indian Railways. Against the above backdrop the financial viability of the project has been adjudged under the following two options:

· **Option I** Relates to the situation when earnings accruing from movement of High Speed Passengers only are considered.

· **Option II** Relates to the situation when incremental costs and earnings as a result of movement of additional freight traffic on the capacity released on the existing corridor are also considered in addition to high speed passenger traffic earnings due to shifting of some Mail/express trains from existing corridor to high speed corridor.

The traffic projections at the rate of 5% per annum has been considered. For the purpose of the appraisal the passenger projections have been considered for 20 years from the date of opening of the high speed corridor, thereafter the traffic has been assumed to be stabilised.

5.9 Financial Internal Rate of Return:

(Option I):

All the costs and benefits that would accrue to the implementing agency solely on account of running of the High Speed trains on the proposed High Speed corridor between Mumbai – Ahmedabad have been considered on year to year basis. As stated earlier, all items included in costs and benefits of the projects are estimated at constant prices (Financial Year 2004-05 prices). In other words, throughout the analysis period, prices are kept at constant values, without any adjustment for inflation or demand-supply factors. The Discounted Cash Flow technique has been adopted to arrive at the Financial Internal Rate of Return (FIRR) of the project. The financial internal rate of return (FIRR) of the project under Option I works out to 1.9%.

(Option II):

Financial Appraisal under this Option has been carried out by considering the net benefits that would accrue to Indian Railways on account of running of the High Speed trains and additional freight trains on the capacity released on the existing corridor.

High speed corridor would create additional paths on the existing corridor by diverting the fast moving passenger trains on the proposed high speed corridor because of which existing corridor would be able to cater to more freight trains.

The financial internal rate of return (FIRR) of the project works out to 3.2%.

5.10 Sensitivity Analysis:

An in-depth sensitivity analysis has been carried out to adjudge the effect of increase in number of passengers and fare rate on FIRR under both the options. Since the project FIRRs in both the options are not feasible, therefore, sensitivity analysis has been evaluated to test its worthwhileness from the viability point of view. In this case, either no increase in capital cost or reduction in projected passengers has been carried out which would further lower down the FIRR. One aspect has also been evaluated by assuming the situation if land is available free of cost through govt.

Change in FIRR (%)

	Fare @ Rs 3 Per PKM		Fare @ Rs 5 Per PKM	
	Option I	Option II	Option I	Option II
Increase in Passenger Traffic				
No increase in traffic	1.9	3.2	4.3	5.4
10% increase	2.3	3.6	4.9	5.9
20% increase	2.6	3.8	5.3	6.3
30% increase	3.0	4.2	5.9	6.8
40% increase	3.3	4.4	6.2	7.2
50% increase	3.6	4.7	6.7	7.6
Without land cost	3.1	5.0	6.7	8.2

It can be seen from the above table that even if subsidy in capital cost in the form of grant for land which accounts almost 37% of the capital cost, the project does not turn out to be viable.

5.11 Conclusion :

The Proposed project of developing a High Speed rail corridor between Mumbai – Ahmedabad (492 km) yields a FIRR of 1.9% under option I viz., when the net benefits of the running of high speed passengers is only considered but it gets slightly improved to 3.2% under option II when the earnings on account of additional freight operations on the existing corridors is taken into account. As the return is low and the market rate of interest for long term loans may vary from 9% to 10% p.a., the project is not found viable for implementation. However, if budgetary support from Government of India and grants from respective State governments in incurring majority of expenditure on infrastructure cost is provided, the project could be implemented. Such projects do need government subsidy in initial stage.

Financial appraisal of Mumbai-Ahmedabad High Speed Corridor given by RITES reflects a return of only 3.2% However traffic projection assumed by RITES is seems to be on conservative side. With present growth scenario by 2030 passenger traffic is likely to rise to 5 fold and freight traffic to 7 fold from the current level. It means that the line capacity created through constructing High Speed Corridor will be full utilized, if not by running sufficient number of High Speed train, then at least by diverting/introducing mail express and Rajdhani Shatabdi Trains.

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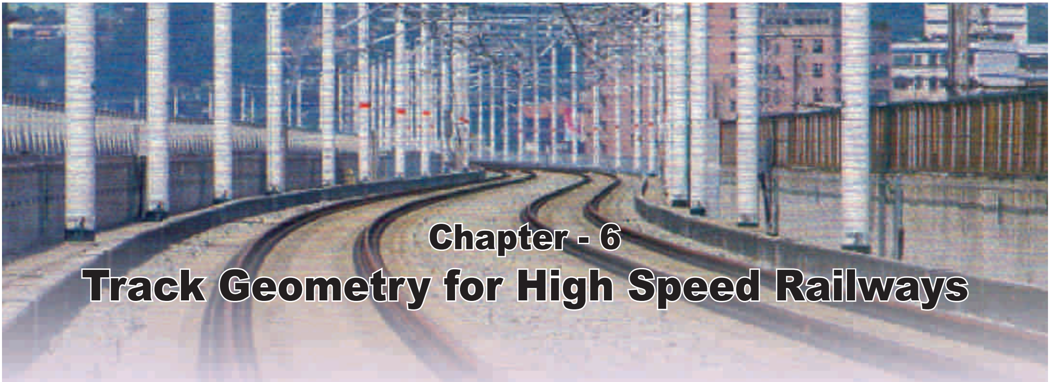

Chapter - 6
Track Geometry for High Speed Railways

6.1 Introduction:

Among the consideration for high speed railway corridor, One of the first subjects to be considered is the "reserve of speed" that all (or nearly all) new lines have from the point of view of the route of the infrastructure. It appears wise to keep this margin for the future because of the different life of all the parts involved in the operations of a high speed system.

The consideration of the type of traffic is very important, since it has immediate and basic consequences on the route of the track, on the maximum axle loads permitted and on the conditions and the equipment for the operation and the maintenance.

From this point of view, the co-existence of freight traffic and trains which travel at speeds above 300 km/h does not appear to the very desirable, because of the possible problems with capacity and excess cant.

In view of this, it is very difficult to recommend values for the route parameters. The traffic and the presence of hills play an important role in the decisions that have to be taken for this.

This Chapter deals with a literature survey where a short introduction is given for track geometry and track/vehicle interaction. After the introduction, a survey over the present standard and practices in Europe and Japan is made. In particular the recent proposals for a common European standard (CEN) and TSI (Technical Specification for Interoperability) are reviewed. Suggestions for adopting track geometry parameters in Indian Railway is also incorporated. It is required for Indian Railways where only Broad gauge system is desired.

The purposes of the Technical Specifications of Interoperability (TSI) is:

- to specify the essential requirements for the subsystems and their interfaces,
- to establish the basic parameters that are necessary to meet essential requirements,

- to establish the conditions to be compiled with, to achieve the specified performances for each of the following categories:
  lines specially built for high-speed,
  lines specially upgraded for high-speed,
  lines specially built or upgraded for high-speed, which have special features as a result of topographical, relief or town-planning constraints,
- to establish possible implementing provisions in certain specific cases.

Furthermore, according to TSI, the performance levels of high-speed trains can also be enhanced by adopting specific systems, such as vehicle body tilting.

In Sweden does exists a regulation called Banverket regulation BVF 586.41[5] and a handbook, BVH 586.40[4] concerning track geometry parameters. The regulations is mandatory while the handbook is informative. The regulation is called BVF while the handbook is called BVH.

In the following paras different track geometry parameters are discussed and values adopted and or recommended by different regulations and leading high speed countries are compared. All these values are for standard gauge. There is no experience available with B.G. Accordingly values to be adopted for Indian B.G. high speed corridor are also arrived and recommended.

6.2 Design track geometry:

Track geometry is very important for the behavior of vehicles. In this section an introduction to the most common quantities of track geometry will be presented. These quantities are:

a) Track gauge
b) Track cant
c) Cant deficiency and cant excess
d) Rate of cant and rate of cant deficiency
e) Transition curve and super elevation ramp
f) Horizontal curve radius
g) Gradient
h) Vertical curve radius

6.3 Track gauge:

Every high-speed rail system pioneer in running high speed trains in the world have 1435mm designed track gauge called STANDARD GAUGE.

In India Broad Gauge track is 1673mm, therefore same gauge is desired to be opted for high speed track also for better utility and interchangeability of trains from high speed track to conventional track and vice versa.

6.4 Track cant:

Cant or super elevation is the amount by which one rail is raised above the other in a curve. In a very highly canted curved track, it is possible that the vehicle standing or traveling over the curve at a very low speed may overturn about the inner rail. Such overturning can occur on account of the combination of the following adverse factors:

a) absence of centrifugal force due to very slow speed causing substantial off loading of the outer rail

b) wind pressure blowing on the vehicle towards the inside of the curve

c) Vibration and other disturbing forces

6.4.1 Consideration of over turning:

The worst case is when the vehicle is stationary. Taking movement about the inner rail

$$\frac{Ca}{G} = \frac{G}{2H}$$

where Ca = cant

G =Dynamic Gauge (=1500mm for standard gauge and

=1750mm for Indian BG).

H = Ht of C.G. of vehicle over rail level= 1676 mm for B.G. Indian Coaches.

Taking a factory of safety of 3 against wind pressure and other minor disturbing forces.

$$Ca = \frac{G^2}{6H} \quad = 304 \text{ mm for B.G. Tank}$$

However, before the condition for over turning around the inner rail are reached, it is more likely that derailment by wheel climbing would occur if the train is moving.

6.4.2 Consideration of maintainability:

Maintainability of a canted track is yet another important factor, which determines the limiting values of cant that can be provided. It has been generally recognized that from consideration of maintainability on lines which are meant to carry only one typed traffic viz high speed passenger lines, maximum cant shall be limited to G/8. At 180mm cant, it was considered possible to maintain fairly easily the ballast slopes between the 2 tracks of a curved double line section. Thus maximum permissible value of cant worked out to be 187mm for standard gauge and 218mm for B.G.

6.4.3 Limiting values of cant due to consideration of overturning due to wind, vibration, etc:

The Table 6.4.3 indicates the calculated minimum wind velocity which will overturn the coach in a curve, considering the effect of car vibration acceleration equal to 0.1g as recommended by UIC at speeds 80 km/h and above.

Table: 6.4.3 Wind velocity (m/sec) to overturn the train on standard gauge

Radius (m)	3500		4000	
Cant (mm)	C_a=180		C_a=180	
Train speed (Km/h)	Overturn to inside	Overturn to outside	Overturn to inside	Overturn to outside
V=0(Stopping)	41.0	54.7	41.0	54.7
V = 80	35.8	49.3	35.6	49.5
V=160	39.0	46.8	38.5	46.8
V=200	41.2	45.0	40.5	45.7
V=250	44.4	42.0	43.5	43.0

It can be seen from the above table that the minimum wind velocity required to overturn the vehicle inside the curve is 35.6m/sec (129 km/h) and35.8m/sec (129 km/h) on curves of radii 4000m and 3500m respectively. These wind speeds are fairly high and hence can be considered rare enough to cause trouble in train operation. The minimum wind speed required to overturn the coach outside the curves are still higher viz 43m/sec (155km/h) and 42m/sec (151 km/h) on curves of radii 4000m and 3500m respectively when trains are traveling at the maximum speeds of 250 kmph. From this analysis, it is clear that a maximum cant of 180mm on standard gauge can be safely provided without fear of the coaches being overturned either towards the inside or outside the curve by high winds.

6.4.4 Consideration of Derailment:

With curves having very large radii as provided on high speed corridors, the curving forces were not expected to be large and hence there was no danger of unfavorable Y/Q leading to derailment of the leading outer wheel of a bogie, even if a train was traveling very slowly on a highly canted curved track with resultant offloading of the leading outer wheel.

6.4.5 Consideration of Comfort:

At 180mm cant on standard gauge track, passengers do not feel uncomfortable when the train is stationary or moving at a slow speed.

According to the TSI the cant for new high-speed lines in the design phase shall be limited to 180mm . Further the TSI says that for tracks in operation, a maintenance tolerance of 20mm is allowed, without trespassing a maximum cant of 190mm. This value may be raised to 200mm maximum on tracks reserved for passenger traffic alone in accordance with the specifications in the CEN provisional standard on maximum limiting value.

Table 6.4.5 shows values of cant according to CEN.

Table: 6.4.5 Limiting values of cant According to CEN

Traffic categories	Mixed traffic lines designed for passenger train $200<V\leq 300$	Mixed traffic lines with passenger train $V \leq 230$ (or 250 on upgraded lines) with vehicles incorporating special technical design characteristic	High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting value [mm]	160	160	160
Maximum limiting value [mm]	180	180	200

On the Shinkansen lines (Japan), maximum cant adopted is 180mm.

According to Banverket (Sweden) cant shall not exceed 150mm.

In India, maximum permitted cant for existing B.G. track is 165mm. Considering the values for S.G. track, for High Speed B.G. track a cant of 200mm may be adopted. However in exceptional cases 220mm may be considered.

6.5 Cant deficiency and cant excess:

The cant deficiency continues to be the essential parameter to fix the geometric characteristics of the route, once the maximum speed is established.

Equilibrium speed of a train is the speed at which the effect of centrifugal force is exactly balanced by the cant provided. Corresponding cant for a given radius of curve and given vehicle speed (v) is called equilibrium cant (Ceq)

For standard gauge Ceq = $\frac{11.8V^2}{R}$

For Broad gauge Ceq = $\frac{13.76V^2}{R}$

Where V is train speed in kmph

And R is the radius of horizontal curve in meters

It is not possible to provide actual cant equal to equilibrium cant due to various constraint.

For several reasons, fully compensated track plane acceleration can not be achieved in all cases.

Not all trains have the same speed, therefore, it would not be possible to achieve fully compensated lateral accelerated for all trains anyway. It is a possibility that a train stops or runs slowly in a curve. Therefore, the maximum cant has to be limited. It is then desirable to allow a cant deficiency i.e. a certain amount of uncompensated lateral acceleration ay remains in the track plane.

6.6 Cant deficiency:

When the actual cant provided is less than the equilibrium cant C_{eq}, cant deficiency arises. The cant deficiency is the additional cant that is needed to achieve equilibrium cant. Cant deficiency C_d is the difference between equilibrium cant C_{eq} and actual cant C_a and is thus determined by the following equation.

$$C_d = C_{eq} - C_a$$

6.6.1 Safety against over turnings:

When a train is traveling on a curve at a speed higher than the equilibrium speed for that curve, the excess or unbalanced outward lateral acceleration will tend to overturn the vehicle around the outer rail. It can be proved that on the considerations the maximum cant deficiency permissible will be $\frac{G^2}{8H}$, assuming a factor of safety of 4 against overturning. Where

G=dynamic gauge, H= Height of C.G. of the vehicle above rail. This would work out to a value of C_d = 228mm for B.G. (G=1750) H = 1676mm for BG coaches in India. Safety against derailment: Field study conducted by RDSO (Refer C&M Report No.1 & C-138 of RDSO) have shown that for B.G. C_d upto 150mm could be permitted without danger of derailment.

6.6.2 Maintainability and Comfort:

Higher C_d is more difficult to maintain due to unbalanced forces. C_d is an index of discomfort felt by the passengers and on this score only, through out the world, limits of cant deficiency have been set based on the studies, the UIC (Union of World Railways) in their Master Plan for the European Railways have specified that the (unbalanced) lateral acceleration (P) should be with in 0.4 to 0.7m/Sec^2. It is desirable to limit the lateral acceleration to the lower value of 0.4m/sec^2.

$\Delta P = \frac{C_d}{G}$ .g where C_d is cant deficiency in mm.

G = acceleration due to gravity (=9.8m/sec^2)

C_d is worked out for B.G. is 71mm to 125mm and for standard gauge it is 61mm to107mm.

6.6.3 Standard adopted by different countries:

Table below shows the permissible cant deficiency and its corresponding lateral acceleration for three different categories of rolling stock according to Banvedrket (Sweden).

Permissible cant deficiency and the corresponding lateral acceleration

Train category Deficiency (mm)	Permissible cant (m/s^3)	Lateral acceleration, a_y
A	100	0.65
B	150	0.98
S	245	1.60

The different train categories have the following meaning.

- Category A - conventional vehicles with older running gear and freight trains;
- Category B – vehicles with improved running gear, according to approval.
- Category S – vehicles with improved running gear and car body tilt system.

In Germany different train categories are not used in the same manner as in Sweden. A classification is used where values are prescribed with or without permission. Design values for equilibrium cant according to German standards are shown in Table 6.6.3 :-

Table : 6.6.3 Design values of equilibrium cant, Actual Cant and Cant Deficiency

Without permission	**Equilibrium cant**
Recommended	C_{eq} = 170mm
Limit	C_{eq} = 290mm
Without permission	**Actual cant**
Recommended	Ca = 100mm
Limit	Ca = 160mm(ballast track) Ca = 170mm(ballastless track)
Exception (permission necessary)	160mm<Ca<=180mm (ballast track) 170mm<Ca<=180mm (ballastless track) Ca> 180mm
Without permission	**Cant deficiency**
Recommended	C_d= 70mm
Limit	C_d= 130mm
Exception (permission necessary)	C_d= 150mm

In France (SNCF) Experiment shows that the non compensated lateral acceleration should not exceed 0.10g to 0.15 g (1.0 to 1.5 m/sec2) according to comfort requirements. SNCF allows a cant deficiency of 150mm (exceptional value 160mm).

At SNCF the limiting value of cant is about 160mm and exceptionally 180mm. A cant of 180mm was utilized as limiting value at the high speed line Paris-Sud Est.

6.6.4 Standard suggested by TSI:

According to TSI the limit values of cant deficiency on plain track is given in the table 6.6.4 (a), (b), (c).

Table 6.6.4 (a) : Cant deficiency for lines specially built for high-speed without tilt (TSI)

Speed range (km/h)	Limiting value (mm)
$250 \leq V \leq 300$	100
$V > 300$	80

Table 6.6.4 (b) : Cant deficiency for lines specially upgraded for high-speed and connecting lines (TSI).

Speed range (km/h)	Limiting value (mm)
$V \leq 160$	160
$160 < V \leq 200$	150
$200 < V \leq 230$	140
$230 < V \leq 250$	130

Table 6.6.4 (c) : Cant deficiency for lines specially built or upgraded for high-speed involving very strict topographical constraints for H.S. trains without tilt (TSI).

Speed range (km/h)	Maximum limiting Value (mm)	Cant deficiency range for which the length of curve is limited to 20% of the total curve length (mm)
$V \leq 160$	180	$160 < C_d \leq 180$
$160 < V \leq 230$	165	$150 < C_d \leq 165$
$230 < V \leq 250$	150	$130 < C_d \leq 150$
$250 < V \leq 300$	130	$100 < C_d \leq 130$

6.6.5 CEN Provision:

According to the CEN standard the values of cant deficiency and its corresponding lateral acceleration are based on the following considerations:

- Track forces and safety;
- Economic aspects of track maintenance
- Ride comfort and roll flexibility coefficients of the vehicles

Table 6.6.5 lists the limiting values of cant deficiency in accordance to CEN standard.

Table 6.6.5 : Limiting values of cant deficiency for high speed trains without tilt

Traffic categories		Recommended limiting value [mm]		Maximum limiting value [mm]	
		Freight	Passenger	Freight	Passenger
Mixed traffic lines designed for passenger trains $250 < V \leq 300$	$200 < V \leq 300$	100	100	150	150
	$250 < V \leq 300$	80	80	130	130
Mixed traffic lines with passenger trains $V \leq 230$ (or 250 km/ on upgraded lines) With vehicles incorporating special technical design characteristics	$V \leq 160$	110	160	160	180
	$160 < V \leq 200$	X	140	X	160
	$200 < V \leq 230$	X	120	X	160
	$230 < V \leq 250$	X	100	X	150
High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$	$V = 250$	X	100	X	150
	$V > 250$	X	80	X	130

It is always desired to lay a new line exclusively for high speed passenger traffic. It is possible to see a tendency to reduce the value of the cant deficiency as the speed increases with a view to ensure more safety for high speed trains.

In light of the values mentioned in above paras for standard gauge, it will be advisable to limit Cd on B.G. section to 100 for high speed corridors in India. However exceptional a value of 125mm may be adopted.

6.7 Cant excess:

Cant excess (Ce)represents the unbalanced in word lateral acceleration if a train moves at lower speed than the equilibrium speed. Same discomfort criteria as for cant deficiency should be applied in this case also for a high speed route exclusively for passenger traffic.

According to Banverket (Sweden) cant excess should not be larger than 100mm on tracks with radius larger than 1000m. On tracks with radius less than 1000m cant excess should not exceed 70mm.

SNCF allows a cant excess of 70 to 100mm (exceptional values between 105 and 135mm), in dedicated high-speed operations, without freight trains).

The TSI does not discuss cant excess. However, CEN provisional standard gives as guidance, the following limiting values for cant excess:

- 110 mm as recommended limiting value;
- 130 mm is a maximum limiting value.

In India value of cant excess (Ce) permitted for existing B.G. track is 75mm. However this value is basically for freight train running. On High Speed Corridor for slowest mail/express train a value of 100mm may be adopted safely. However under exceptional circumstances it may be increased to 150mm.

6.8 Rate of cant and rate of cant deficiency

Rate of cant deficiency (rcd) describes the change of lateral acceleration (in the track plane) as a function of time. Another word for rate of cant deficiency is lateral jerk.

It is also called the rate of change of unbalanced outward/inward lateral acceleration. It also has a direct bearing on passenger comfort. The desirable limit is 0.02g /second; though in exceptional cases, a higher value of 0.03g/second can be permitted. Incidentally, these values are adopted for existing B.G. track in India.

Dp/ second = (Cd.g)/G per second

where Dp = unbalanced lateral acceleration

Cd = Cant deficiency

g= acceleration due to gravity

G = dynamic gauge (=1750mm for BG and 1500mm for standard gauge)

For Broad Gauge :

Cd per second = 0.02g x 1750/g

Cd per second = 35 mm/second

Exceptionally this figure can go up to 0.03 x 1750 = 52.5 mm/second

For standard gauge :

Cd per second = 0.02g x 1500/g

Cd per second = 30 mm/second

Exceptionally this figure can go up to 0.03 x 1500 = 45 mm/second

It can be seen that for same rate of change of unbalanced lateral acceleration the values work out are different for B.G. and S.G. Values for B.G. are higher than that of S.G.

All out effort should be to work within the desirable rate of change of cant deficiency (cd) i.e. 35mm/second for B.G.. Only in exceptional cases, where room is not available to lay the adequate length of transition, we can increase to the exceptionally permitted limits. These limits of cd are purely on consideration of comfort. From safety considerations a much higher rate of change of cant deficiency can be permitted.

6.8.1 CEN standard:

According to CEN standard the limiting value of rate of cant as a function of time is shown in tables below:

a) Limiting values of rate of cant as a function of time: The values apply to cant gradient with uniform slope for high speed trains without tilt

b) Limiting values of rate of cant deficiency: The values shown apply

Traffic categories	**Mixed traffic lines designed for passenger train 200< V $\leq$ 300**	**Mixed traffic lines with passenger train speeds V $\leq$ 230**	**High-speed lines with dedicated passenger traffic 250 $\leq$ V $\leq$ 300**
Recommended limiting value [mm / sec]	50	50	**50**
Maximum limiting value [mm / sec]	60	60	**60**

to all forms of transition curves, high speed trains without tilt.

Traffic categories	Mixed traffic lines designed for passenger train 200< V $\leq$ 300	Mixed traffic lines with passenger train speeds V $\leq$ 230	High-speed lines with dedicated passenger traffic 250 $\leq$ V $\leq$ 300
Recommended limiting value [mm]	50	50	**50**
Maximum limiting value [mm]	75	90	**75**

Presently, in India limiting value adopted for B.G. track is 35mm/sec to 55mm/sec. The corresponding values for standard gauge track is worked out to be 30 to 45mm/sec which is less and safer than CEN provision mentioned above.

6.8.2 Sweden standard:

In Sweden used values for maximum rate of cant and rate of cant deficiency is shown in Table 6.8.2.

Table 6.8.2 - Maximum rate of cant and rate of cant deficiency

Train category	Maximum rate of cant	Maximum rate of cant deficietncy
A	46mm/s	46mm/s
B	55mm/s	55 mm/s
S	70mm/s	79mm/s

- Category A - conventional vehicles with older running gear and freight trains;
- Category B – vehicles with improved running gear, according to approval.
- Category S – vehicles with improved running gear and car body tilt system.

6.8.3 Cant gradient:

It indicates the amount by which cant is increased or reduced in a given length of transition eg 1 in 1000 means that a cant of 1mm is gained or lost in every 1000mm of transition length.

Cant gradient is governed only by safety consideration. In the design of transition curves, if the consideration of cant gradient is not taken into account, and if only rate of change of cant and rate of change of cant deficiency/excess are considered, then for very slow speeds, the transition length required will be too small, leading to steep cant gradients, which after all are twists in the track and are to be limited to some specified values from safety consideration. Cant gradient is not to exceed 1 in 720 for B.G. In exceptional cases, where adequate room is not available for providing sufficiently long transitions, the cant gradient may be increased to 1 in 360. These values of cant gradient are without speed reference.

Limiting values of rate of cant as a function of length shall apply to the following values, although not critical at high-speed operations:

Recommended limiting value : 2.25mm/m ie 1 in 444.

Maximum limiting value : 2.5mm/m ie 1 in 400.

In India for B.G. track the following values are adopted. Cant gradient (i) = 1 in 720 desirable and 1 in 360 maximum

Rate of (rcd) = 35mm/sec desirable = 55mm/sec maximum

After comprising these values from the word experiences it may be adopted for high speed corridor also as these values are much safer than the corresponding values adopted for standard gauge.

6.9 Transition curve and super elevation ramp:

6.9.1 Length of transition curves in the horizontal plane:

Transition curves are used between tangent track and circular curves or between two adjacent curves to allow a gradual change in curvature and lateral acceleration.

Transition curves also introduce cant via super elevation ramps. A super elevation ramp is a section of the track where the cant changes gradually.

The length of transition curves in the horizontal plane should, according to European standard be determined by the limiting values of rate of cant deficiency as a function of time, and rate of cant as a function of length.

The change of lateral acceleration with respect to time is called jerk. The jerk can also be described as a change of cant deficiency with respect to time. Thus, the length of transition curve is dependent of the allowed amount of jerk. The allowed rate of cant deficiency is a question of comfort.

According to Banverket (Sweden) transition curves should be arranged with linear curvature changes (clothoids) and super elevation ramps should be arranged with linear changes of cant. The transition curve shall coincide with the super elevation ramp in both shape and position. Generally, the length of transition curves depends, among others, on the permitted gradient of cant, which is an important safety aspects because of wheel offloading and thus the risk of derailment. However, in long transition curves, which is the case in high speed operations, ride comfort aspects usually determine the minimum length of transition curves.

In a superelevation ramp the cant changes linearly. The twist 1:n states the change of rate of cant per unit length. n is called ramp number.

In Japan on the New Tokaido Line (NTL) and subsequently on shinkansen lines, transition length was determined from the following three considerations:

(1) Average rate of change of cant (r_{ca}) not to exceed 44.8 mm/sec.

(2) Average rate of change of cant deficiency (r_{cd}) not to exceed 37mm/sec

(3) Average cant gradient not to exceed 1 in 400

The above three considerations, give three transition lengths L_1, L_2, and L_3 respectively as given below and the maximum length out of the three was adopted.

$L_1 = 0.0062\ C_a\ V^{max}$

$L_2 = 0.0062\ C_d\ V^{max}$

$L_3 = 0.0062\ C_a$

Where C_a, C_d are in millimeters

V^{max} = maximum speed in km/h

However, it was realized that since the shape of the super elevation diagram was a sine curve, the cant gradient and rate of change of cant would not be uniform over the sine transition and that the maximum cant gradient and rate of change of cant would occur at the central portion of the transition, equivalent to 1.57 times the average values of the same. Hence, in order to keep the maximum cant gradient and maximum r_{ca}, on the New Sanyo Line and other new lines not to exceed 1 in 400 and 44.8mm/sec respectively (which are the average values for the transitions, the length of transition from considerations of rca, and r_{cd} viz. L_1 and L_2 were increased by 1.57 times and fixed as follows:

$L_1 = 1.57 \times 0.0062\, C_a V^{max} = 0.0097\, C_a V^{max}$

$L_2 = 1.57 \times 0.0062\, C_d V^{max} = 0.0097\, C_d V^{max}$

L_3 was retained as 0.4 C_a, because in high speed transitions, L_3 will be too small to influence the decision regarding the length of transition to be adopted.

In India the minimum length of transition for existing B.G. track is being calculated by the following equations.

$L_1 = 0.008\, C_a V^{max}$

$L_2 = 0.008\, C_d V^{max}$

$L_3 = 0.72\, C_a$

The maximum of these values are provided. These values may be adopted for Indian High Speed B.G. corridor also.

6.10 Horizontal curve:

The most distinguished parameter for a circular curve is the radius. The parameters that shall be considered in the determination of the minimum curve radius according to CEN standard are:

- The maximum and minimum operating speeds;
- The applied cant;
- The limiting values for cant deficiency and cant excess

The minimum allowable curve radius for the maximum operating speed shall be calculated using the following equation:

$$R = \frac{11.8}{Ca + Cd} V_{max}^2$$ for standard gauge

$$R = \frac{13.76}{C_a + C_d} V_{max}^2$$ for Broad Gauge

The minimum allowable curve radius for the minimum operating speed shall be calculated using the following equation:

$$R = \frac{11.8}{Ca - Ce} V_{min}^2$$ for standard gauge

$$R = \frac{13.76}{C_a - C_e} V_{min}^2$$ for Broad Gauge

The minimum curve radius should be optimized so that the values of cant, cant deficiency and cant excess comply with the limits specified and satisfy the following conditions:

$$\frac{11.8}{C_a - C_e} V_{min}^2 > R > \frac{11.8 V_{max}^2}{C_a + C_d}$$ for standard gauge

$$\frac{13.76}{C_a - C_e} V_{min}^2 > R > \frac{13.76 V_{max}^2}{C_a + C_d}$$ for broad gauge

Where Ca = actual cant in mm

Cd = Cant deficiency in mm

Ce = cant excess in mm

V^{max} = maximum speed in kmph

V^{min} = minimum speed in kmph

R = Radius in m

6.10.1 Horizontal curve radius:

The recommended horizontal curve radius in Banverket (Sweden) is a value calculated with cant Ca = 150mm and cant deficiency Cd = 100 mm in the formula for equilibrium cant. For new lines it is recommended that the dimensional speed is multiplied with a speed factor y = 1.3. This factor is used to get a margin with respect to ride comfort and increased speed in the future.

Recommended and minimum horizontal curve radius adopted in Sweden

Speed	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Recommended radius [m]	3200	5000	6300	7200	8700	9800
Minimum radius (m)	1888	2950	3700	4248	5240	5782

The recommended horizontal curve radius according to DB (GERMANY) is shown in Table below. This recommendation is based on an equilibrium cant of 170mm, i.e. 100mm of cant and 70mm of cant deficiency.

Recommended horizontal curve radius in Germany

Horizontal curve radius	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Recommended radius	2776	4338	5542	6247	7559	8503

The limit of horizontal curve radius (without permission) is based on an equilibrium cant of 290mm.

Limit value of horizontal curve radius in Germany

Horizontal curve radius	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Limit radius [m]	1628	2543	3190	3662	4431	4984

According to DB (Germany) a value of horizontal curve radius where permission is needed is based on an equilibrium cant of 330mm with a cant of 180mm and a cant deficiency of 150mm.

Permission on value of horizontal curve radius in Germany

Horizontal curve radius	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Permission value [m]	1430	2234	2803	3218	3894	4380

Examples of optimized cant and optimized horizontal curve radius

V_{max} [km/h]	V_{min} [km/h]	Cd [mm]	Ce [mm]	Ca [mm]	R[m] [m]
300	80	100	110	126	4696
300	120	100	110	150	4247
300	160	100	110	193	3618
350	80	80	110	120	7209
350	120	80	110	135	6713
350	160	80	110	160	6017

Planned alignment and track parameters of new lines of the second generation high-speed railways

Line	V^{max} [km/h]	R_{min} [m]	ca^{max} [mm]	cd^{max} [mm]	Unbalanced lateral acceleration [m/s^2]
DB[a]	300	3200	200	130	0.85
JR[b]	350	4000	200	160	1.05
SNCF[a]	350	4000	200	160	1.05

Gentle horizontal curves are generally adopted on high speed tracks. Gentle curves become necessary in view of restrictions on maximum values of cant deficiency and cant excess. The minimum radius of curvature for the various high speed lines in other countries generally varies from 4000m to 7000m for standard gauge.

For Broad Gauge for a maximum speed of 350 kmph, it is proposed to adopt minimum curvature as 1000m. However, due to constraints at few locations near important bridges, stations etc radius of curvature to be adopted may be 5000m. On such location suitable speed restrictions shall be imposed.

6.11 Gradient:

The topographical conditions usually require some kind of vertical-longitudinal gradients, along the way. Building bridges and tunnels is a very expensive way to manage the topography constraints. In particular heavy railway traffic has problems to overcome large longitudinal gradients. Therefore restrictions for the amount of gradient are needed. The following requirements need to be considered because they have an effect on railway traffic.

- The power supply and energy consumption will increase with large gradients.
- Braking distances increase for high-speed in an descending gradients.

Thus, large gradients result, principally, in heavier locomotives, increased locomotive power, and/or reduced speed and line capacity, and/or requirement of higher braking capacity, and/or larger signalling distances.

According to TSI, gradients as steep as 35%° shall be allowed for main tracks at the design phase, provided the following requirements are met:

- The slope of the sliding average profile over 10 km is less than or equal to 25%°;
- The maximum length of continuous 35%° gradient does not exceed 6 km.

Those recommended limiting values shown above apply only to high-speed lines dedicated to passenger traffic. Exceptions are made for France, which already has gradients up to 40%° on one line (Paris-Sud-Est). Furthermore, the new line between Cologne and Frankfurt is also using gradients as high as 40%°.

Banverket (Sweden) prescribes a largest permissible gradient of 10%° on track with heavy freight trains. 12.5%° can be permitted if the mean value does not exceed 10%° over each kilometer. On track with only passengers trains and light freight trains higher values may be allowed.

DB (Germany)have prescribed a largest permissible gradient of 12.5%° for mixed traffic main lines. For commuter lines and secondary lines. the maximum gradient is 40%°. Also, in the new-build high-speed lines the higher gradient 40%° is used. Normally for high speed passenger corridors EMUs are used for faster acceleration and deceleration.

6.11.1 Ruling Gradient:

Though the steeper gradients are allowed on high speed lines than the conventional lines but considering the possibility of using existing locos and coaches on the high-speed corridor for running of long existing passenger trains also a gradient of 1 in 150 has been considered for the design of high speed corridor.

6.12 Vertical Curve radius:

Introduction of vertical curves at the junction between two gradients (whether the junction is a summit or sag) is a highly desirable feature from two considerations.

a) Safety against off-loading of axles

b) Passenger comfort

However comfort is the primary consideration, similar to the lateral acceleration to which passengers are subjected while transversing a horizontal curve, passengers are subjected to vertical acceleration while vehicles negotiate vertical curves. This vertical acceleration (up ward in the case of summit and downward in the case of sags) causes discomfort to the passengers if its intensity exceeds some specified limits. The limits have been laid down as 0.3 to 0.45 m/sec^2 according to the UIC Master Plan and can be accepted as a general guide line for design of vertical curves.

The radius of the vertical curve can be worked out based on the following relationship between speed of the vehicle, radius of the vertical curve and permissible value of vertical acceleration.

$$R_v \geq \frac{V^2}{a_v}$$

where R_v = radius of vertical curve in meters

V = Speed of the vehicle in M/sec

a_v = permissible vertical acceleration in m/sec^2

It is suggested that the minimum radius of vertical curves on the Indian Railways should be laid down in such a way that equivalent vertical acceleration gets limited to 0.3m/sec^2. If vertical curves are provided with this consideration, then in addition to ensuring comfort to passenger, it will also ensure that off loading of wheels is kept well within acceptable limits on summits. Vertical curves do not have much of significant at lower speed but at high speed they have great significance and must be accurately provided.

As per Banverket (Sweden) regulation the vertical curve radius shall be in accordance to the following equation.

$R_{min}>0.16V^2$

Minimum vertical curve radius as per Banverket (Sweden) regulation

Speed	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Minimum vertical radius [m]	6400	10000	12544	14400	17424	19600

Banverket prescribes in their handbook a recommended vertical curve radius:

$$Rec>0.25(1.3V)^2$$

Recommended vertical curve radius as per Banverket (Sweden) regulation

Speed	200 km/h	250 km/h	280 km/h	300 km/h	330 km/h	350 km/h
Recommended vertical curve radius [m]	16900	26500	33200	38100	46100	51800

As per Germany regulation vertical curve radius are as follows:

Design value for vertical curve radius as per Germany regulation

Without permission	
Recommended minimum value	$Rv = 0.4\ V^2$
Limit value	$Rv = 0.25\ V^2$
Permission necessary	
	$Rv = 0.16\ V^2$ on a crest
	$Rv = 0.13\ V^2$ in a hollow
	$Rv \geq 2000$ m

As per CEN standard limiting values of vertical acceleration and Radius are as follows: .

Limit values of vertical acceleration (CEN standard)

Traffic categories	**Mixed traffic lines designed for passenger train 200< V ≤ 300**	**Mixed traffic lines with passenger train speeds V ≤ 230**	**High-speed lines with passenger traffic 250 ≤ V ≤ 300**
Recommended limiting value [mm]	0.22	0.22	**0.22**
Maximum limiting value [mm]	0.44	0.31	**0.44**

Limit values of vertical acceleration (CEN standard)

Traffic categories	**Mixed traffic lines designed for passenger train 200< V ≤ 300**	**Mixed traffic lines with passenger train speeds V ≤ 230**	**High-speed lines with passenger traffic 250 ≤ V ≤ 300**
Recommended limiting value [mm]	$0.35V^2$	$0.35V^2$	$0.35V^2$
Maximum limiting value [mm]	$0.175V^2$	$0.25V^2$	$0.175V^2$

6.13 Track geometry comparison in tunnels :

Comparison of latest provided Track Geometry in CTRL 2 section and TGV Moditerran Section are given in the following table:

Track parameters	**CTRL Section 2**	**TGV Moditerran**
Maximum cant	156mm	160mm
Normal cant deficiency	85mm	110mm
Normal minimal radius of vertical curve	21000 m	16000 m
Exceptional minimal radius of vertical curve	19000 m	14000 m
Horizontal radius of curve	6000 m	4000 m

6.14 Recommendation of RITES for Mumbai –Ahmedabad high speed corridor:

RITES in their feasibility report for Mumbai - Ahmedabad Corriodor has suggested track geometry parameters, described belows.

a) Gauge: The high speed trains will run on double line dedicated tracks which will have inter-connection with Western Railway main line tracks at Vadodara and Surat. Considering the proposal to operate other fast express trains such as Rajdhani, Shatabdi etc on the same track, Broad Gauge track is proposed along the dedicated corridor.

b) Speed Potential: The high-speed corridor has been designed for a maximum speed of 270 kmph, so that conventional express trains running at speeds of 100 Kmph or more can also use the same track.

c) Ruling Gradient: Though the steeper gradients are allowed on high speed lines than the conventional lines but considering the possibility of using existing locos and coaches for plying of existing Rajdhani/ Shatabdi trains also on the high-speed corridor, a gradient of 1 in 150 has been considered for the design of high speed corridor.

d) Curves: For Broad Gauge it is proposed to adopt minimum curvature as 5000 m. However, due to constraints at few locations near important bridges, stations etc. radius of curvature to be adopted may be less than 5000 m. On such location suitable speed restrictions shall be imposed.

e) Maximum cant, Cant deficiency, Cant Excess, Cant Gradient: In order to run he existing locos and coaches on high speed corridor, it is proposed to keep these parameters as same as recommended for group `A' routes. Thus these parameters shall be as under:

- i. Maximum Cant: 165 mm
- ii. Maximum Cant deficiency: 100 mm
- iii. Maximum Cant excess: 75 mm
- iv. Maximum Cant Gradient: 1 in 720

These parameters are not very much justified in context with the parameters derived for Broad gauge track, on the basis of High Speed experience on standard gauge world wide.

6.15 Track Geometry parameters which may be considered for Indian High Speed Corridor

Track geometry parameters has been discussed in detail from para 6.4 to 6.12 of this chapter. Parameters desired for High Speed Corridor on Broad Gauge track has also been arrived at, where ever possible. The gist of all the track geometry parameters (recommended and exceptional) derived in Para (6.4 to 6.12) for Broad Gauge High Speed Corridors are enumerated in the table below. They are differing from the proposed parameter by RITES. These parameters may be adopted for Broad gauge High Speed Corridor in India.

Track geometry parameter	Recommended Value	Exceptional Values
Track gauge	1673 mm	—
Track Cant (Maximum)	200 mm	220 mm
Cant Deficiency	100 mm	125 mm
Cant excess	100 mm	150 mm
Cant gradient	1 in 720	1 in 360
Rate of changed cant & cant deficiency	35 mm/sec	50 mm/sec
Maximum speed	350 kmph	—
Minimum speed	140 kmph	—
Horizontal curve radium	7000 m	5000 m
Gradient (maximum)	1 in 150	1 in 100
Vertical curve radius (minimum) in meter	19600 m	51800 m
Length of transition Curve (minimum) = Maximum of L_1, L_2 & L_3	$L_1 = 0.008Ca\ V^{max}$ $L_2 = 0.008Cd\ V^{max}$ $L_3 = 0.72\ Ca$	

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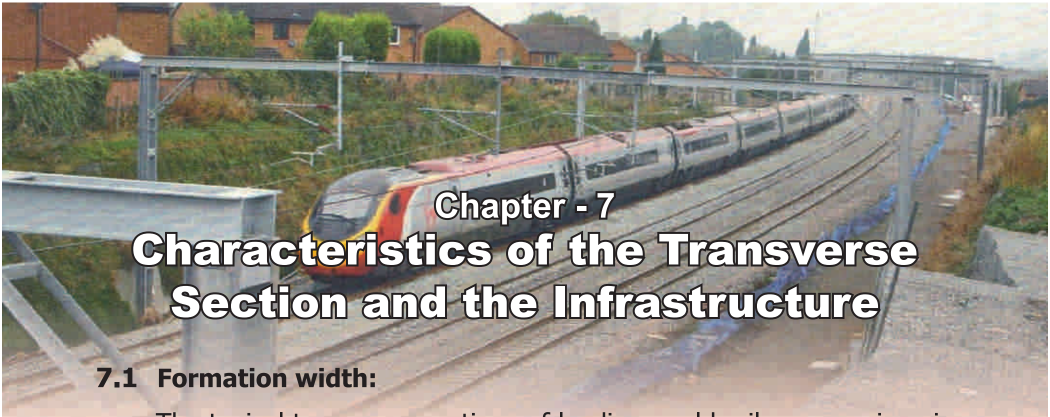


Chapter - 7

Characteristics of the Transverse Section and the Infrastructure

7.1 Formation width:

The typical transverse sections of leading world railway are given in Table-7.1. It can be seen that the most significant parameters from the point of view of the increase in speed are the distance between the track centre lines, the cross sectional area of the tunnels and the position of the walkways for the maintenance staff.

Table-7.1: Comparison of the cross section of high speed lines:

Railway	SNCF	SNCF	DB AG	FS	GIF	SNCB
Speed (km/h)	300	350	300	300	350	320
Distance between track centre lines (m)	4.5	5.0	4.5	5.0	4.7	4.5
L (Half Width of Subgrade) (m)	6.95	7.40	6.05	6.80	7.00	6.96
E (half Distance between track centre lines) (m)	2.25	2.50	2.25	2.50	2.35	2.25
D (Safety Distance) (m)	2.30	2.50	2.20	2.80	2.95	2.91
P. Walk Way (work Zone) (m)	1.40	1.40	8.00	0.70	0.90	0.80

7.1.1 The general geometrical characteristics of the new lines given in table 7.1.1 for different world railways gives an idea for deciding the transverse section.

Table-7.1.1: Design criteria for some infrastructure parameters:

	Country									
Parameter	**France**		**Germany**		**Italy**		**Spain**		**Belgium**	**STI**
Speed in Kmph	300	350	300	350	300	350	300	350	320	350
Minimum distance between track centre lines (m)	4.2	4.5	4.5	4.7	5.0	5.0	4.3	4.7	4.5	4.5

Country										
Parameter	France		Germany		Italy		Spain		Belgium	STI
Speed in Kmph	300	350	300	350	300	350	300	350	320	350
Width of subgrade (m)	13.9	14.2	12.1	13.3	13.6	13.6	13.3	14	13.9	—
Section of tunnels for double track (m^3)	70	100	92	103	82	100	75	100	150	103
Distance from the side of the service track to the external side of the rail (m)	3.00	3.00	2.21	2.71	2.15	—	2.21	2.72	2.75	—

RITES has proposed bank formation of 12.20m width with 2H:1V side slope with minimum bank height as 2.5m for Mumbai – Ahmedabad high Speed Corridor.

Formation width for conventional B.G. double line track being adopted in India is 12.155m for embankment and 11.555m for cutting.

It may be desirable to adopt 14.5m formation width for B.G. high speed corridor for B.G. high speed corridor in India.

7.2 Distance between Track Centre Lines :

The most significant parameters from the point of view of the increase of speed are the distance between track centre lines (with economic implications that can be expensive), the cross section of tunnels and the position of the paths for maintenance staff (an extremely important point for safety).

Wide spacing between the lines is important for high-speed track because when two trains pass each other, the speed difference can be as much as 700 Km/h. If two trains are too close together, there is burst of air pressure when they first pass and then a drop of pressure between the carriages. Although this is not enough to push the trains off the track, repeated stress on the windows may cause fatigue, which result in breakage of window glasses. Wider spacing between tracks has economic implications. Minimum distance between track centre adopted by some of the high-speed networks using standard gauge is given in table 7.1.1.

The STI specifies a minimum distance of 4.50 metres for standard gauge between track centre lines (for speeds greater than 300 km/h). This value could be decreased and adapted according to the performance levels and could be 4.20 m if 250 < V = 300 km/h and 4.0 m if speed V = 250 km/h.

Different railways have adopted figures that are in some cases different without the reasons being clear in every case.

The economic implications can be considerable if the transverse section is increased. Studies show that an increase of 30cm in the width of the sub-grade would involve an increase in cost of the civil engineering works by 1%.

Track distance most frequently used in Sweden is 4.50 metres, although there are exceptions in both directions.

Indian Railways adopt spacing of 5.30m between tracks of broad gauge for new construction projects, which may be considered as sufficient for high speed routes also up to 350km/h.

7.3 Tunnels :

The cost of construction of tunnels are much higher as compared to cutting and embankment construction. But tunnels are unavoidable due to curvature and gradient constraints especially for high speeds alignments where site conditions are not feasible. In high speed routes, sharp curves are not desirable and therefore, change in alignments will be further restricted. In such cases it is inescapable to have tunnel in the alignment. Some times, for high speed routes, artificial tunnels are required in thickly populated areas to avoid noise pollution in surroundings.

In the part of the Technical Specifications for Interoperability (TSI) which deals with the infrastructure parameters, it is important to mention that the section of tunnels must meet the criteria for the maximum variations of pressure allowable. For this reason it is specified that tunnels should be designed so that the maximum pressure variation that exists along an interoperable train should not exceed 10 kPa while the train is running through the tunnel at the maximum permitted speed.

This restriction is for the case where the sealing system fails and the values are based on consideration of the health of the passengers not on their comfort.

In the two track tunnels of mixed traffic lines, the running of freight trains raises two problems the aerodynamic effects and safety in the case of an accident. This is why it is necessary to consider the reduction of speed of high speed trains in tunnels or to avoid mixed traffic at the same time and to organize the running of freight trains and highs speed trains at different times of the day.

The lining of tunnels is favourable from the point of view of the aerodynamic effects.

The question of the safety of trains running inside tunnels must be dealt with by UIC from the point of view of the infrastructure, as well as their suitability for the emergency cases.

In view of this, a question to discuss is that of the permissible length for tunnels, the maximum length in double track . It appears that the present trend is to build independent tunnels for reasons of safety, for speeds above 300 km/h with internal connection for two way working, emergency exits.

Geometry of Tunnels will be guided under the influence of various features discussed here:-

Tunnel cross sections on high speed lines will be guided by the aerodynamic phenomena in the tunnel during passing of trains with other structural and dimensional features.

Air compression waves generate while passing the trains through the tunnel at very high speed and therefore the aerodynamic air drag is considerably higher than in the open air. Tunnel air friction will also play a considerable role in pressure variation along the length of tunnel.

When train enters into the tunnel with very high speed, a compression wave is formed at the entrance of the tunnel. This compression wave propagates inside the tunnel and when it reaches at the exit, a portion of it radiates outside as a pulsed compression wave. The pressure gradient of the compression wave at the tunnel entrance is related with cubic of the train speed. This causes the generation of micro pressure waves which is proportional to pressure gradient These micro pressure waves cause explosive sound during the entry and exit of train in tunnel with heavy vibrations in train doors.

To reduce this effect, tunnel hoods are specially designed with pressure release shafts. The diameter of the hood is kept 1.4 to 1.5 times of the diameter of tunnel. This is also advisable to provide separate tunnels for separate lines to avoid the combined effect of micro pressure waves due to simultaneous passing of trains.

At high speeds, airwaves are generated inside the tunnels, which can be detrimental to the health of passengers. To mitigate all these issues, following features become essential requirement during the design of tunnels:-

- Increased cross-sectional area of the tunnel to reduce the sharpness of aerodynamic forces. Excess aerodynamic forces and generation of air compression waves have adverse effect on safety of trains besides requiring extra tractive efforts.
- Avoiding double line tunnels. During simultaneous passing of trains on double lines in tunnel, aerodynamic air drag will be considerably higher.
- Operating only air sealed coaches to prevent interface of airwaves of tunnel with the coach inside. Compressed airwaves generated during passing of trains through tunnels are detrimental to passenger health.
- Provision of pressure release shafts along the tunnels and Provision of pressure release shafts along the tunnels and specially designed tunnel hoods as required.
- Special shape of the tunnel entrance is designed to smoothen the application of aerodynamic forces during entry of train into the tunnel. Train's bow is also designed streamline to reducethe aerodynamic drag

A combination of above things is adopted depending upon the requirements. Existing clearances are to be checked for new high speed tracks.

7.3.1 Avoidance of Tunnels:

Generally speaking engineers try and avoid tunnels on high speed lines. This is because a train causes large pressure changes when it enters a tunnel at speed. This can be painful and harmful to passengers' eardrums. A solution to this was to pressure seal trains as with the TGV Reseau. However with very high speed trains (350km/h) the pressure changes can be so large that it can shatter the windows, particularly when two trains pass in opposite directions in a tunnel with a closing speed of 700km/h in a confined space. However German and Italian high speed lines include tunnels but they have subsequent speed restrictions. As a result the best average speeds along German (200km/h) and Italian (165km/h) lines are considerably lower than in France (254km/h) and Japan (262km/h), and even a British conventional railway outperforms the Italian high speed line in terms of speed with an average of (180km/h) between London and York.

7.3.2 A Case study: Construction of Channel Tunnel Rail link section-2 in London (CTRL-2):

In selecting a route into London – section 2 – it was concluded that a tunnel was the only realistic option. The cost and risk of a surface railway running at high-speed through a densely built up urban area ruled it out. Safety has been at the heart of the design of the Channel Tunnel Rail Link (CTRL) Project in London – now called as High speed I – but perhaps nowhere more so than in the complex section 2 of the route, more than half of which is in tunnel. The open route is traditional ballast and some sleeper construction, identical to the already open section 1. The track in all these tunnels is slab track, utilising booted twin block sleepers cast into a concrete slab. The boots are rubberised to minimize ground borne vibration and have varying stiffness, dependant on the location.

7.3.3 CTRL-2 Tunnel Design Concept:

A long tunnel, and originally the tunnel route was 20km long, considered to be unsafe, unless it had a service tunnel and or escape shafts at 1 km spacing, which also made it too expensive and very difficult to find shaft sites. The solution was found by splitting the tunnel into two elements with an open section approximately 1 km long in the middle, at Stratford. The Stratford box was necessary to provide an open air escape facility for the long tunnel. The box also provided a site for high speed cross over to replicate the cross-over caverns of the Channel Tunnel, thus allowing one section of the tunnel to be closed for maintenance or incident, with bi-directional running in the adjacent bore. This way the maximum length of tunnel became 10 km and it was possible to show that shafts at 3 km separation and cross passages at 375m between the two bores provided passenger escape facilities were adequate to deal with emergencies. Unlike the Channel Tunnel, a service tunnel is not required as the non-incident tunnel is used to provide a place of relative safety, a safe haven. It is suggested that the CTRL design is safer than the existing railways and tube lines, and safer than alternative modes of travel, as a place of relative safety is provided (the cross passing and non-incident tunnel), unlike on airlines and ferries, they do not provide an escape route at 10 000m up or in mid-Channel.

7.3.4 Cross passage spacing in CTRL-2 Tunnel:

A very significant decision in terms of cost benefit was the distance between cross passages. The original intention was to provide cross passage spacing at 375m nominal intervals as per the Channel Tunnel, however the Jubilee line and Heathrow Express tunnels, which are of similar design to the CTRL, provide escape points at 1000m intervals. Using data from early risk analysis of cross-passage spacing schemes, it was noted that, as cross spacing was increased up to 1200m, there was a negligible increase in safety risk to tunnels users. However due to other considerations, such as the maximum distance that a fireman could walk using breathing apparatus, and the requirement to allow flexibility in the selection of locations and ground conditions where the cross passages were to be dug by hand, it was decided to focus on a maximum distance of 750m. In terms of safety benefit, the additional cost of providing cross-passages at 375m spacing was grossly disproportionate compared to the benefits gained. Spacing at 750m provided the optimum safety benefit at least cost.

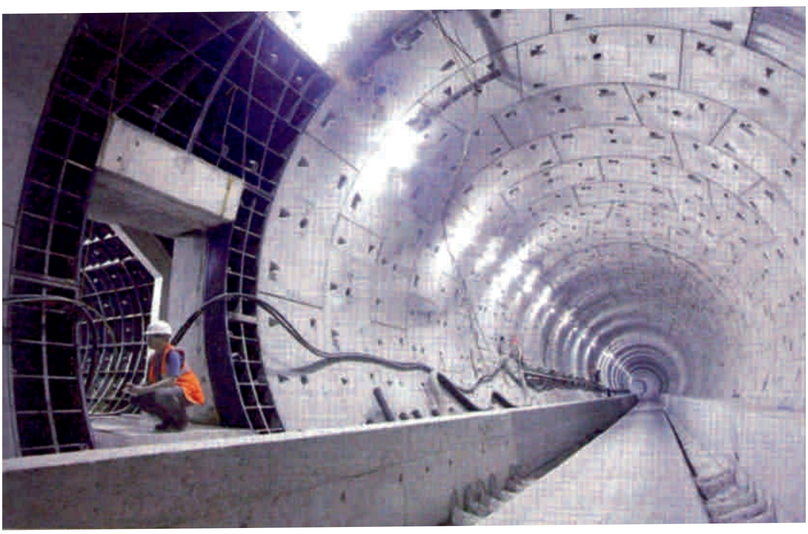


Fig.7.3.4 : Cross-passages between the tunnel bores at maximum 750m intervals

7.3.5 Ventilation in CTRL-2 tunnel – normal operation:

The ventilation control system (VCS) uses specially developed software to provide comprehensive control, monitoring and reporting for the equipment that controls the movement of air in the London and Thames tunnels. It also monitors the position of each cross-passage door during normal operation and whether it is locked as mandated during engineering work to prevent accidental access into the tunnel that is open for normal train operation. Normally the passage of trains provides sufficient ventilation to the long, twin bored, London and Thames tunnels. If during normal operations one or more trains are perceived to be stationary or moving very slowly, the operator can select automatic supplementary ventilation mode.

This mode is provided by jet fans operating in the direction opposite to train travel, to pass air over stationary or slow moving trains in a tunnel bore. This is done automatically when the VCS detects any train moving less than 10km/h (from track circuit occupancy data) and will be switched off when all trains are moving at more than 20 km/h.

No ventilation system is provided in the North Down and Pepper Hill tunnels. Being single bore twin track tunnels, they are considered to be of sufficiently large cross section to permit natural ventilation.

Fig. 7.3.5 Bi-directional jet fans at the London tunnel portals automatically pressurize the non-incident tunnel during an emergency, allowing passengers to escape along the evacuation walkway (right) without risk of smoke following them

7.3.6 Design Challenges in CTRL-2 Tunnel - Tunnel Track design:

Section 2 of CTRL is unique in that it spends most of its length under a major city, rather than doing either round it or joining existing lines into it. Most major cities have very little, if any, space for expansion of over ground railway lines, leaving just three options; use existing corridors, go under, or create an out-of-city parkway station with light rail transit into the centre. CTRL goes under emerging just over 1 km from the buffers of the terminus. From a design point of view, this is a major challenge, threading through existing underground infrastructure and, more importantly, not impacting on the people living above, either during construction or in the life of the railway. This means innovative use of a track system that delivers the high speeds necessary but with minimal radiated noise or vibration. On CTRL this was achieved with a slab track system, similar to the one used on LGV Mediterran, but with an incredibly soft pad system having a dynamic stiffness of 10 MN/m per block as opposed to the 35MN/m used on the SNCF line. This has the effect of significantly damping the radiated vibration but may impact ongoing rail life with predicted life reduced by about 30%.

7.3.7 Slab / ballast transitions CTRL-2 Tunnel:

While slab is used throughout the London tunnels and under the Thames, the ends of the tunnels have transitions to ballast either side, including for the 1.5km through Stratford station. These transitions are designed to minimise the maintenance effect of settlement of the ballast under load. This is achieved by using a reduced ballast side (nominally 250mm) with an increasing depth until the full depth is achieved. This restricts the possible ballast compaction under load while still allowing for tamping. Adjustable fastenings either side of the transition allow small changes in level to be accounted for locally (up to 16mm of settlement can be accommodated as a maximum). Under sleeper pads and a ballast mat are also included to create the necessary system characteristics, moving from the dynamic stiffness of the slab, to that of 'normal' open route track.

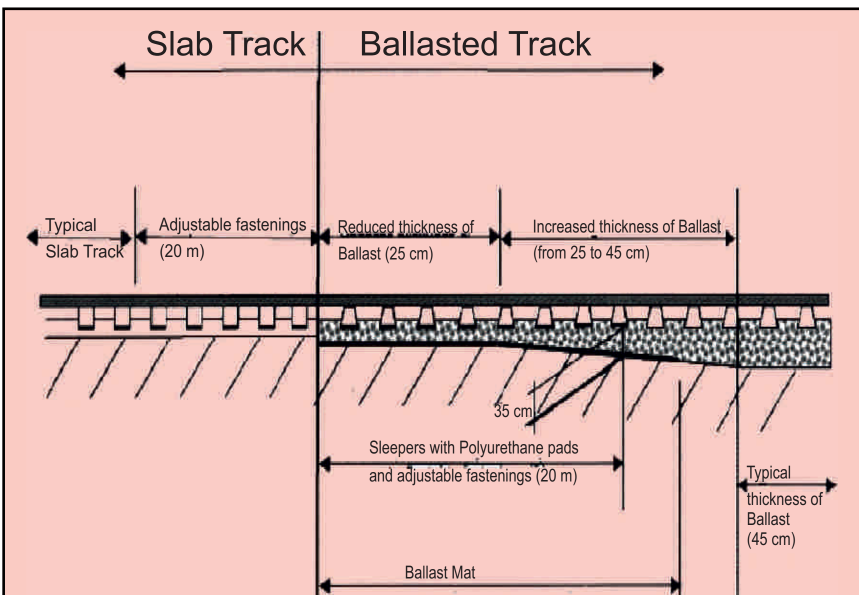


Fig.7.3.7: Slab/Ballasted transition

7.3.8 Comparison of the construction of three tunnels is shown in table 7.3.8 :

Table No.7.3.8 Tunnel Track Design

Description	SATEBA System		
Mitigation level	TGV Mediterrance	S1 (Thames tunnel)	S3 (London tunnels)
Sleeper Type	SATEBA SAT S312 NAT	SATEBA SAT S312 V	SATEBA SAT S312 V
Description	Twin-Block	Twin-Block	Twin-Block
Length of one concrete block (lower part)(mm)	660	660	660
Height below rail seat (mm)	215	215	215
Complete length of the sleeper (mm)	2250	2298	2298
Sleeper/Block Mass (kg/sleeper)	186	186	186
Rail pad thickness (mm)	10	9	9
Sleeper resilient pad vertical dynamic stiffness (MN/m pr block)	35 (thickness 12 mm)	32 (Thickness 12 mm)	10 (Thickness 16 mm)
Second stage concrete thickness (mm)	150 (average)	174	180

7.4 Safety of Maintenance Staff :

An extremely important question for the safety of maintenance staff is that of the distance between the internal side of the service track and the external side of the rail. Once again a wide range of criteria were found for the specification of this parameter.

The STIs specify that trainsets at 250 km/h shall not cause an unacceptable slipstream on people 2 meters away.

For high speeds, each railway must consider the possibility of introducing additional precautions, such as higher distances screens, etc.

7.5 Bridges :

Bridges as well as bridge approaches are the vulnerable points, where a thorough analysis for structural adequacy is required in view of running of high speed trains from safety and comfort criteria.

It is proposed to forbid the placing of piers close to points. In addition it seems advisable to provide protection for the columns in underground stations adjacent to high speed lines due to the possibility of derailments.

The design of long viaducts must aim (as far as possible) to reduce the number of expansion devices (or even to do away, with them completely), which also raises problems for maintenance

7.5.1 Dynamic effects on Bridges :

After the first high speed lines were taken into service, problems were experienced on certain bridges due to the appearance of defects in the ballast bed which caused destabilizations of the track and the deterioration of its geometry. This implied a certain risk for trains in service.

A detailed study of this problem showed that it was associated with vertical accelerations of the deck (of the order of 0.7g to 0.8g) caused by trains running at certain speeds (not necessarily the maximum speeds).

The bridges were designed in accordance with the UIC 71 load cases and UIC Leaflet 776-1.

The theoretical and experimental analysis of this question showed:

a) With vertical accelerations of the order of 0.7g to 0.8g, the ballast tends to be reduced to a liquid and as a result loses its capacity to resist the loads applied on the track.

b) The introduction of an elastic mat between the deck and the ballast increased the accelerations in the ballast and, as a result, made this problem worse.

c) Accelerations of the order of 1.0 g on decks which do not have ballast (directly laid track) can reduce the Q forces of the wheel-rail contact down to acceptable limits (even to wheel lifting off the rail).

d) The regular and repeated distribution of the wheel sets of high speed train sets in certain speed ranges can produce resonance situations in the deck, with large amplifications, both in the deflections and in the vertical accelerations.

e) Among the actual trains that have been used for the definition of the UIC 71 load cases, and the dynamic coefficient to be applied, only one train (300 km/h turbo train) reached the speed indicated. This train was made up of two vehicles, with a total length of 38.4 metres, and 8 axles each loaded to 170kN. Modern high speed train sets can be up to 400 metres long (according to the STIs) and have total weight of 10 000 kN, with speeds in excess of 300 km/h.

As a result it is essential to check, when the civil engineering works are designed, how the railway structures which have to carry the high speed trains will behave. In particular it is necessary to check that :

1) The vertical acceleration on the track bed of ballasted track will not exceed the value of 0.35g (with a safety factor of 2) in the frequency range below 20 Hz.

2) The vertical acceleration on the track bed of non-ballasted track will not exceed the value of 0.5g (with a safety factor of 2) in the frequency range below 20 Hz.

These checks must be done for the trains specified.

The new high speed lines are particularly sensitive to the transitions between earthworks and the civil engineering structures (bridges, viaducts and tunnels). These are a delicate points of the infrastructure which can have two types of problems, subsidence and change of stiffness. The subsidence problems are normally associated with different amounts of setting between the two types of structure which affect the longitudinal level. This gives rise to additional maintenance costs, mainly in the first few years of operation of the line. After this the problem reduces. The change of vertical stiffness is directly affected by the speed and is due to an increase in the Q forces in the interaction between wheel and rail, deterioration of the track and ballast and also the increase in maintenance costs. It also affects passenger comfort.

The problem also occurs on non-ballasted track.

There are several solutions to this problem, especially on the basis of the use of selected and / or treated granular materials (technical blocks) with variable geometry, composition and dimensions depending on the country. The costs of construction are generally high. Given the large number of civil engineering works in new high speed lines, it appears advisable to carefully consider the solutions and dimensions necessary for these transition items.

7.5.2 Bridges design criteria: RITES report for proposed high speed corridor between Ahmedabad and Mumbai :

Identified the following Design Criteria for bridges proposed to form part of the HSR so as to maintain the safety of operation and to ensure the comfort of passengers:

(i) Vertical acceleration of the deck;

(ii) Twist of the deck

(iii) Rotation at the end of the deck;

(iv) Horizontal deflection of the deck (for curve alignment).

(v) If the train speed is higher than 220 km/hr or the natural frequency of the structure is outside the specified limits, the deck vertical acceleration shall be checked to ensure the stability of the ballast. It is derived in the transient dynamic analysis under actual trainloads with only one track loaded.

7.5.3 Introduction to Bridge design for HSR in India:

The classical way to take into account the dynamic effects in bridge design being used in Indian Railways is to use a dynamic factor (based on few dynamical parameters) and to multiply all static effects (deflection, moments, stresses etc.) with this dynamic factor. However, detailed dynamic analysis has confirmed that this method does not cover some resonance effects caused due to excitation caused by high-speed rails with regularly spaced bogies. High Speed Railway Vehicles, crossing long span bridges or multi span viaducts produce much higher displacements and accelerations of bridge superstructure as compared to the loads acting statically.

These effects increase rapidly with speed and have become well known in design of high-speed railway structures. The consequences of increase of displacements and indeed those of accelerations are two fold. Force resultants, stresses and deformation of Bridge structure increase rapidly with train speeds and loading models may become inaccurate or under estimate the effects of real train vehicles. In addition, the bridge deck accelerations may exceed the values at which track ballast looses its cohesion and behaves as liquid leading to instability of long welded rails. On other hand, deformations and accelerations of superstructure may on their turn be transmitted to the train cars. Interference of the train car movement with these time dependent quantities cause increasing resulting train car accelerations and discomfort to passengers. As a consequence, passengers can feel nauseated.

To account for the above the bridges shall be designed for Modified Broad Gauge loading of Indian Railways as per existing norms of Indian Railways and checked for various serviceability limits for actual High Speed Rail vehicle loading. In absence of any guidelines from Indian Railways for high-speed lines, European Standards (EN1991-2) shall be used to account for dynamic behaviour of bridges.

7.5.4 Design Criteria:

a) Serviceability Criteria for Bridges:

For railway bridges, it is necessary to consider specific additional criteria in order to check the deformations and displacements of the bridge decks.

The requirements limiting the deformation of structures carrying rail traffic to maintain the safety of operation and to ensure the comfort of passengers are:

i. Vertical acceleration of the deck;.

ii. Twist of the deck

iii. Rotation at the end of the deck;

iv. Horizontal deflection of the deck (for curve alignment).

It is also necessary to ensure that any deformations remain within the elastic limits of the materials used.

b) Design Requirement for Train Speeds < 220 km/hr:

This section specifies the limits of deformation and acceleration to be considered in the design of bridges for the train speeds up to 220 km/m.

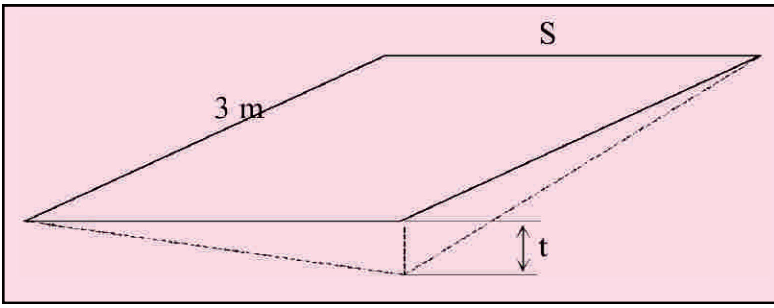
- **Vertical Acceleration of the Deck**

When the train speed V is less than 220 km/hr and the natural frequency of the structure is within specified limits, excessive acceleration is unlikely to occur.

Nevertheless, for some values of deflection excessive accelerations can occur. As a first approach it is recommended that the limits of deflection, given in the table of subsection below, should be satisfied.

- **Twist of the Deck**

The twist of the bridge deck is to be calculated under actual high speed train loading multiplied by the dynamic factor.



The maximum twist measured over a length of 3 m of the track gauge S shall not exceed the following values.

Train speed - V (km/hr)	Maximum twist "t"
V < 120	t < 4.5 mm / 3m
120 < V < 220	t < 3.0 mm / 3m

- **Rotations at the End of the Deck for Ballasted Tracks**

The angular rotations at the end of the deck under actual high speed train loading multiplied by the dynamic factor and combined with differential temperature loading shall be limited to values given in Table 7.5.4.1.

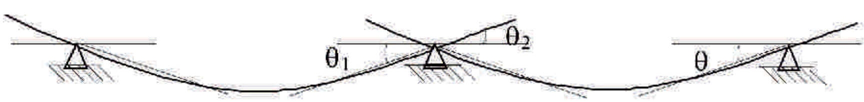


Table 7.5.4.1: Limiting Rotation

	θ **(rad)**	$\theta_1 + \theta_2$ **(rad)**
Type of bridge	for transition between the deck and the adjacent earthwork	between two consecutive decks
Single track bridges	6.5 x 10 - 3	10 x 10 - 3
Double track bridges	3.5 x 10 - 3	5 x 10 - 3

- **Horizontal Deflection of the Deck**

For the curved alignment, the horizontal deflection of the deck h, shall be checked for:

- Actual high speed train load multiplied by the dynamic factor
- wind loads
- nosing loads and
- centrifugal forces.

The limit values of the angular variation $_h$ and the horizontal curvature radius $R = L^2 / (8\,\delta_h)$, are given as in Table 7.5.4.2

Table 7.5.4.2: Limiting angular variation

Train speed V (km/hr)	Maximum angular variation (rad)	Minimum radius of curvature (m)	
		Single deck	Multi-deck bridge
V < 120	0.0035	1,700	3,500
120 < V < 220	0.0020	6,000	9,500

- **Vertical Deflection of the Deck**

The limiting values for the maximum vertical deflection are governed by the comfort of passengers and the train speed. Passenger comfort as classified in Table 7.5.4.3 is a function of the vertical acceleration inside the coach during travel.

Table 7.5.4.3: Passenger comfort

Level of comfort	Vertical acceleration
Very good	1.0 m/s^2
Good	1.3 m/s^2
Acceptable	2.0 m/s^2

To ensure passenger comfort, the maximum vertical deflection (d) of railway bridges, under UIC 71 loads has been established as a function of the span length L and the train speed V. The ratio d/L shall not exceed the values given in Table 7.5.4.4.

Table 7.5.4.4: Limiting Vertical Deflection

Train speed V (km/hr)	Span L (m)				
	L < 15	15 < L < 30	30 < L < 50	50 < L <90	90 < L < 120
V < 120	1/800	1/900	1/800	1/600	1/600
120 < V < 160	1/900	1/1200	1/1200	1/800	1/600
160 < V < 200	1/1000	1/1400	1/1500	1/1300	1/600
200 < V < 280	1/1200	1/1500	1/2100	1/2100	1/1400

The values in the table are established for successive simply supported structure, with the number of span "n" > 3 and a maximum vertical acceleration of 1.0 m/s^2.

The limiting values should be multiplied by:

- factor of 1.1 for continuous structures
- factor of 2.0 for structures with 1 span and
- factor of 1.5 for structure with 2 spans
- limiting vertical acceleration when greater than 1 m/s^2.

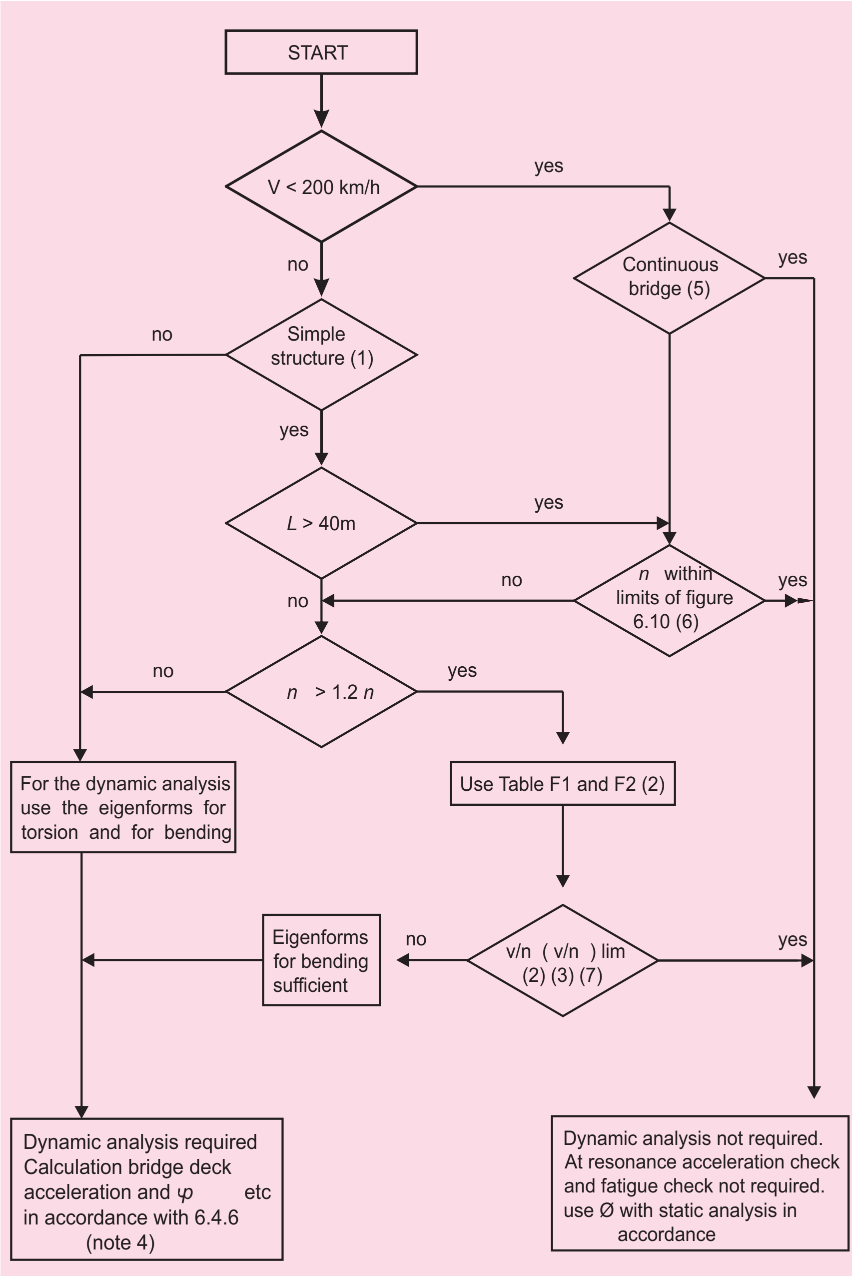
In no case, should the maximum deflection exceed L/600 for single track and L/800 for double track.

c) Requirements for Train Speeds > 220 km/hr :

In addition of the criteria applicable for train speeds up to 220 km/hr, the following additional analysis and checks shall be performed. If the train speed is higher than 220 km/hr or the natural frequency of the structure is outside the specified limits, the deck vertical acceleration shall be checked to ensure the stability of the ballast. It is derived in the transient dynamic analysis under actual trainloads with only one track loaded.

·**Need for dynamic Analysis**

The EN 1991 –2 standard gives a flow chart (Fig.7.5.4.1), which helps to decide whether dynamic analysis is required. All bridges where the Maximum Line Speed is greater than 200 Km/hr, dynamic analysis shall be carried out. Dynamic analysis shall also be performed where train speed is less than 200 Km/hr, but the natural frequency of structure is not within upper & lower limits of Fig. 7.5.4.2.



Flow chart for determining weather a dynamic analysis is required

Fig. 7.5.4.1 – Need for dynamic analysis

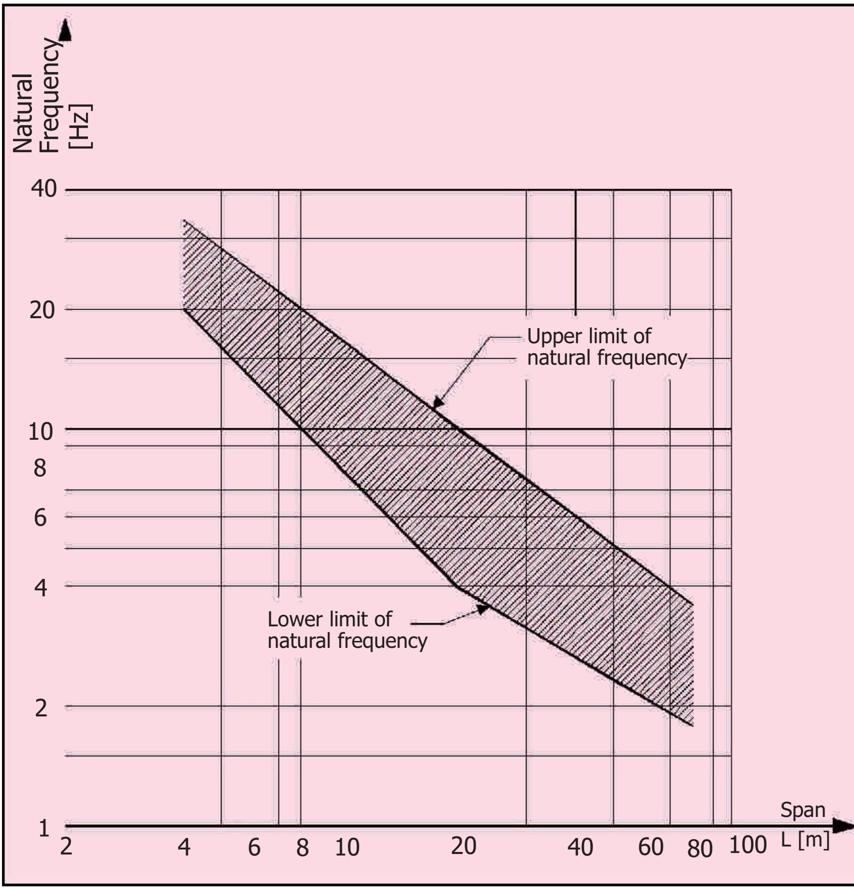


Fig 7.5.4.2 – Limits of bridge natural frequency n_0 [Hz] as a function of L (m)

The parameters of this chart are the following:

- maximum speed of the line
- simplicity of the structure;
- span
- first natural bending frequency n_0
- first natural torsional frequency n_T

For high speed lines, for simply supported structures where L > 40m and n_0 within limits of Fig 7.5.4.2, no dynamic analysis is required.

Dynamic calculations will be carried out in order to verify that the dynamic effects of train traffic are covered by the dynamic factor F and to determine the acceleration and displacement of deck under the actual trainloads.

1) When the train speed is higher than 220 km/hr.

A dynamic analysis of bridge under actual trainloads is to be performed. The dynamic effect factor is:

F r= Max [δ_{stat} /δ_{dyn}] for 0 < V < V_{max}

- If Φ_r actual load < Φ_2 UIC load, the bridge must be designed considering V< 220 km/hr
- If Φ_r actual load > Φ_2 UIC load, Φr with actual train load will be considered or the structure will be redesigned for finding Φ_r actual load < Φ_2 x UIC load.

2) When the natural frequency of the structure is not within the upper & lower limits, even if V < 220 km/hr, a dynamic analysis of bridge under UIC loads is to be done. The dynamic effect factor, in this case, is determined by following expression:

$$\Phi_r = \text{Max } [\delta_{stat} / \delta_{dyn}]$$

If $\Phi_r > \Phi_2$, Φ_r will be used instead Φ_2 or the structure will be redesigned.

- **Structure Displacement**

Under traction and braking forces, including reduction factors, the relative longitudinal movement between two decks or between one deck and the abutment shall be limited to:

- 5 mm, without a rail expansion joint
- 30 mm, with a rail expansion joint.

Under seismic actions, the relative longitudinal movement between two decks or between one deck and the abutment shall be limited to:

- 25 mm, without a rail expansion joint
- 100 mm, with a rail expansion joint.

- **Rail Structure Interaction**

The continuous welded rail is stressed by temperature variations and by local loads due to the train wheels. This governs:

i. The possible locations of the structural expansion joints;

ii. The maximum rotation of the bridges at the structural expansion joints;

iii. The possible displacements under traction/braking forces and the rigidity (sizes, shapes) of foundations, pier shafts and bearings.

In general it is desirable to limit the number of expansion joints in the rails and this may require the introduction of additional joints in the structure. There is a limit to the relative longitudinal movement that can be tolerated between the deck and the rail and this is one of the criteria that governs the position of structural joints.

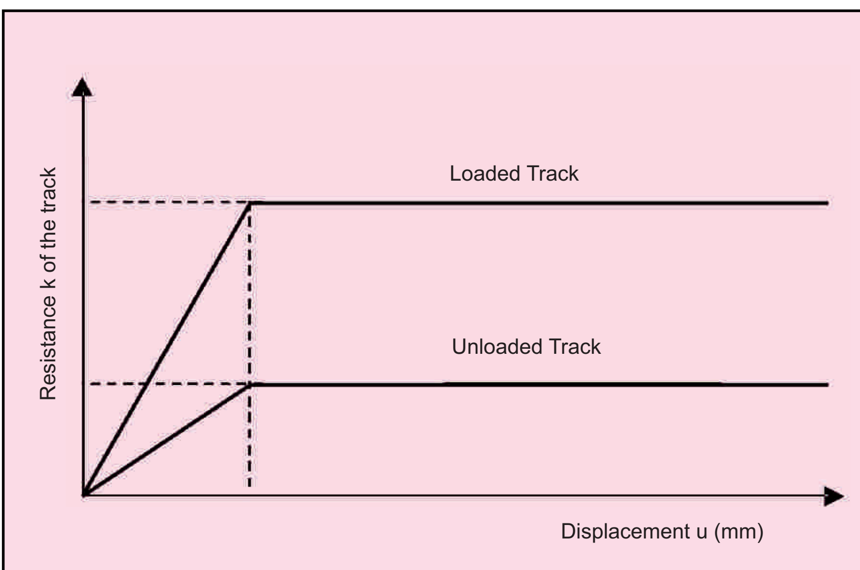
The structural expansion length of the deck is the distance from the structural joint to the centre of deck expansion. The combined expansion length at a joint is the sum of the expansion lengths of the two decks (one only for an abutment) which meet at the joint.

For continuous tracks, without any rail joints or turnouts, the structural expansion length shall be limited to:

- 60 m for steel structures supporting ballasted track without special rail attachments;
- 90 m for concrete or composite carrying ballasted track.

- **Track Behaviour**

The resistance of the track against longitudinal displacements is a function of the displacement of rails relative to its supporting structure. Bi-linear conditions, compatible to that of Pandrol fastening system, shall be considered as representing track resistance. These conditions are shown in the figure below:



The characteristic values for ballasted track are assumed as follows:

Displacement between elastic and plastic zone u_0 = 2mm

Resistances k per unit of length for one track in the plastic zone:-u_0 = 2mm

Resistances k per unit of length for one track in the plastic zone:

- k = 20 kN/m for unloaded track;
- k = 60 kN/m for loaded track.

- **Design Forces**

The following thermal effects shall be taken into account in the combined structure and track system. The reference temperature for bridges is the temperature of the deck when the rail is fixed.

- The temperature variation from the reference temperature shall be limited to ± 35°C in the deck and to ± 50°C in the rail.
- In case of track with an expansion device, the difference in temperature between deck and track does not exceed ± 20°C.

In case of CWR a variation in the temperature of the track does not cause a displacement of the track and thus is no interaction effect due to the variation in the temperature of the track.

- **Traction and Braking Forces**

The characteristic values of traction and braking shall be multiplied only by the factor á as defined above for the actual high speed train load model.

- For a deck, which carries two tracks, the longitudinal force on the deck shall be evaluated with traction force on one track and braking force on the other.
- For the deck, which carries one track, braking and traction forces shall be assumed to act in either direction.

- **Bending of the Deck**

Traffic loads cause flexure in the deck, which introduces a rotation of the end sections and displacement of upper edge of deck. The loads applied for RSI analysis are those of actual high speed train load model as defined above without impact effects.

Note that other actions such as creep, shrinkage and temperature gradient shall be neglected for a ballastless track wherever provided. Creep and shrinkage are assumed to be complete at the time of track construction phase unless it is laid immediately after concrete placement.

- **Load Case Combination**

For the calculation of the total support reaction and in order to compare the global equivalent rail stress with permissible values, the global effect is calculated as follows:

$$\sum F = \alpha F(\Delta T) + \beta F(braking) + \gamma F(bending)$$

Where: α, β and γ are combination factors. For the calculation of the global values of rail stresses and displacements, all factors equal to 1 for continuous or simply-supported decks.

- **Rail stress due to Rail Structure Interaction**

For track with at least 300 mm ballast under concrete sleepers which have a maximum spacing of 650 mm, and using UIC 60 rail (tensile strength 900 N/mm^2) or for equivalent track construction, the maximum allowable additional stress in the rails due to Rail Structure Interaction are limited as follows:

+ maximum compression : 72 N/mm^2

+ maximum tension : 92 N/mm^2

7.5.5 Bridge Configurations for various spans:

Bridges may be ballasted decks. For bridge superstructures, the general rules as listed in Table 7.5.5 shall be applied.

Table 7.5.5 : Bridge configuration

Length in m	Structure
L < 6	Box culverts
6 < L < 10	Steel I – beams with concrete deck or Prestressed concrete slab (Fig. 7.5.5.1)
10< L< 20	Prestressed concrete box girder for each track or Prestressed concrete T - beams with reinforced Concrete slab (Fig. 7.5.5.2)
20 < L < 30	Prestressed concrete box girder for each track(Fig. 7.5.5.3)
30 < L< 45	Prestressed concrete box girder for both tracks (Fig. 7.5.5.4)

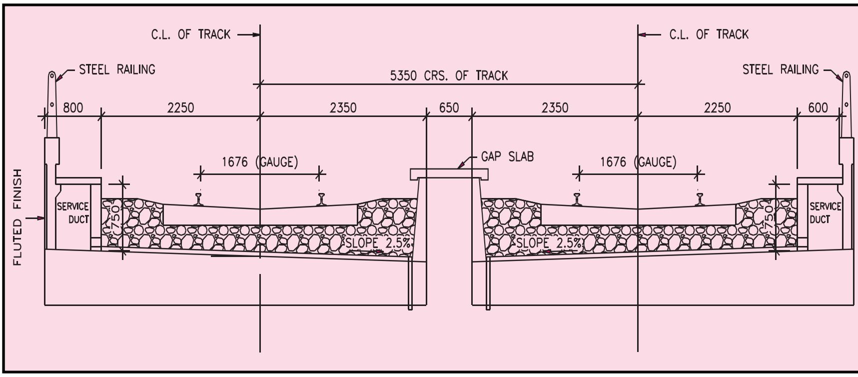


Fig.7.5.5.1 Typical Cross section of PSC slab spans 6mto10m

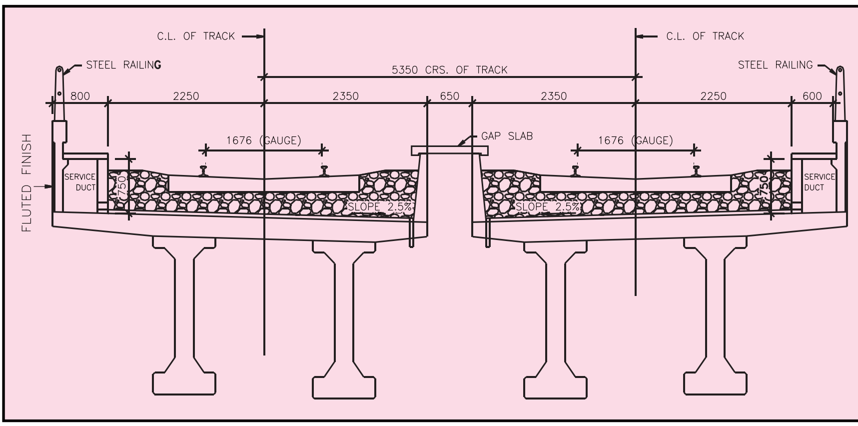


Fig.7.5.5.2: Typical Cross section of PSC T Beam girder spans 10m to 12m

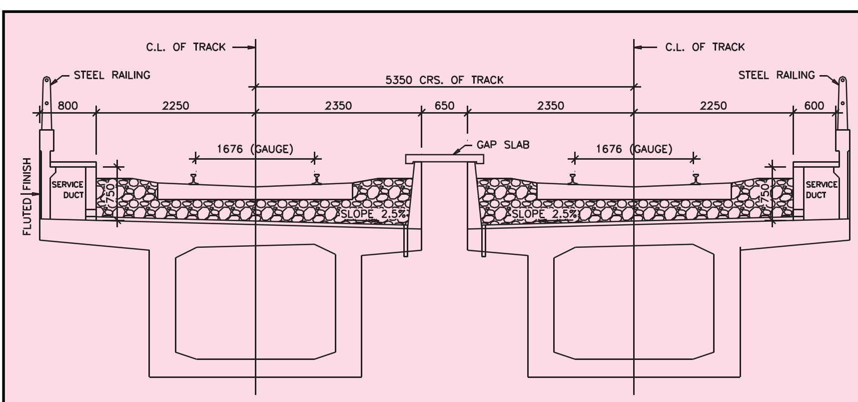


Fig.7.5.5.3: Typical Cross section of PSC box girder for spans 20m to 30m (each track)

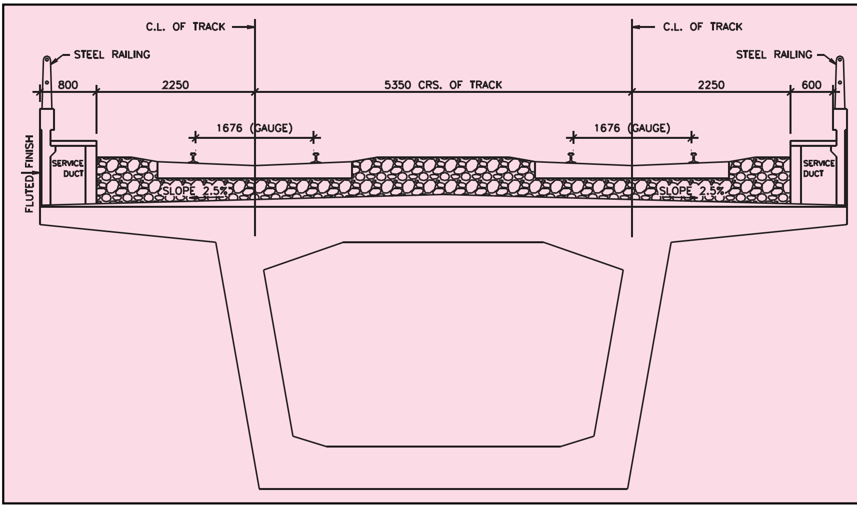


Fig 7.5.5.4: Typical Cross section of PSC box girder spans 30m to 45m (for both tracks)

For Substructure, the design of pier caps may consider that any jacking of deck (e.g. in case of bearing replacement) will be undertaken with the bridge closed to traffic. Well foundations are proposed for major bridges on rivers. For ROBs & RUBs pile foundations or rafts shall be used.

7.5.6 Bridge Approches (Embankment – Bridge Transition) :

The transitions between earth works and civil engineering structures are the cause of problems due to the change of stiffness. This change of stiffness is directly affected by the speed and is the cause of an increase of forces which result in the deterioration of the track and the ballast as well as reduction of comfort.

The difference in track stiffness on embankment & bridge affects the vertical movement of vehicle resulting in increasingly pronounced vertical acceleration in vehicle, which may mean that the criteria for passenger comfort or maximum dynamic track force are not met. A marked increase in forces lead to accelerated deterioration of track geometry and hence to additional maintenance.

The effect of change in stiffness of track on embankment and bridge is less relevant for train speeds less that 160 km/hr. However the discontinuities become relevant for train speeds between 200-300 km/hr. Therefore, it is important that the transition structures are designed in such a way as to result in :

- A smooth transition between embankment and rigid structure : (hereby a smooth transition over a relative short distance results in a larger limitation of the dynamic load on the train than small discontinuities in a longer transition structure).
- A uniform decrease of settlements and a uniform increase of stiffness of embankment and the sub soil in the direction of the rigid structure.

Various methods adopted for smooth transitions are :

i. Using cement lime stabilization of transition portion of embankment.

ii. Provision of approach slabs resting on conventional abutments.

iii. Use pile/raft system under transition portion with varying stiffness.

Typical section and effect of rail pad stiffness on transition are shown in Fig. 7.5.6.1 and 7.5.6.2.

The detailed design of transition including the system to be adopted shall depend on actual location and shall be based on Soil-structure Analysis which shall include soil stiffness at the location based on actual ground data.

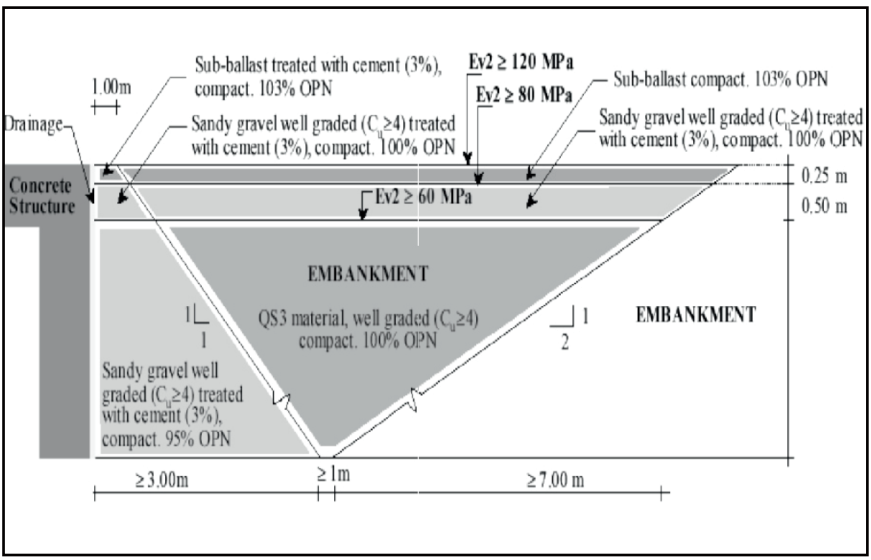
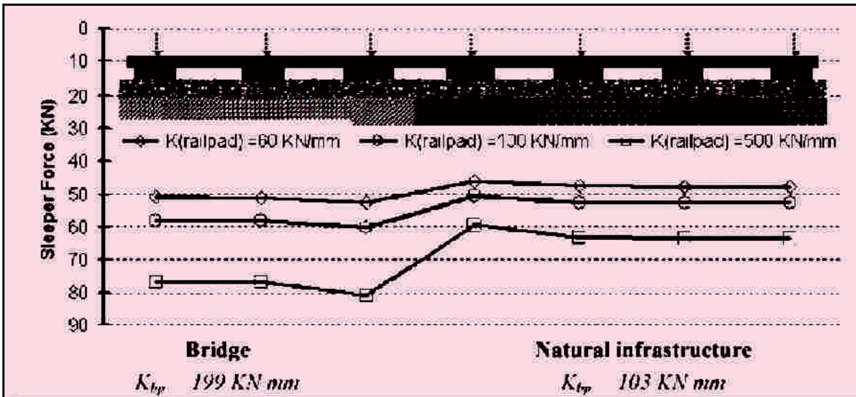


Fig.7.5.6.1: Typical Longitudinal section of Embankment – Bridge transition



K (railpad) = 500 KN/mm

K_{min} *(track)* = 252 KN/mm — K_{max} *(track)* = 196 KN/mm

max K_1 / K_2 = ***1,29*** [between consecutive sleepers]

K (railpad) = 100 KN/mm

K_{min} *(track)* = 145 KN/mm — K_{max} *(track)* = 130 KN/mm

max K_1 / K_2 = ***1,12*** [between consecutive sleepers]

K (railpad) = 60 KN/mm

K_{min} *(track)* = 111 KN/mm — K_{max} *(track)* = 103 KN/mm

max K_1 / K_2 = ***1,08*** [between consecutive sleepers]

Fig.7.5.6.2 Effect of the rail pad stiffness on a transition bridge-embankment

7.5.7 Construction Methods:

This sub-sections describe the principal construction methods that may be used in the construction of the bridge structures/embankment :

i. Cast-in- Situ-Decks

The decks are entirely cast-in-situ using scaffolding. The pre-stressing of the deck is done by means of post-tensioned tendons located in the webs and in the slab. This solution requires a large working area below the deck and usually leads to a poorer quality of the concrete.

ii. Pre-cast, Post-tensioned Decks

The decks are entirely cast and pre-tensioned in the plant area. They are moved to their final location using trucks (usually moving on the already built deck) and launched using gantries. This solution is limited by the self weight of the deck.

iii. Pre-cast Post-tensioned Beams and Cast in Place Slab

The construction method could be an alternative to the pre-cast, pre-tensioned deck in case of transportation problems.

iv. Embankments

The height of embankment on proposed alignment varies from zero to 8.0m. If one account of any reason, enough land acquisition is not possible, Reinforced Earth embankments shall be used.

Entire base soil has to be properly treated wherever soil quality is poor. These will however be based on detailed soil investigations in field to be carried out at detailed design stage. The earth to be used in the embankment will be imported good quality soil, which is free from expansive and organic material.

The primary objective at all times will be to strictly control the post-construction settlement of embankment.

7.6 Environment :

The aspects which concern the environment (the noise in particular) must also be considered when a new line is designed for speeds which exceed 300 km/h.

The aspect of the environment, mostly affected by the increase in speed is the subject of noise. In fact, the nature and source of the noise changes with the speed. At a speed of 120 kmph, noise of train is predominant. But at a speed of 160 kmph, noise of track will also play a role and further at a speed of 300/350 kmph, the noise of pantograph and aerodynamic noise will also come into picture.

In case of high speed trains, when the speed increase, the intensity of Noise & Vibration pollution increase and become a major environmental problem for the nearby residents.

7.6.1 Problem of noise from high speed trains:

Noise problems of High Speed trains have been determined through extensive measurement programs conducted by researchers in many countries. Noise level from high speed trains increase exponentially. Rail wheel noise generally increases as the cube of velocity up to a transition speed where aerodynamic noise sources on the body surface begin to dominate; above the transition speed the noise level increases as the sixth power of speed.

7.6.2 Noise emission level:

Noise emission regulations pertaining to rail road operations are given in Environmental Protection Agency (SA) for Rail road l safety standards.

Unacceptable level - 80 dB(A) for 60 minutes or more in 24 hr. period. -
75 dB(A) for 8 hours or more in 24 hours period.

Normally acceptable level - 65 dB (A) for 8 hours in 24 hours period.

The rolling stock STI specifies the noise emission by the value at 25 metres.

By way of example, the maximum levels of noise to be met in France on the front of dwelling close to high speed lines are 60dB during the day (6.00 am to 10.00pm) and 55 during the night.

In Spain, the limitations for noise are as follows:

55 dB , between 10.00 pm and 07.00am

65 dB , between 07.00 am and 10.00 pm

A further limitations (still in Spain) is that there is a limit of 90 dB, measured 2 metres from the front of buildings (85 in zones of high acoustic sensitivity.

7.6.3 Noise emission Sources:

The noise radiated by the track is strongly related to the stiffness of the rail fastening, in particular the rail pad between the rail and the sleeper. Soft pads minimizes noise from the sleeper but allows the rail to vibrate more freely. Conversely, with stiff pads the contribution from the rail is reduced but that from the sleeper is increased, A compromise can be reached when the sleeper contribution is equal to the rail component.

When rail corrugations form on the rail head, the noise from both tread-braked and disc-braked stock increases. The normal remedy is to grind the rail.

The use of disc brakes and the elimination of supplementary block brakes on high-speed trains, such as the ICE and the latest-generation TGV, is largely responsible for the fact that these trains are no noisier at 300 km/h than traditional (tread-braked) stock at conventional speeds of 140-160 km/h.

Propulsion Noise from electric traction motors, control units & associated cooling fans contributes at high speed. Aerodynamic noise due to air flow over train and aerodynamic noise from pantograph itself also contributes considerably at high speed.

For high speed trains, Pantograph noise is a big issue from noise pollution aspect. Pantograph noise has three compositions-

- Aerodynamic noise from pantograph itself
- Spark noise caused by contact loss
- Sliding noise generated between the contact strips and the overhead contact lines

Special attention should be given to assessment systems for the level of noise. Regarding the limitations, each country has its own regulations and the limits are very different.

To overcome the problem of Pantograph noise, Shinkansen-Japanese Railways has developed a new type of pantographs like PS207, PS9037, PS9038, single arm type pantograph and <-shape pantographs. These pantographs have been provided with multi segment contact body structure with enhanced insulation system. Central part of contact strips are set on a leaf spring made of titanium and it is moveable. Contact strips are set on glass fibre reinforced silicon rubber to provide dampening like effect to sound generation.

7.6.4 Vibration Problems for High Speed Trains :

In comparison with noise, ground borne vibration is less widespread as an environmental problem. People exposed to vibration, tend to be those whose homes or places of work are near a city street with buses or trolleys, or near a highway or railway. When a vehicle passes by, these people may experience feel able movement of the building floors, rattling or windows, shaking of items on shelves or walls, and rumbling sounds, all of which can lead to annoyance when the events happen many times during a day and night.

7.6.5 Measures to Control Noise and vibrations:

For keeping noise pollution and vibrations within control following measures may be adopted:

- Reduction of Rail Pad stiffness by providing soft pad
- Rail Shape optimization by reducing rail height/width
- Reduction of rail corrugation.
- Reduction of rail roughness & wheel roughness.
- Increase of Contact area & decrease of contact stiffness.
- Layout away from inhabited areas
- Noise protection walls
- Noise protection embankments
- Artificial sound barriers/acoustic baffles
- Covered sections
- Artificial tunnels for noise protection.
- High and modified maintenance practices

- Modification in rolling stock
- Modified Pantographs

7.6.6 Noise reduction measures in Japan:

Japan has some of the strictest noise, pollution standards of any country, and this has a major influence on acceleration strategy.

The principal sources of noise and vibration are the current collection system, the under floor area (wheel/rail and bogie noise), aerodynamic noise from the upper part of the car body, noise from the nose area, and structure-borne noises. Current collection represents the biggest share of the noise generated by Shinkansen trainsets. As well as changing from two collectors to one, Japan has developed two types of low noise pantograph. One has a dogleg-shaped main frame and the other has a 'straight stick' shape. Both have streamlined lower parts. In addition, noise insulation shields around 7m long are installed on both sides of the pantograph. The cross section of these panels was chosen through acoustic testing to maximise the noise reduction effect.

Noise barriers are fitted along most of the high speed lines to diffuse the sound coming from the lower parts of the trains, but these do not mask it completely. Sound waves bounce between the walls, and are diffracted and attenuated, before bouncing over the walls and away from the track area. To try and tackle this problem, Japan has fitted sound-absorbing materials on the lower exterior and underside of the vehicles for the first time on a Shinkansen trainset. To reduce aerodynamic noise from the nose and upper body shell it is necessary to make the roof, side and nose completely smooth. Paying particular attention to the joints between vehicles, Japan has developed a metallic covering for the gap, with a removable linkage inside. These are fitted between all vehicles in the prototype train set.

When a Shinkansen train enters a tunnel at full speed, a compression wave is created. This is transmitted through the tunnel at the speed of sound, and creates a shock wave at the other portal. To minimise the effect of these so called micro-pressure waves, Japan has already optimised the nose shape on their various trains, and installed buffering at the entrance of the tunnels.

For any future speed increases, it will be necessary to suppress the micro-pressure waves to below the current level. For Fastech 360, Japan extended the length of the noses to 16m, and optimised their shapes using 3D CFD analysis. Japan has also reduced the cross sectional area of the car body .At locations where these changes cannot deliver the target noise reductions, Japan is developing low cost buffering and pressure wave attenuation measures to be installed inside the tunnels.

Electromagnetic actuators have been installed between each bogie and the car body, providing an active suspension which has a large thrust and good responsiveness to suppress lateral oscillation and improve ride comfort. This augments the air bag secondary suspension which is derived from that already in use on the Series E2 sets. Fastech 360 is one of the first Shinkansen trainsets to feature an 'air-spring-stroke' tilt system, to reduce the centrifugal force experienced by passengers and improve ride comfort and improve ride comfort through curves.

Depending on the radius of the curve and the speed of the train, extra air is pumped into the airbag secondary suspension on the outer side of each bogie, tilting the car body inward by up to 2. To minimise interior noise levels, the sound insulating properties of the car body have been greatly improved.

7.7 Level crossing / grade separation:

No level crossing will be provided for high speed train operation and therefore, for road transport, either road over bridges or road under bridges needs to be planned. LGVs are fenced along their entire length to prevent trespassing by animals and people are not permitted and bridges over the line have sensors to detect objects that fall onto the track. All LGV junctions are with tracks crossing each other using or eliminating crossing other tracks on the level.

7.8 Fencing :

On high-speed lines, trespassing is very risky and thus not at all permitted. Therefore, the entire high-speed track is to be provided with fencing. It is noticed from the experience of high speed corridors, world around that at very high speeds, track ballast stones sometimes fly off and hits the surroundings. To avoid such incidences, track fencing is required to be provided.

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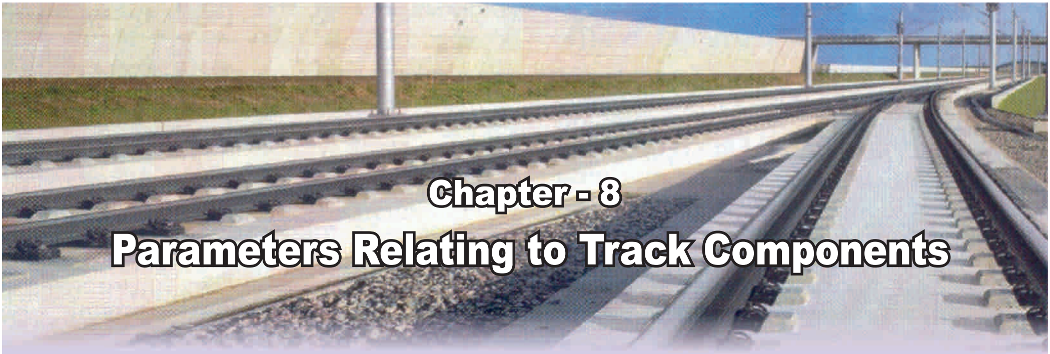


Chapter - 8
Parameters Relating to Track Components

8.1 Rail :

There is general agreement between the various railways on the fact that it is not necessary to use different types of rail for different speeds. Thus both for 300 km/h and for 350 km/h, it is the rail type UIC 60 which is recommended. There is the same agreement on the grade of steel (900 A).

The quality of the rail is not, in principle, affected by the increase in speed above 300 km/h, if the rail to be laid is of the "top of the range" type. However, it is recommended that attention should be paid to the aspects : acceptance, assembly, welding, surface defects etc.

Certain railways consider that the length of the individual rails should not be close to 36 meters, to avoid running on some particular points due to the welding which have a critical wave length. Standard length of 25m in Japan, 54m/62m in Germany and 108m in France has been utilized. CWR is used to improve the ride quality and to reduce noise and vibrations.

The inclination of the rail is 1:20 as is normally used in all the countries concerned, with the sole exception of Germany which uses 1:40. The STIs recommend 1:20 for speeds above 280 km/h. However now for high speed 1 in 40 is being recommended and used.

The STIs specify the values of the distance apart, inclination and wheel profiles which enable the lowest possible equivalent conicity to be obtained above 280 km/h (without distinction between 300, 350km/h, etc.)

Other things being equal, the higher the speed, the less should be the equivalent conicity. It is necessary to study the wear profile, vis-à-vis the economy of operation and to observe the equivalent theoretical conicity.

Generally 60 kg/m rail track is considered acceptable all over the world for high speed corridor. Thus, it is proposed to have 60 kg 90 UTS FF UIC new rails with CWR/LWR over the entire stretch as per the provision of permanent way manual for Indian High Speed Corridor.

There is no problem with the quality of the rail, but attention needs to be paid to aspects such as, acceptance assembly, welding and surface defects. The equivalent conicity should be further and further reduced as the speed is increased and the wear profiles should also be monitored

8.2 Sleepers :

Prestressed concrete sleepers have been a better choice as they have long life of 50 to 60 years. Sleeper density of 1660 is being used over Indian Railway and is adequate for high speed route as this is the maximum density to carry out machine maintenance.

Table 8.2 shows the parameters of the different type of sleepers used by the railways.

TABLE-8.2 - Parameters of the different types of sleepers used by the railways.

	Country									
PARAMETER	France		Germany		Italy		Spain		Belgium	SIT
Speed in Kmph	300	350	300	300/350	300	300/350	300	350	350	350
Type	Two block/ monoblock	Two block/ monoblock	Monoblock B 90	Monoblock B75	Monoblock	Monoblock	Monoblock	Monoblock	Monoblock	-
Sleeper (spacing number of sleepers/km)	1 666	1 666	1 666	1 587	1 666	1 666	1 666	1 666	1 666	1 600
Weight (kg)	245/290	245/290	330	380	400	400	300	320	300	>220
Length (mm)	2415/ 2 500	2415/ 2 500	2 600	2 800	2 600	2 600	2 600	2 600	2 500	. 2250
Width (mm)	290	290	320	330	300	300	300	300	300	-
Height (mm)	220	220	180	200	220	220	222	242	200 to 215	-
Effective surface area per rail (cm2)	2 436/ 3944	2436/ 3944	3 340	3 780	3900	3 900	3 010	30 10	3688 (approx.)	-
Other characteristics	-	-	In general for V > 200 km/h, track without ballast	-	-	-	-	-	-	-

One difference that can be identified between the various railways is that of the weight. Except in Spain, no distinction is made in the other countries for trains running above 300 km/h.

The height of the sleepers used in Spain (242mm) is greater than those used in other countries.

The effective surface area of the sleepers is an essential factor for the distribution of the vertical forces exerted on the ballast, but the magnitude of this surface area and its possible variation depending on the speed have not been dealt with in an explicit manner. There is no obvious problems for sleepers (checking of the bearing surface only).

8.3 Rail Pads, Fastening Systems and Stiffness of the Track :

The stiffness of the track must be limited in order to reduce the vertical dynamic forces between wheels and rails, by the use of rail pads under the rail with appropriate characteristics. There is lot of interest on the other hand for rail pads, in particular with respect to their stiffness (stiffness of the rail pads and overall stiffness of the track).

Double elastic rail fastenings are necessary for the concrete sleeper track. Rubber pads are used as cushioning material between the rail and sleepers fastened by leaf spring/wire spring/TGV Nabla/ICE Vossloh fittings for distribution of vertical load and for dampening the vibrations. SNCF uses two types of rubber pads. Normal rubber pads of 9mm thickness with a resistance of 90 KN/mm and soft type rubber pads of same thickness with low resistance of 56 KN/mm. Soft type rubber pads are mainly used for noise mitigation.

As far as ballasted high speed lines are concerned (according to the STI), the dynamic rigidity of the rail pads under the rail must not exceed 600 MN/m.

Similarly, the total dynamic stiffness of slab track systems must not exceed 150MN/m.

Rail pads are generally formed of rubber or elastomer elements and one of their main characteristics is the vertical stiffness. It is especially critical on bridges, tunnels and slab track. Table 8.3 summarises the existing criteria in each country and indicates the thickness of the rail pads used.

TABLE 8.3 : Thickness and Static Vertical Stiffness of the Rail Pads

	Country							
Parameter	**France**		**Germany**	**Italy**		**Spain**		**Belgium**
Speed in Kmph	300	350	300	300	350	300	350	320
Thickness (mm)	9	9	10	10	10	6	7	10
Static vertical stiffness (kN/mm)	100	100	27	100	100	500	100	50-100
NOTE : It is necessary to check that all the stiffnesses are calculated in accordance with the same standard.								

The analysis of the above data shows that there are important differences between the values used from country to country, both regarding the thickness of the rail pads and for their vertical stiffness. The optimum value stiffness of the track(as an assembly)is found to be 50KN/mm for 200 kmph and 78KN/mm for 300 kmph. An excessive increase in the stiffness of the rail pads can have negative consequences on concrete sleepers. The stiffness of the existing 6 mm rubber pads being used in Indian railway is between 150 to 250 KN/mm.

In view of the importance of the vertical stiffness of the track in the track-vehicle dynamic system, this point should be carefully considered so that the optimum value can be found for each variable.

Germany has opted to have reduced track stiffness in future and has established a correlation between the weight of the sleepers and the stiffness of the rail pads (it is necessary to specify that it is the secant stiffness, measured between two given values of load).

A fastening system has been developed with a distribution plate on an elastic pad with a surface area double that of the rail pad under the rail.

There is a tendency to choose an overall stiffness of around 100kN/mm. In France, the same characteristics have been selected and have not been changed by the increase in speed.

The homogeneity of the stiffness values needs to be checked all along the line.

In order to assess the ability of the track to carry trains running at speeds of more than 300 km/h, with a minimum maintenance cost it is necessary to try to establish a reference value both for the vertical stiffness of the track and for its damping capacity.

8.4 Turnouts for High Speed :

When the speed on straight track is above 250 Kmph, High speed turnouts with speed on curved track from 80 to 100 Kmph are warranted.

The main factors affecting design of turnout are

(i) Kink in the turnout route at the toe of switch rail

(ii) Entry from straight to curve without transition

(iii) Lead curve without super-elevation

(iv) Entry from curve to straight without transition

(v) Gap at the V of crossing

As the wheel negotiates the toe of switch, there is abrupt change in direction resulting in lateral jerk on bogie and corresponding heavy lateral force on tongue rail. The magnitude of force primarily depends on switch entry angle. By reducing the switch angle, entry gets smoothened and flange force gets reduced. The small switch angle is obtained by providing curved/ tangential switches. In tangential type, very small switch angle is possible. Tangential types of switches are used over foreign railways for HSR. As per D72 ORE report and trials over SNCF railway, higher speed can be permitted over T/out by reducing SEA.

Absence of super elevation over Turnout causes unbalanced lateral acceleration and affects safety and comfort. In high speed turnouts, Switch Entry Angles are small and the permissible cant deficiency on the TO curves becomes main criteria for evaluating the permissible speed.

Up-gradation in turnout technology in the railway system has been guided by the following considerations:

(i) Higher speeds on straight and curved tracks with reasonable level of passenger comfort. Designs have been evolved for a speed up to 230 Kmph on turn out track.

(ii) Least life cycle cost with minimum traffic interruption for repairing.

(iii) Track geometry maintainability comparable with the normal track

(iv) Safety and comfort

(v) Planned maintenance without emergencies

The result of the trial made on the SNCF Railway have given very favorable results by adopting

(i) Adoption of tangential layouts for higher speeds and Thick web switches.

(ii) Flatter Switch entry angle by tangential layouts thereby reducing the angle of attack and reduced lateral forces resulting in increased passenger comfort.

(iii) Use of spring operated switch setting device to ensure proper flange way clearance.

(iv) Use of movable nose crossings housed in a specially designed cradle, thereby avoiding gap at crossing.

(v) Introduction of transition curves thereby improving the running characteristics of the curved tracks.

(vi) Use of asymmetrical profile section ZU- 1in 60 forged to standard rail profile (UIC 60) at the end.

(vii) Continuation of canting of rails through turnout resulting in smoother ride over turnouts.

(viii) Use of higher UTS steel, further hardened to reduced wear.

(ix) Effective holding of stock rail.

(x) Use of non greasing eco friendly base plates.

(xi) Use of specially designed synthetic rail pads for reduced vibration of switch assembly.

(xii) Use of flatter angle of crossing i.e. 1 in 32 or 1in 24. Sophisticated pulling techniques including introduction of hydraulic systems.

(xiii) Surface hardening of load bearing areas.

By above modifications, the forces, accelerations and rolling movements, were less than the normally allowed limits. Further the actual sensation felt by the passenger was very good. Based on the above data turnout for HSR can be designed.

8.4.1 Rail Wheel Dynamics and noise over the Turn Outs:

As speed increases, the dynamics of rail wheel interaction become more sensitive to geometry. Dynamics in turnouts are further more sensitive due to inherent imperfections in turnouts like discontinuity at crossing portion, thinning of rail section at switch.

At higher speeds, noise is another parameter that comes into play which is normally not a parameter at all at lower speeds. Due to imperfections at turnouts, the noise levels at these points is further more.

Even a slight geometrical imperfection causes increase in noise levels. Rail wheel dynamics need to be simulated to evolve the design methodologies.

Various manufacturers world over, based on their own research came out with their own designs of turnout systems i.e switches, crossings, sleepers, signaling systems etc. These designs need to be customized for adoption in India. Most of these designs are patented and for standard gauge. For Indian scenario, if these patented designs are directly adopted, it will be a huge drain on finances. Thus adoption of any design is a techno economic decision and the implications are huge.

A Ballastless turnout (1 in 38) used in Japanese Railways is shown in Fig. 8.4.1.1 which allows 160 kmph on turnout side.

Fig. 8.4.1.1: 1 in 38 Turnout in Japanese Railway

Ballastless turnout with lead radius of 10,000 m in Beijing – Tianjin line of China where the main line speed is 350 kmph is shown in Fig. 8.4.1.2

Fig. 8.4.1.2: A turnout used in China High Speed Railway

Fig. 8.4.1.3: An under construction high speed turnout

Various high speed railway uses mostly turnout designed and manufactured by the following firms:-

(i) Vossloh Cogifir / France

(ii) VAE GmbH / Austria

(iii) BWG / Germany

(iv) Balfour Beatty Rail Track Systems Limited / UK

(v) Rail.one / Germany (turnout sleepers manufacturers)

8.4.2 Important critical design factors for high speed turn outs:

The following design factors are to be considered for high speed turnout.

(a) Crossing Angle :

Crossing angle is the major factor for deciding the speeds on turnouts. Flatter the crossings, more are the speeds allowed and more the costs. Japan used 1 in 38 turnout with lead curve radius of 4200m and overall length of 135m. This allows 160 kmph on turnout side. On SNCF, 1 in 43 turnouts are used. For new lines, crossing angle can be decided based on the speed requirements. But for existing lines, to change the crossing angle, is a major decision and has got severe financial and operational repercussions. Therefore, crossing angle for new lines as well as on existing lines has to be judiciously decided taking into account various factors.

(b) Switch Entry Angle and Toe of Switch :

Switch entry angle is primarily responsible for wear and damage to the thin switch portion. The lesser the switch entry angle, the lesser is the damage to switch and higher is the permitted speed. Ideally, switch entry angle and thickness of Toe should be ZERO. In SNCF Railway, 0^0 4' 23" switch angle is adopted for a speed of more than 200 kmph on turnout.

(c) Switch Radius and Transition:

One of the major constraints of our conventional turnouts is non transitioned lead curve. With this design, at higher speeds, limiting the jerk to the desired level of 1 m/s^3 is difficult. BWG's high speed turnout design uses a non-constant radius. To reduce jerking at the transition from the straight to the curve, the switch is modified using clothoid transition whereby the initial radius reduces continuously towards the final switch radius. At the outer end of the divergence, another clothoid section increases the radius infinity. This design reduces the maximum jerk at the start of the turnout to 1 m/s^3, ensuring a good ride quality and improved tangential stability.

(d) Inclined points & Crossings:

In the conventional turnouts being used in India canting/inclination is not provided throughout the turnout. It results in poor rail wheel dynamics and more noise. By providing inclined running table by creating desired switch profile, the turnout for high speed guarantees perfect continuity of running over the points and crossings. It reduces maintenance, avoid jolting, thus improving passenger comfort.

(e) Lubrication free Switches and the environment:

Vossloh Cogifer uses two ways of elimination of the lubrication of switches or movable switch diamonds to reduce pollution:

Roller Slide Chairs : Manufactured with quenched steel rollers and Cast Iron cages, roller slide chairs reduce mechanical stress and enable points to be moved easily. They are easy to fit and can be adopted for vertical or inclined mounting.

Nickel Chromium Treatment : A Nickel chrome metallization is applied to the switch sliding surfaces. The surface treatment applied to cast iron, engineering steel or carbon steel is obtained by ultra high speed projection of metal powder with high nickel and chrome content.

(f) Movable Manganese mono block crossing:

Conventional Crossings get lot of impact due to discontinuities. This impact causes loosening of packing, fittings, fast wear of crossing & wing rail. Manganese mono block crossings effectively addresses this problem by providing continues guided path to the wheel.

It produces less noise, have longer life cycle and eliminate check rail. It allows operating speed of more than 320 kmph on through track and 230 kmph on turnout track.

Fig. 8.4.2.1: Movable manganese monoblock crossing

(g) Manganese mono block crossing with welded legs:

This is the most important innovation in the field of Manganese Crossings. It is an industrial process for welding rails to the crossing rather than fish plating them, thus ensuring perfect continuity on straight or curved track.

RDSO has already developed a design for this and some firms are also approved for manufacturing these crossings.

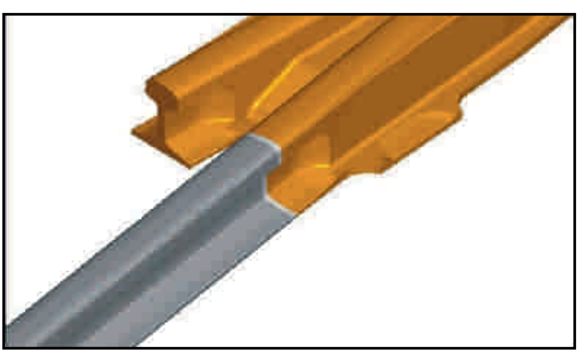


Fig. 8.4.2.2: Manganese monoblock crossing with welded legs

(h) Curved Gauge Face of Crossing:

If the straight portion of leg of the crossing is made "ZERO", radius of lead curve increases and speed potential increases. Eliminating kink at weakest point (of gauge face discontinuity) will greatly reduces the impact on the crossing assembly. Curved gauge face crossing of one of the high speed Railway systems is shown in fig. 8.4.2.3

Fig. 8.4.2.3: Curved Gauge Face of Crossing

(i) Divided sleepers in Crossing portion:

During machine packing, alignment and level corrections are first made in the main line. When packing machine is shifted to turn out side, correcting Alignment is very difficult because any attempt to correct turn out alignment disturbs the main line alignment due to the rigid and longer sleepers in crossing portion.

With the result, the turnout side alignment can not be corrected. To take care of this problem, the crossing sleeper is divided and connected by a mechanical system. With this system designed by BWG/Germany, the turnout alignment can be corrected independent of Main Line alignment. By this divided sleepers technology, handling and transportation of sleepers also become easier. Principle of the splitted sleepers is shown in Fig. 8.4.2.4.

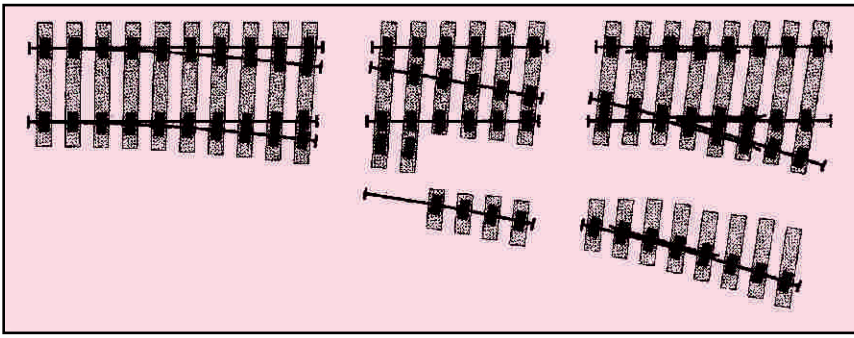


Fig. 8.4.2.4: Principles of splitted sleepers

Fig. 8.4.2.5 Picture of a turn out laid with splitted sleepers

(j) More Ease for Machine Packing:

For machine packing of P&C in the existing design, some difficulty is experienced due to fixing point machines away from the switch and using the rods to give the point pull. If the point machine is an integral part of an ordinary sleeper, the machine packing becomes very simple. Such integrated design developed by Vossloh Cogifer is shown in fig. 8.4.2.6. This electromechanical cum hydraulic operation device is integrated into a P&C sleeper which is exactly same as the sleepers on either side; It can provide point, heel or movable crossing control. Its shape makes mechanical packing considerably easier.

Fig. 8.4.2.6: Electromechanical cum hydraulic device

(k) Improved Design of fittings:

Improved stock rail fittings and improved check rail for high speed turnouts are shown in Fig. 8.4.2.7 & Fig. 8.4.2.8

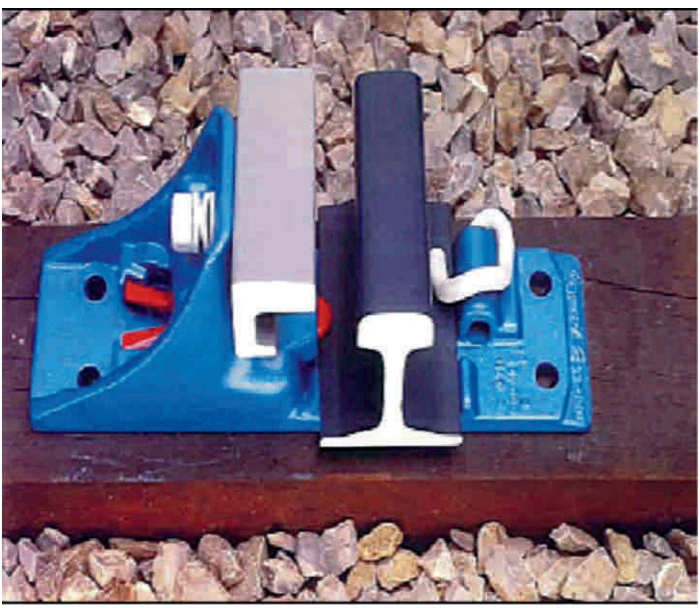


Fig. 8.4.2.7: Improved design of check rail brackets

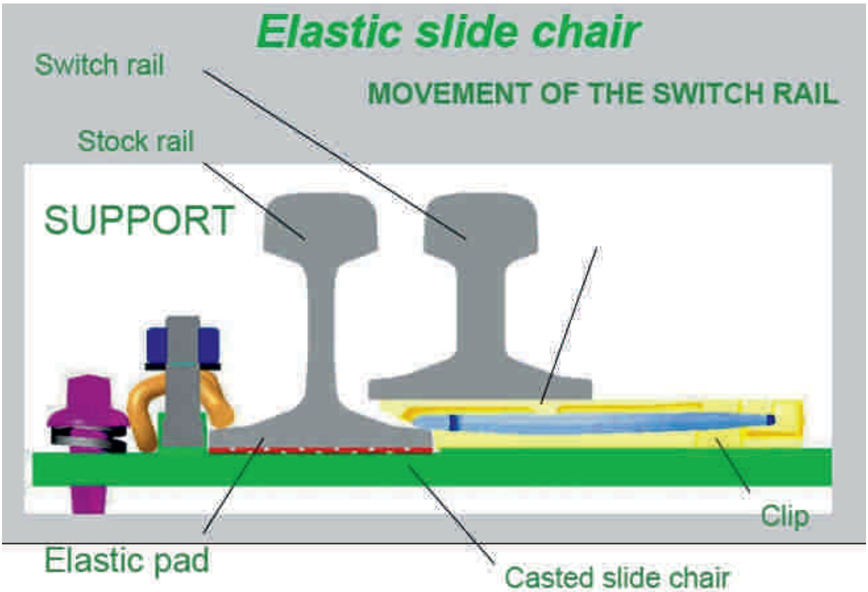


Fig. 8.4.2.8: Elastic slide chair

(I) Improvements to Signaling and Interlocking:

For allowing higher speeds, signaling and interlocking needs upgradation. Multiple point pull, Hydraulic pull, clamp lock, moveable point lock, traffic detector, solid state interlocking etc are some of the improvements needed to improve the reliability of interlocking as well as increasing the speeds. Movable point lock is shown in fig. 8.4.2.9

Fig. 8.4.2.9: Movable point lock

8.4.3 Challenges in transportation and laying of high speed turnout assembly:

Due to the longer lengths, heavier weights and precision, handling turnouts from production spot to final location is a big challenge.

For Taiwan high speed lines, all turnouts were produced, tested and approved in Germany, and then dismantled for shipment to Taiwan.

The turnouts were re-assembled at the China Steel Machinery Corp premises in Kaohsiung, with Taiwanese technicians. Modules up to 55 m long weighing as much as 50 tons were transported by road for distances of up to 300 km.

Taiwanese developed a special road trailer for the largest assemblies.

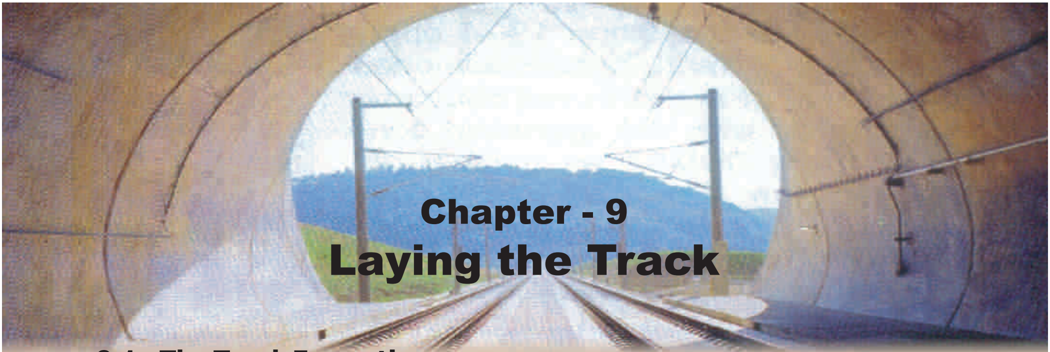
All routes had to be assessed in advance, and obstacles such as walls and traffic lights removed temporarily to allow for the passage of the vehicle. Special permits had to be obtained to carry out these movements at night to ensure that the material was available on-site for the next morning.

At some locations, soft ground required extensive earth work. Special equipment was developed in Germany to unload the individual parts and maneuver them onto site. In some places two 200 ton cranes were needed to lift the switch units. A technique was developed to make the installation of preassembled switches more efficient. The Turnout Shifting System allowed a quick initial alignment of switch assemblies to an accuracy of ±5 mm in both horizontal and vertical directions. A modular temporary track allowed the switch components to be transported along the line from unloading site to final position - in some cases as much as 1·5 km.

In other cases, assemblies were moved along the newly-installed running rails. Measuring and final alignment of the switch modules was completed using an electronic system developed for high speed lines in Germany. The final co-ordinates of each switch were analyzed using a manually-operated measuring vehicle, and all alignment data logged. A second check was undertaken before the start of concreting. Switch transportation wagon and relating machine shown in fig. 8.4.2.10 & 8.4.2.11.

Fig. 8.4.2.10 : Switch transportation wagon WTW

Fig. 8.4.2.11 : Switch relaying machine WM 500



Chapter - 9
Laying the Track

9.1 The Track Formation

At high speeds, requirement of track quality during service is very high. The track right from the subsoil, formation protection layer, sub-ballast, ballast bed, sleepers and track components is to be considered as one system. The main task of these components is to transmit load and divert forces caused by the trains to the sub soil with least possible disturbance to the track geometry.

Though for high speed passenger corridors, axle load is normally not more than 18t, yet the formation plays a very important role for stability and durability of strict track geometry.

The typical parameter for formation is the modulus of deformation (E) derived from the plate load bearing test.

A schematic diagram showing the transfer of load and resultant stresses is shown in Fig. 9.1.

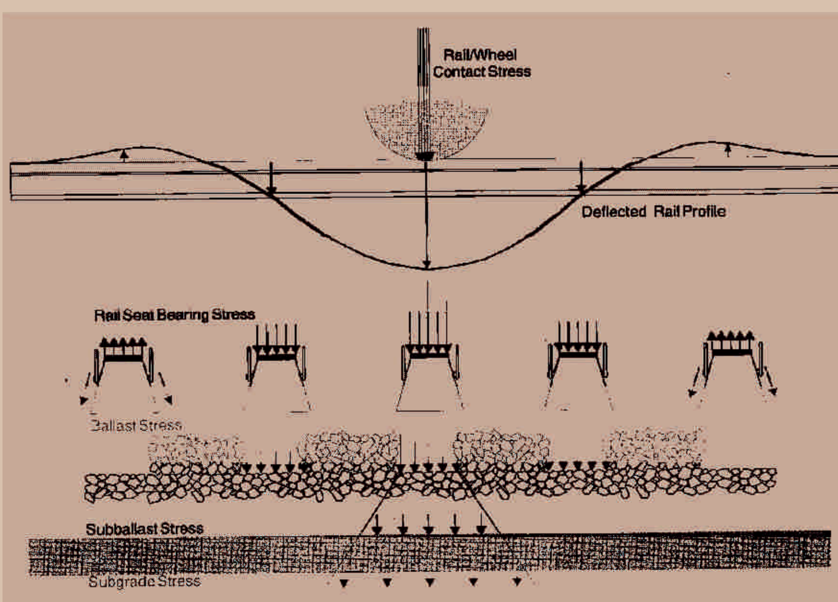


Fig 9.1 : Typical wheel load distribution into the track structure

9.2 Sub-grade:

Formation can be divided in two distinct entities i.e. substructure/sub-grade and protective layers/sub ballast. The basic aim of formation design is to minimize formation settlement.

Sub grade /substructure settlement can result from various reasons such as

a) Excessive plastic deformation.
b) Consolidation and massive shear failure.
c) Progressive shear failure.
d) Excessive swelling and shrinking.
e) Frost heaves and thaw softening.
f) Sub grade attrition.

For the high-speed tracks, quality of sub grade/substructure plays very important role. Any weakness or deficiency in the sub grade may likely to disturb track geometry. Therefore, good quality of sub grade is of prime importance.

There are four alternatives for the improvement of the sub-grade:-

a) Altering sub grade properties of new formation by grouting lime slurry pressure injection or by electrical treatment.
b) By compaction and admixture stabilization with cement, lime, bitumen and fly ash.
c) By asphalt-concrete applications
d) Slip stabilization, by improving drainage, by providing retaining structures and by giving suitable and stable slopes including benching.

Formation improvement measures should ensure constant modulus of elasticity of at least 4.5 kN/cm^2 – optimum value – 12 kN/cm^2 over the entire track length. The modulus of elasticity should decrease continuously, otherwise mud would be pumped up. It should have life time of more than 20 years and low installation costs. The only method to meet all these requirements is the insertion of a formation protective layer.

9.3 Sub ballast or protective layers :

Sub ballast or protective layers are provided to fulfill the following functions:

a) Supporting layer : The load distribution effect protects the subsoil from too high a stress, if its bearing capacity is insufficient.

b) Frost protective layer : Its thermal insulating effect protects frost-sensitive soils from frost, if the soil below the formation is also sensitive to frost

c) **Filtering and separating layer** : Prevents the ballast from mixing in with the substructure and fines from rising into the ballast

d) **Equalizing layer :** If due to extreme differences in bearing capacity the track is supported unevenly or if, e.g., on rocks no plane formation of the respective cross slope can be established, and

e) **Covering layer with low water permeability:** Protects soil sensitive to water from surface water.

Figure 9.3(a) shows the usual definitions of track structure.

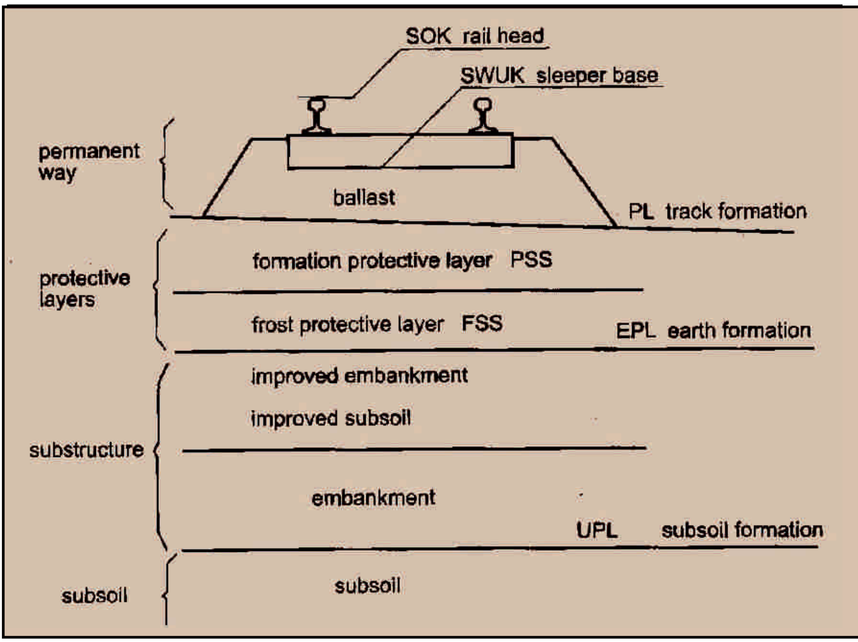


Fig. 9.3(a) : Layers of the track structure on earth formation

Figure 9.3(b) schematically compares a track with a formation protective layer and a track without it. The figure shows that the pressure on the formation without a formation protective layer is much higher because the force transmission area is much smaller. This makes high demands on the bearing capacity of the soil. Soil fines coming up contaminate the ballast bed, the pressure propagation angle is reduced (friction between the ballast grains decreases) and pressure on the subsoil increases. As the ballast bed is contaminated, the durability of tamping deceases – cleaning has to be performed more frequently. The picture on the right hand side shows the advantages of a formation protective layer. Water is led away through the formation protective layer and therefore cannot soak into the subsoil. A formation protective layer of sufficient thickness prevents frost damage. The formation protective layer acts as a filter and prevents fines from rising. The durability of tamping is very high, cleaning becomes necessary less frequently.

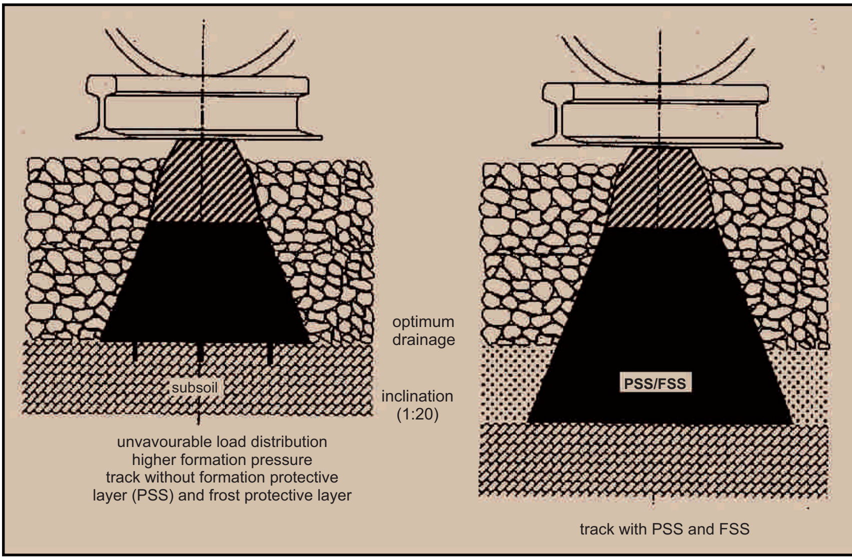


Fig. 9.3(b): Pressure distribution on formations with and without protective layers.

The subballast formation protective layer has:

a) To be impermeable to water to such an extent that the majority of the rain water runs off the formation,

b) To be a stable filter against the substructure or the subsoil. If this requirement is not met, a geotextile should be inserted or the formation protective layer should be made thicker by 100 mm.

c) To be at least of 200 mm thickness and up to 450 mm thick.

d) To make the elasticity as uniform as possible from the ballast to the subsoil,

e) To be inserted in layers and compacted, each layer should not be more than 150 mm thick prior to compaction.

f) To have a layer of at least 200 mm thickness on geotextiles.

The following geometrical requirements have to be met by the formation:

Its cross slope has to be at least 1:20 or 5% with a tolerance of 0.5%.

The formation must not deviate by more than + 20 mm from its design position, and

The formation must be level in its longitudinal direction (<20 mm over a longitudinal basis of 4m), there must not e any troughs or traces of traffic.

9.3.1 Placement of Sub ballast/Protective layer :

After designing proper protective layer/sub ballast material, the same would be spread and roller compacted in layers at suitable moisture content after compacting sub grade surface. The main factor in deciding the quality of formation is the bearing capacity of the track. UIC recommends a thickness upto 450mm.

9.4 Insertion of geotextiles :

Geotextiles contribute a reduction of stress and deformation so as to improve and maintain the bearing capacity of inserted protective layers over a long terms. Geotextiles are inserted between the underlying soil and the formation or frost protective layer. They are laid on the compacted and regulated formation and covered by the protective layer. They have to withstand the static and dynamic stresses of railway operation. They are stressed by hydraulic and mechanical process and have to prevent fines from being pumped up (filtering effect). The function and characteristics of geosynthetic as well as of geotextile are given in table 9.4.1 and 9.4.2.

Table 9.4.1: The main functions and characteristics of geosynthetic are as under:-

Types of Geosynthgetic material	Primary Function				
	Separation	Reinforcement	Filtration	Drainage	Containment
Geotextiles	Yes	Yes	Yes	Yes	No
Geogrids	No	Yes	No	No	No
Geonets	No	No	No	Yes	No
Geomemberanes	Yes	No	No	No	Yes
Geocomposits	Yes	Yes	Yes	Yes	Yes

Table 9.4.2: Tentative specification of Geotextile are given below:-

Composition	Polypropylene/Polyester
Mode of Manufacture	Non woven, needle punched
Thickness	3mm and above
Weight	400 gm/sqm. and above
Tensile strength	Min 60 kg
Elongation at Break	40-100%
Pore size	Max 120 micron
Roll width	Single roll width preferred
Roll Length	As per site requirement

Fig. 9.4.1 : Laying of geotextile

Fig. 9.4.2 : Laying of sub ballast / protective layer

9.4.3 Designed Properties of Geosynthetics:

- It must be tough enough to withstand rigorous placement during Installation process-tensiles strength, shear strength, resistance to ultraviolet light.
- It must be strong and tough enough to withstand static and dynamic loads – burst strength, puncture strength, abrasion resistance, elongation at failures.
- It must be resistant to excessive clogging or blending – permeability.
- It must be resistant to rot. Insects and rodents and to chemicals and diesel fuel.

9.5 Ballast :

In general, in Europe, the majority of the tracks of high speed lines (about 90%) are laid in ballast. Neverthless, DB AG also uses ballastless track, for speeds above 200km/h. This type of track is also used in France in the underground sections where trains run through at a speed more than 220 km/h.

The characteristics of the ballast (size distribution, minimum thickness) and sub ballast are given in Table 9.5 for different countries.

There are no significant differences between countries regarding the smallest size of the particles used for ballasting high speed lines. The differences measured are often the consequence of the (national) standards applied.

Particular attention is drawn to the presence of fines in the ballast. It is also required to consider the mechanical characteristics of the ballast. Among these can be mentioned : the hardness (Los Angeles coefficient, overall hardness coefficient, etc.) resistance to attrition, dimensions, rate of fines, etc.

Table 9.5: Characteristics of the ballast on the high speed lines

Parameter	Country					
	France	Germany	Italy	Spain		Belgium
Speed in Kmph	300/350	300	300	300	350	320
Size distribution of the ballast (1): minimum/ maximum size (mm)	25/50	22/63	30/60	32/63	32/63	25/50
Minimum thickness of the ballast (mm)	300	350 recomm-ended 400	350	300	350	350
Minimum thickness of the sub ballast(mm)	300/700	300	120+ 300(2)	250	300	500/700
(1) Size distribution as specified in a national standard						
(2) 120mm with bitumen sub ballast and 300mm compacted sub layer						

Other things being equal it is possible to conclude that the high quality ballast which exists today could be used without problems for trains that run at 350km/h. In fact, the requirements do not vary greatly between 300 and 350 km/h.

The behaviour of the ballast under vibrations (the possibility of becoming fluid) depending on the speed should also form the subject of an analysis, which should determine at the same time whether it is necessary or not use anti-vibration mates. In general, these mats are not widely used on high speed lines, but are employed by SNCF in some specific cases for use in certain tunnels as well as by DB AG, in tunnels and on bridges (o.10N/mm3, thickness 1 cm).

Some important aspects, such as the attrition of the ballast or other particles on the rail, the effect of the slipstream or the ballast being blown away and the definition of a typical profile for the layer of ballast (which is important, among other things, to prevent the slipstream) must also be considered when speeds are increased.

Grills should be provided on certain bridges to prevent ballast being thrown on the road.

Studies conducted at FAST (Facility for Accelerated Surface Trials, Pueblo USA) have demonstrated that track geometry correction requirement both for alignment and profile variations were least for test sections having ballast depth of 300mm and it has increased for test section having ballast depth both lower (150mm) and higher (450mm) than based on the above discussion, it can be concluded that for high speed corridor at a speed of 250 to 350 kmph, the following specification shall have to be considered apart from properties of ballast metal:-

- Ballasted track on PSC sleepers can be adopted.
- Depth of ballast of the order of 300mm is adequate.
- Higher size of the ballast is preferred.
- Ballast material should be Granite / Basalt only.
- About 150mm thick Sub- ballast layer preferably of bituminous ballast is necessary.
- The shoulder ballast may be increased to 500-700mm.
- The various design parameters should not be decided on the basis of initial cost of laying but on the basis of principles of life cycle costing.

Generally the thickness of ballast cushion varies form 30 to 35 cm over high speed tracks. It is proposed to adopt a thickness of ballast of 35cm along the entire corridor. This ballast cushion should be laid over the sub ballast of thickness 30 cm. The same has been proposed by RITES for Mumbai –Ahmedabad High Speed Corridor.

Fig. 9.5: Profile of protective layer/sub ballast and ballast

Ballasted track for high speed lines should have low average settlement of only 0.3-0.4mm under an axle load of 20 tons, this corresponds to a coefficient of ballast of 0.3-0.5 N/mm^2 .

The advantage of ballasted tracks are considered to be low construction costs, low noise emission, short construction time, the possibility of further development, short repair times in case of damage, cost-effective automated and mechanized maintenance, the fact that the system has been in use for many decades, and the possibility to change superelevation and geometry.

9.6 Ballast less/Slab track:

Certain railways (DBAG, FS, SNCF, JR) have developed high speed ballast less track. In particular, in Germany the decision has been taken recently to build sections of high speed lines (or lines with speeds above 200km/h) by using ballast less track, except for the zones where the train sets must travel at speeds of less than 200km/h, such as stations, etc.)

At first sight the cost of building these tracks greatly exceeds the cost of building tracks on ballast, but experience shows that, especially in tunnels, the maintenance costs are less than the costs of ballasted track (of the order of 1/5th), due to the slower degradation of the geometrical parameters of these track.

The German experience shows that the cost of building slab track is between 50% and 75% higher than that for ballasted track.

According to Spanish estimates, the cost of slab track would be double and the maintenance cost would be half. These estimates assume a life of 60 years for slab track against 30 years for ballasted track.

Ballastless/slab track is also used in Francee in the underground section where trains run through at a speed of morethan 220kmph.

In ballastless/slab track, ballast as the load distributing element is replaced by another material which has stable position, such as concrete or asphalt. The plastic deformation of these materials is very low in regular circumstances. The necessary elasticity has to be provided by inserting elastic elements below the rail or the sleeper, as the concrete or asphalt layer is very stiff.

9.6.1 Requirements of ballastless/slab track:

(a) Non-setting formation/subsoil:

The ballastless/slab track, as opposed to the ballasted track, requires a subsoil which is virtually free of settlement. Due to the small overall height and the lower construction cost resulting from this fact, the slab track is used, above all, in tunnels. Ballasted track requires embankments with a maximum settlement of 2 cm over a track section length of 10m. The resulting waviness of the rail surface may be easily compensated by sophisticated permanent way machinery. These requirements are too low for slab track. The substructure of ballasted track has to be secured by earthwork measures down to a depth of 0.5m below the frost protective layer. On the other hand, the substructure of slab track has to be secured down to a depth of 2.5m blow the bearing plate by earthwork measures.

It is a challenge for the designers of the ballastless track to figure out the suitable and adequate system of the earthwork construction.

The frost protective layer of slab track should not be less than 70 cm (the thickness of the formation protective layer can be taken into account). For embankments, the lower bearing layer of at least 1.8m thickness is made up of the top layer of the filling, for cuttings – of the soil below, or the soil has to be exchanged, if the bearing capacity of the existing soil is insufficient. Soft, cohesive or organic soils in the subsoil should be exchanged at a depth of at least 4m below the upper edge of the track. The consequences of structural measures, such as digging or filling the ground or lowering the groundwater level, must be considered and checked to a higher extent for slab track than for ballasted track.

On earthworks these requirements lead to far higher construction and material costs than those for ballasted track. The line which separates permanent way and substructure is the upper edge of the frost protective layer or the lower edge of the hydraulically bonded bearing layer. For slab track, the ballast is replaced by a concrete bearing layer or an asphalt bearing layer.

One layer of cohesive and one layer of non-cohesive soil material (sandwich layers) – shall be avoided. Nevertheless, if alternating cohesive and non-cohesive soil material layers are necessary, every layer of cohesive soil material will be built with a subgrade surface which has a transversal gradient of 2.5% to the outer side.

Differences in settlement for a narrow range, between +26mm and -4mm, may be compensated by the rail fastenings (by inserting rail pads of different thickness). The lateral position may be corrected within a range of 0-9mm.

Codes provide only a little information about slab track construction concepts. At the moment, only a few safe methods exist to assess the long-term settlement behavior. The life time of slab tracks is still too short to get clear statements on the settlement behavior. Experience gained in road construction shows that higher settlement of high embankments cannot be fully excluded.

In cuttings, the same strict regulations apply. Similar to the requirements for the embankment, the required arrangement of layers and compaction must be guaranteed for at least 3m under the rail. The subsoil must be durable and have a suitable bearing capacity combined with small settlement behavior in time. Soft, cohesive soil must be replaced or other subgrade treatment has to be provided to avoid the influence of soft soil material in the subsoil. The soft soil is responsible for big and uncontrolled settlement, depending on the water ratio and the capacity for dewatering.

These necessary measures to lay foundations on soft soil are mostly complex foundation methods. Thus layers of soft soil can be worked through by bored or driven piles to set up a foundation in deeper soil layers with sufficient bearing capacity. A drainage system is normally necessary in cuttings on both sides of the track. The angle of the slopes must be built according to the regulations or adequately reinforced with anchors, piles or other improvement measures.

(b) Precise construction and strength of the upper bound bearing layers:

Concrete bearing layer:

The required profile tolerance on the surface of concrete bearing layers is + 2mm. The cement content in the concrete is between 350 and 370 kg/m^3. The proportion of reinforcement to limit the formation of cracks must be between 0.8 and 0.9% of the cross section of the concrete. This is to ensure that the width of cracks on the surface remains below 0.5mm. The typical overall height amounts to 200mm. In the case of designs without sleepers the surface is cut at intervals of about 2m to achieve controlled crack formation. The concrete bearing layer can be loaded only after the concrete has hardened and reached a minimum resistance to pressure of more than 12N/mm^2. An increasing thickness of the concrete layer leads to higher bending loads. A minimum thickness of 180 mm should be observed.

Asphalt bearing layer:

Asphalt bearing layers are applied in 4 layers with a total standard thickness (on earth structures) of 300mm. The required construction tolerance on the surface is +2mm. These requirements are significantly higher than the requirements for road construction. Running on the asphalt bearing layer is allowed, when the proper temperature of the asphalt is below 50°C. Asphalt is sensitive to UV-rays, therefore its surface must be covered by stone chips, gravel or similar materials.

Hydraulically bonded bearing layer:

A so-called hydraulically bonded bearing layer is inserted below the concrete or asphalt bearing layer. The typical layer thickness is 300mm. A hydraulically bonded bearing layer is a mix of mineral aggregate (mix of natural sandstone, crushed sand and stone chips) of graded grain size (maximum grain size 32mm), compacted by a hydraulic bonding agent. Portland cements are used as a bonding agent. The content of the bonding agent is about 110 kg/m^3. A minimum width of the hydraulically bonded bearing layer of 3.8m should be observed.

The stiffness which grows from top to bottom thus increasing the total bearing capacity of the entire system is gradually adjusted by the hydraulically bonded bearing layer. The entire system and together with it also the hydraulically bonded bearing layer is designed in such a way as to ensure a modulus of deformation of $E > 120$ N/mm^2 on the surface of the unbound top layer (frost protective layer). The hydraulically bonded bearing layer is inserted with road finishers.

(c) Precise construction and strength of the lower unbound bearing layers:

Frost protective layer:

The frost protective layer also serves to compensate for the differences in stiffness of the various layers towards the subsoil. It consists of fine gravel which is resistant to weathering and frost. Its capacity-breaking property has to prevent water from rising from the subsoil. Furthermore, it has to lead surface water away rapidly. For this purpose values of permeability between $1x10^{-5}$ m/s and $1x10^{-4}$ m/s are required. A modulus of deformation of E $\geq$ 120 N/mm^2 is required for new track and of $\geq$ 100 N/mm^2 for upgraded track.

Subsoil:

Extensive soil investigations have to be carried out, before a slab track can be built on earth structures. For this purpose a soils survey has to be performed every 50m upto a depth of 6m.

The surface of the subsoil for new tracks has an E = 60 N/mm^2 and for upgraded lines an E = 45 N/mm^2. These parameters of bearing capacity are achieved by consolidating the subsoil, using lime or cement to stabilize it. The subsoil has to be compacted to a depth of 3m.

Construction on soft soil:

Measures for sub-grade improvement –

In the design phase one often discuss and calculate many possibilities to improve the subsoil by different compaction methods. The soil is compacted through pushing the lateral surrounding soil. Settlement behaviour and the time for abating of settlement have to be calculated and execution manuals for compaction have to be designed. But a sophisticated and also simple method is the use of CFG (cement, fly ash and gravel mixture) columns and simple stone columns (Fig. 9.6.1).

CFG uses a type of auger to build cement columns by displacement of the surrounding soil. The soil laterally displaced leads to an improvement of the surrounding solid itself. The method can also be used nearby to sensitive structures as existing buildings or structures under construction.

The possibility to control the compression modulus of the cement grout leads to a load-distribution effect between the soil and the CFG columns. Thus allows considerable savings in the required column depth. Contrary to stone columns, there is no limitation of the internal stress in the CFG columns. Hence, there is no risk that the loaded column deforms due to poor bedding conditions of the surrounding soil. The ability to control the effective compression modulus of the grout allows maintaining a reasonable ratio between the modulus of the soil and the column.

A load distributing layer is possible to be arranged on top of the CFG columns. This is avoiding expensive pile cap and concrete slabs. In the classical piles approach, the soil modulus is negligible to the concrete modulus. It means the load applied on the top of the ground is shared between the columns and the soil itself according to the ratio of modules previously defined.

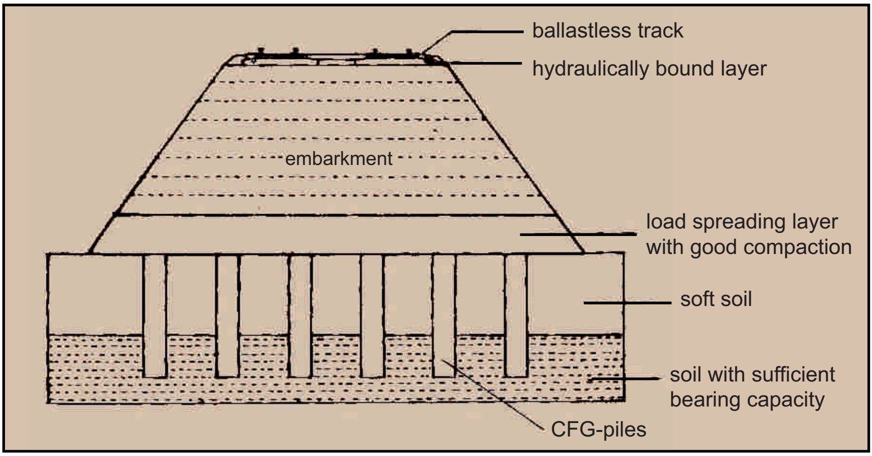


Figure 9.6.1: CFG Piles for subsoil improvement (Cement Fly ash Gravel piles)

(d) Sound protection requirements:

The noise radiation of slab track is significantly higher than that of traditional ballasted track. Compared with ballasted track, structure-borne noise on the rail is distinctly increased within the frequency range of 250-1000 Hz. In connection with noise reflections this leads to the stated increase in airborne noise on the surface of slab track which amount to +5 dB. The reason is the uncoupling of the rail by the elastic rail fastening and the lack of noise-absorption of the ballast bed. The sound emission values of the traditional ballasted track can be achieved only by large-scale noise protective measures (covering the slab track by noise-absorbing material, noise protective barriers, etc.). The simplest method has proven to insert bulky absorbing material and to subsequently compact the surface. The use of soled sleepers ("Acoustically Innovative Slab Track" – AIFF) leads to a great reduction of the noise level. As opposed to slab track, the sound radiation of the railway wheel is effective on ballasted track. Many experiments with a wide variety of noise absorbing media have been carried out. But most of them did not show the required lasting stability or were too much expensive.

(e) Transition from slab track to ballasted track:

Transition areas between bridges, artificial and earth structures as well as between slab track and ballasted track are particularly problematic. Special structural measures, such as additional rails for load distribution purposes and / or gluing the ballast in the transition area are applied.

The standard solution for the transition area from bridges to earth structures is to insert a hydraulically bonded wedge, if necessary, together with a sliding plate, behind the abutment of the bridge.

(f) Requirements for the signaling systems:

As opposed to ballasted track, the corresponding free spaces for the erection of signaling equipment have to be provided in advance. That is to say that the design of the signaling equipment has to be completed, before the slab track is built.

(g) OHE Requirements:

The necessary free spaces for the OHE installations have also to be provided. So their planning has also to be completed before starting to build the track.

The operational currents have to be led back via the rails and, partially in parallel, through the earth.; The permitted voltage difference between the surrounding earth and the rail must not exceed a certain human contact voltage depending on time. Therefore, lower diffusion resistance has to be the aim. All reinforcement parts and other items with metal elements, such as masts, bridge railings and bridges, etc., have to be connected with the railway earth.

On the other hand, a high bedding resistance between the two rails is desirable for signaling equipment. These two contrary requirements have to be coordinated for track building.

A special feature, compared to the ballasted track, is that reinforcement parts, if present, have to be well connected to each other electrically In order to prevent the occurrence of voltage differences. Therefore, the reinforcement of slab track has to have such dimensions as to safely lead away reverse current and short circuits without destroying or damaging the structure. Reinforcement parts have to be earthed at each catenary pole. Some railways use a separate return transmission line.

9.6.2 Slab track in tunnels:

For a tunnel the simplest solution is to build a slab track. The asphalt or concrete bearing layer may be inserted directly on the tunnel base and, provided that corresponding calculations can be proved, its thickness can be reduced, compared to slab track on earth structures.

9.6.3 Comparison between ballasted and ballast less/slab track:

The laying of the track (track on ballast compared with track without ballast) still forms a subject for discussion for which the question is not restricted to checking the cost of the life cycle of each, but also the implications with many parameters and elements.

Provided high quality ballast is used it can be concluded at first sight that the requirements do not vary much between 300 and 350km/h.

However, the main problem with ballast at very high speed are the proliferation of fines and the segregation of the material, the behaviour of the ballast under vibrations (possibility of becoming fluid), the attrition of the ballast or other particles on the rail and the slip stream effect or flying ballast when trains go by.

An essential criterion for a technical comparison is the stability of the track geometry. Here the slab track shows advantages as against the ballasted track. A disadvantage of the ballastless/slab track is the higher airborne noise emission value. This means additional economic cost for the required active or passive noise protective measures which lower the economic efficiency. The slab track is often economically efficient in tunnels, because here the insertion of matting below the ballast is prescribed for ballast track with higher speeds. Furthermore the slab track requires a lower total height.

Further advantages of the slab track are more favourable locations of the lines which can be adapted to the terrain and to existing structures by applying higher superelevation and cant deficiency values. Another advantage is the lower expense for vegetation control.

But on the whole, the ballastless/slab track on earth structure, compared to the ballasted track, is not as effective economically, because the construction costs are too high.

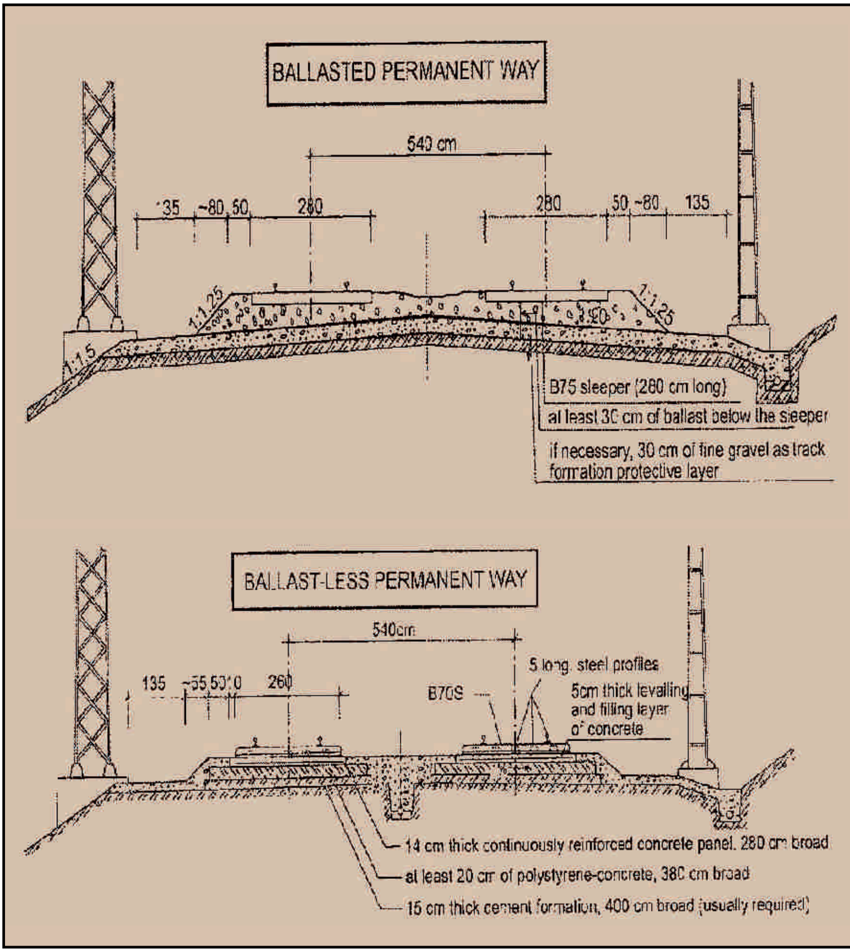


Fig. 9.6.3 Comparison between standard cross section of ballasted track and ballastless/slab track of Rheda design

9.6.4 Advantages of slab track:

The most important advantages of the ballastless/slab track today are seen in the reduced maintenance cost and, consequently, the lower traffic hindrance costs, compared to ballasted track.

The expected life cycle of the slab track (50-60 years) is longer than that of the ballasted track (30-40 years).

The ballastless/slab track ensures a more cost-effective line positioning, as narrower curves at high superelevation and cant deficiency can be applied.

No ballast or solid particles are whirled up on slab track. As the safety against lateral forces is very high, the eddy current brake can be applied without problems. The advantage must, however, be regarded as relative, as the majority of repeated breakings occur only in certain place, e.g., near signals or at station entrances, and is usually of no advantage as against the ballasted track on plain line track.

9.6.5 Disadvantages of slab track:

Cement concrete slab tracks are rigid bearing layers, which can break after their operational strength has been reached – this might be compared to the occurrence of rail fracture. The deterioration of the track geometry in this case occurs suddenly and unforeseeably.

The quality of slab track has to be guaranteed by appropriate high-level quality assurance measures. This means extra cost and time for the construction works and their control. Any quality defect would remain for the entire expected life cycle (50-60 years) and can be eliminated only by applying costly measures.

The rigid structure of the slab track allows only few improvements in the future. Adaptations to changed conditions, such as changes in track geometry, can be performed only with difficulty and at high cost. In case of accidents, damage is considerable.

A slab track cannot be built in certain geological circumstances, such as deep cuttings in clay soils, embankments on soft peat layers, or in earthquake areas.

9.6.6 Types of Ballast less tracks:

A multitude of different design types of the slab track has been developed in the world. A few important and popular one are discussed below:

9.6.6.1 The Rheda design:

The name "Rheda" originates from the first slab track constructed in 1972 in the Rheda-Wiedenbruck station. The "Rheda" design is free of any patent rights. Therefore, during the past years a multitude of structural versions have been developed by various contractors.

Renewal attempts, apart from positive experience during operation, were not convincing. Repairs require a longer track closure. Lever corrections of a greater magnitude can hardly be carried out. In practice, individual sleepers cannot be replaced due to the existence of a through longitudinal reinforcement. The sleeper cribs cannot be used to insert sound absorbing materials.

Common to all design types is the fact that concrete sleepers of 2.60m length are inserted on trough-shaped or through concrete bearing layers. The required exactness of track position is achieved by vertical and horizontal adjustment. After the adjustment the sleeper position is fixed by filling in with concrete. In order to prevent a change in the sleeper position during the hardening of the concrete due to temperature influence, the rail fastenings have to be released.

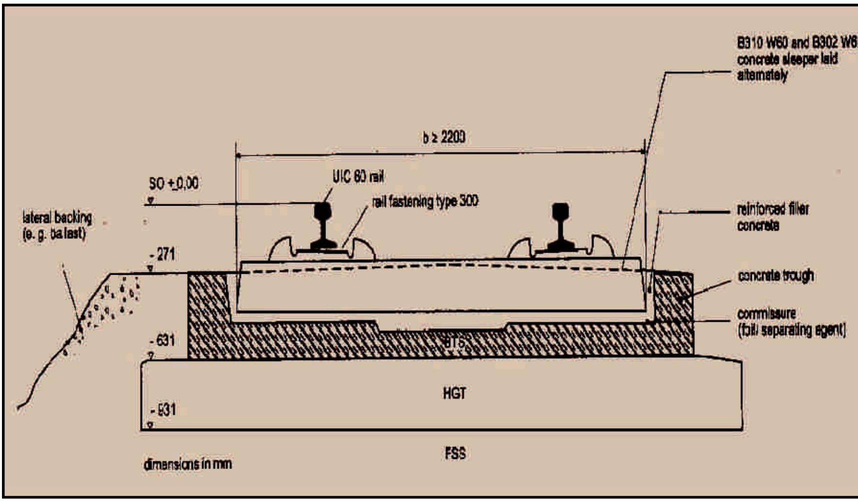


Fig. 9.6.6.1 : Rheda design

9.6.6.2 Rheda 2000 Design:

The Rheda - 2000 design uses modified twin-block sleepers with untensioned braced girder reinforcement. No concrete trough is used. The aim of this sleeper type is to achieve a better adhesion between the reinforcement of the track plate and that of the sleeper. The longitudinal reinforcement of the track plate is integrated into the braced girders of the twin-block sleeper. The sleeper reinforcement, braced girders, projects at the lower surface of the entire sleeper system and therefore can hold the reinforcement of the concrete bearing plate. All elements are cast in concrete in one go without a gap. This is an advantage against the previous Rheda designs, where undesirable gaps could develop between the casting concrete and the trough-shaped concrete bearing plate. Another advantage is the small overall height. This is the most popular slab track system in the world and is being used most extensively.

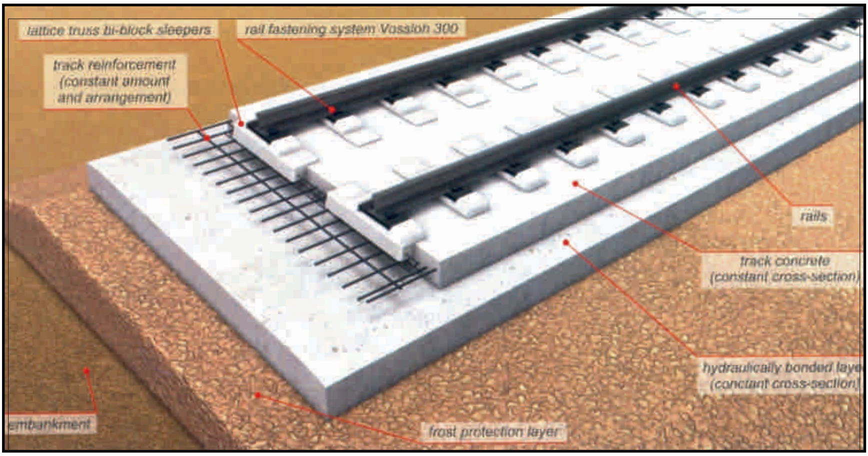


Fig. 9.6.6.2 (a) : Rheda - 2000 system

Fig. 9.6.6.2 (b) : Rheda - 2000 construction

9.6.6.3 SATO design:

The SATO (Studiengesellschaft Asphalt-Oberbau) design type lays Y-steel sleepers on an asphalt bearing layer. The steel sleepers are welded to a flat steel strip running in a longitudinal track direction by using Nelson bolts (tie bolts). The flat steel strip together with the tie bolts is embedded in the asphalt bearing layer. In this expensive structure the Y-steel sleepers are fixed in both their horizontal and vertical directions.

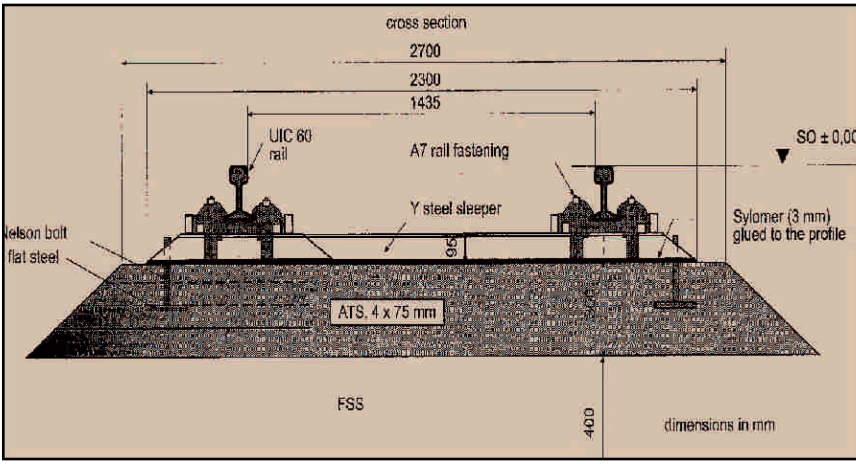


Fig. 9.6.6.3: SATO design of slab track

9.6.6.4 Bogl design:

The Bogl design uses pre-fabricated concrete plates made of steel fibre concrete which are 20 cm thick and 6.5m long. The width of the plates is 2.55m. A characteristic feature of these pre-fabricated plates are breaking points arranged between the supporting points (notches every 0.65 cm). They prevent random crack formation. Due to the specific crack development the plates turn into a system of wide sleepers coupled in a longitudinal direction.

The projecting threaded steel elements of the pre-fabricated plates are coupled in a longitudinal direction by turnbuckles. Exact level and alignment are produced with the help of an adjustment device integrated into the assembly plates. After adjustment a bitumen cement mortar is cast into the space below the assembly plates. After hardening, the gaps between the plates are filled up with sealing concrete. After the cast gaps have hardened, the turnbuckles are closed and tensioned. Then the broad gaps are also sealed. Track settlement up to 26mm can be compensated within the rail fastenings. If larger settlement occurs, the assembly plates can be separated from the sealing material by a cable saw. Readjustment is carried out with the help of the integrated spindle. The developing cavity is then sealed again with bitumen cement mortar. The weight of the plates without rail fastening is about 9 t.

Figure 9.6.6.4 (a) and (b) shows the standard cross section with pre-fabricated plates of the Bogl company. This design attaches particular importance to the most effective drainage possible. 5 cm of the outer lateral projecting edges of the hydraulically bonded bearing layer were laid below the plate edges. Thus, the penetration of water below the plates is significantly impeded. The usual 5% is applied for the cross fall of the track formation.

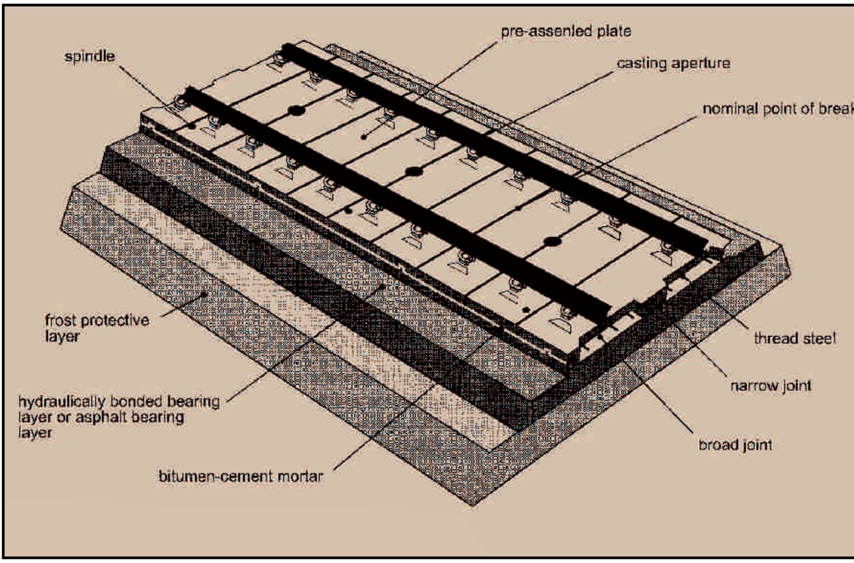


Fig. 9.6.6.4 (a) : Bogl design with assembly plates

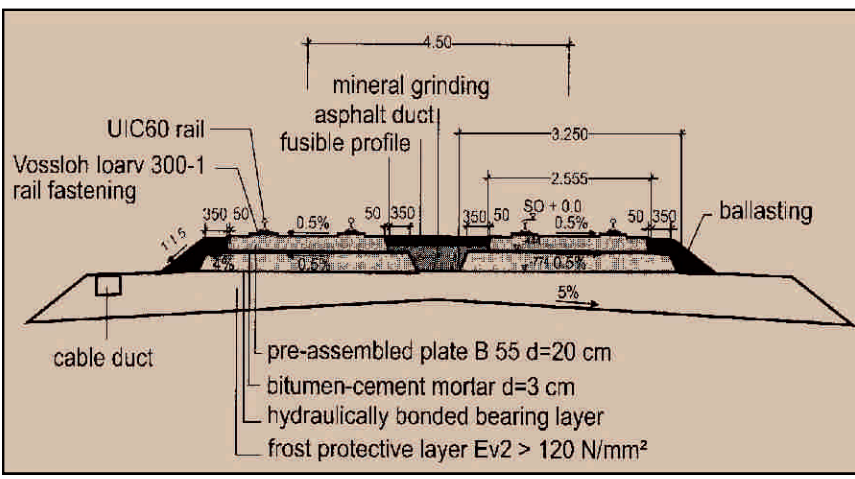


Fig. 9.6.6.4 (b): Standard cross section, Bogl design on earth structures

9.6.6.5 FFYS design:

The FFYS (Feste Fahrbahn Y-Stahlschwelle) design is a further development of the SATO system. Two web plates located below the sleeper (cross beams) engage in a groove milled into the asphalt bearing layer and are connected to the asphalt bearing layer by a sealing compound. This enables lateral forces to be transmitted.

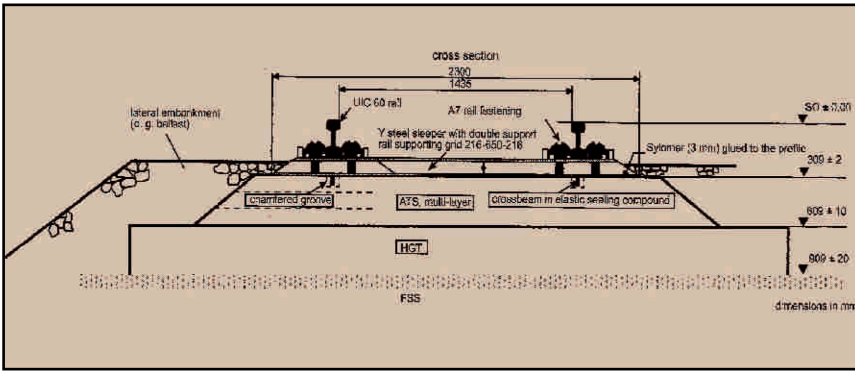


Fig. 9.6.6.5 : FFYS design slab track

9.6.6.6 BTD design :

The BTD (Betontragschicht mit Direktauflagerung) design uses mono-block sleepers only. Every second sleeper has a hole in its centre through which a steel dowel is inserted. The steel dowel engages in a bore in the concrete bearing layer and thus tensions the sleeper. The bore is made after alignment of the track grid.

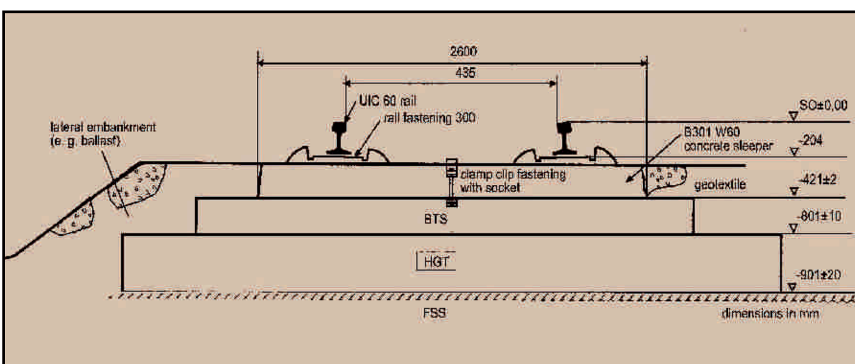


Fig. 9.6.6.6 : BTD Design

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Chapter - 10
Electrification, Signalling, Telecommunications & Other Line Equipment

10.1 Signalling and Telecommunication :

At present Continuous Train Control System called CATP system in used for high speed train operation. This uses track circuits for detecting the position of trains and AC current in rear of the train is coded/modulated suitably according to its position from the track occupied by the train. Antennas or Pick up coils installed ahead of the First shunting axle of following train pick up this information which is suitably decoded by the On board equipment and is converted into speed code at which the train can travel in the track section. This information is fed to the continuous speed control system on board which causes brakes to be applied automatically if the actual train speed is higher than the permitted speed and the driver ignores the command to reduce speed.

10.1.1 Principles:

The principles that were laid down by the first railway system in the world to exceed 200 kmph in commercial service – the JNR on the new Tokaido line, form the basis for the proposed High Speed Railway. These principles are as follows:

1. The practice of installing the line side signals is abandoned. There are two basic reasons for this:
   - Firstly, observation of the signals by the driver becomes difficult at speed above 200 kmph.
   - The second reason is connected with the lengthening of stopping distances, which increase with rather more than the square of the speed. Therefore alternatively signalling indication must be available to the driver at his driving position, which is called cab signalling.
2. Track to train transmission of signalling information must be continuously available in cab in the form of continuous pre-set speed accompanied with braking sections by indication of target speed and target distance. The appearance in cab of any information relating to a speed reduction must be accompanied by an audible alarm signal.

3. The signalling must not merely be indicatory, it must be mandatory that main cab signalling must be associated with a speed check and application of automatic brake whenever the actual speed exceeds the set speed limit.

10.1.2 Means of adherence to the Principles:

The automatic mechanism of speed control is defined below:

a) Spacing of trains – protection of danger points:

The spacing of trains must be automatically controlled. The spacing used, must guarantee a minimum time interval between trains. This value can be set individually for each line. The spacing system used must automatically control the consequences of a coupling breakage (protection of rear portion of the train).

The spacing of trains is guaranteed on the basis of line being divided into sections where entry into a section under normal running conditions is blocked when it is occupied. The entrance to a section then constitutes a stop point. The signalling system must be capable of providing the cab tractive unit with information commanding them to stop before this stop point using service braking.

b) Protection of unexpected obstacles:

Since the traditional means (flags, lanterns, detonators etc) used to protect unexpected obstacles by staff becomes ineffective at high speed, it must be possible immediately to provide this protection by some other means.

To this effect, trains must be equipped with ground/ train communication line (e.g. ground/ train radio). The communication system can also be used for conveying information to the driver regarding unexpected obstacles.

An expected obstacle may be:

i. Discovered by the train driver
ii. Discovered by a staff member on ground
iii. Signalled at the nearest station or traffic controller
iv. Detected automatically
v. Detected and signalled by a distributed control position

The time equipment must enable the train driver who discovers the obstacle to emit signal carrying the immediate stop of train on his own line or an adjacent lines within a given distance.

In case a staff member who discovers an obstacle on site (broken rail etc) under all circumstances will have access within a reasonable limit through some local means of giving the stop command to the cab of train on each track and in each direction.

Similarly, the station or traffic controller must be able to command the immediate stopping of all trains on each track and in each direction.

c) Speed Limits:

The signalling system must be able to provide in the cab of tractive units the following necessary information with regard to speed limits.

1. Permanent speed limits on sections of some lengths and permanent speed limits on short section (curves, etc)
2. Speed limits that vary depending on the route (facing points), they must be indicated automatically in the cab by signalling system depending on the route.
3. Temporary speed limits that are planned (track works) or unexpected obstacles.

It is desirable for the signalling system to show in the cab both temporary and permanent speed limits so as to avoid any recourse to line side signals.

d) Speed Controls:

The role of speed control is to act such that when speed limit is exceeded, particularly during braking period, the excess speed automatically brings out, before safety is compromised the emergency braking that is more powerful than service braking and is capable of bringing the train to regulation running condition.

The nature of the control depends on the interaction in the form of speed code information supplied through interactive unit to the signalling system.

e) Miscellaneous Requirements:

A new high-speed line shall not have level crossings.

It must be possible to carry out locally controlled shunting movements using special information received in the cab.

It must be possible to link the signalling system to various safety devices such as hot axle boxes detectors, detectors of obstacles falling on line, damaged catenary etc whose role is to trigger an alarm wherever necessary resulting in trains slowing down or stopping.

The signalling system must have overall availability and reliability such that the quantity and regularity is at least equal to what can be obtained on the best existing lines.

Regarding the signaling systems, it has been shown that the ERTMS (European Rail Traffic Management System) is in principle, valid up to 500km/h.

f) Location of signals:

Location of signals and track vertical alignment is instrumental in deciding the location of neutral sections. Besides the location of overlaps is dictated by the stop signal locations. The OHE structures and other trackside traction equipment may hinder signal visibility and therefore their location vis-à-vis location of signals needs to coordinated particularly on curves so that the line of sight is clear of such obstructions. The location of signals have also to be electrically clear of the overhead equipment wire runs and have to be provided with appropriate safety measures like earthed safety screens etc.

10.2 Signalling System on various high speed world railways:

10.2.1 Shinkansen System (Japan):

(a) Intelligent Technology:

The Shinkansen system incorporates various types of telecommunications and communications technology for improving the reliability of train operation and passenger services, and for optimizing system maintenance like:

(i) Various types of information (text news and radio broadcasts) are supplied to the passengers over a communication line.

(ii) The operating conditions of onboard devices are transmitted by a mass transmission system (spectrum diffusion system).

(iii) The standard running pattern is displayed on the operation support information device to support efficient train operation.

(iv) The operating conditions of various devices are displayed on the monitor on the driver's desk.

(v) Operational information is transmitted from the driver's desk to the control center via a communication line (LCX or Leaky Coaxial Cable).

(vi) The monitoring system allows the driver to ascertain conditions of the underfloor devices, car doors, air conditioning equipment, failed devices etc from his desk.

(b) Traffic Control System:

The high density operation of more than 291 trains per day has been made possible by the combination of the traffic control system, advanced system management technology, and operational expertise.

COMTRAC (Computer aided Traffic Control) was introduced in 1972 to effectively respond to the increase in the number of Shinkansen trains operated and the increased complexity of vehicle management. COMTRAC can constantly monitor the condition of all trains in operation on the basis of the operating conditions of each individual train. If any train is not operated as scheduled, the COMTRAC issues an alarm calling for suitable adjustments.

A new traffic control system called COSMOS (Computerised Safety Maintenance and Operation system of Shinkansen), based on conventional COMTRAC, has been introduced. It is a highly integrated, next-generation system that performs transport planning, and traffic control, manages equipment, vehicles, and maintenance, controls information.

The Shinkansen Control Centre precisely controls huge volumes of traffic information to coordinate all transport operations.

(c) Automatic Train Control:

The Shinkansen has no wayside signals. It has an on board interactive type Automatic Train Control (ATC) system. The train is provided with a database, which contains all the information necessary for train speed control, including line conditions and vehicle performance. The wayside ATC device transmits the position of the preceding train, the condition of the turnout, and other information to the onboard ATC device via digital signals. The onboard ATC device next retrieves the appropriate braking pattern from the database and performs the prescribed calculation for optimum brake control.

10.2.2 TGV system (France):

TGV system exclusively uses in-ca signalling for high speed running. TGV lines do not have line side signals; they are too difficult to read at speed. All signalling information is transmitted to the train through the rails, and appears to the engineer in the cab. In general, TGV trainsets are heavily computerized, and many important functions are controlled digitally.

The nerve centre of the TGV operation is situated behind the maintenance depot at Lille Flandres in the north of France. Such is the power generated by a TGV train that each has to be fitted with an interference current monitoring unit, to ensure electrical interference does not exceed safe levels.

Trains are fitted with automatic train protection systems, which automatically apply the brakes if a signal is not responded to or passed at danger. TVM430 (Transmission voie-machine, or track-to-train transmission) is a cab-based signalling system which monitors train progress and informs the driver of the maximum speed possible at any given time to maintain headways between trains. Belgium's high speed rail system also uses the same TVM430 technology.

Information is transmitted to trains via electrical pulses sent through the rails, providing speed, target speed, and stop/go indications directly to the driver via dashboard-mounted instruments. This high degree of automation does not eliminate driver control, though there are safeguards that can safely stop the train in the event of driver error.

The boundaries of signalling block sections are marked by distinctive boards. The line is divided into signal blocks of about 1500m with the boundaries marked by blue boards with a yellow triangle. Dashboard instruments show the maximum permitted speed for the train's current block and a target speed based on the profile of the line ahead. (with steadily decreasing speeds permitted in blocks closer to the rear of the next train), junction placement, speed restrictions, the top speed of the train and distance from the end of the LGV.

As trains cannot usually stop within one signal block, which can range in length from a few hundred metres to a few kilometers, drivers are alerted to slow gradually several blocks before a required stop.

10.2.3 DB AG System (Germany):

Frankfurt-Köln line boasts of a pioneering signalling system, completely dispensing with traditional lineside signals on two thirds of the route in favour of a radio-controlled system. A derivative of automatic train protection, known as Computer Integrated Railroading (CIR).

The NBS high speed line in Germany is controlled by two computerised interlockings at Inglostadt Nord and Nürnberg-Fischbach. Trains on the

300km/h line are controlled by moving block cab signalling which keeps trains at a safe distance from each other by indicating to drivers the maximum speed they should attain. GSM-R communications have also been specified in line with European Union interoperability rules for high-speed lines. On the ABS (Ausbaust recke) section south of Ingolstadt, all signalling has been renewed and replaced with a computer-based interlocking at Petershausen, north of Munich.

10.2.4 AVE (Alta velocidad Espanola) system of spain:

German technology of cab signalling system coupled with a continuous speed control facility is used on Madrid-Seville and Barcelona-Narbonne speed sections. Siemens has supplied on ISDN communication system, which transmits speech, data, text and images. Tilting trains between Madrid and Valencia (RENFE) is fitted with the ASFA200 in cab signaling system.

10.2.5 Pendolino Systems (Italy):

The first generation of new rolling stock ETR500s (300 kmph) are fitted with automatic train control and protection systems. However, the ETR460 and 480 trainsets (250 kmph) run on conventional absolute block signalling, with in-cab warning system. It is planned that the Naples-Rome line will use signalling to the highest specification, Level 2 ERTMS.

10.2.6 Signalling and Communications (Finland):

Internal facilities provided on the Pendolino (220 kmph) include an office compartment containing telephones, fax machines and overhead projectors for business class passengers; information monitors in each coach. Signalling up gradation on the route has involved renewal of the multiple-aspect colour light signalling.

10.2.7 Signalling/Communications (USA):

The provision of control systems for the Acela project (240 kmph) is by Alstom and North American systems specialist GRS. Trainsets will be equipped with a two-frequency, nine aspect cab signalling system, which receives information transmitted through the rails in the form of electrical signals, and is displayed to the traincrew in the cab. The driver is supervised by an Automatic Train Control (ATC) system, and the trains are also governed by Amtrak's own ACSES (Amtrak Civil Speed Enforcement System) equipment, which automatically adjusts a train's speed within lineside speed restrictions.

10.2.8 Signalling/Communications system in China:

The existing Beijing-Shanghai corridor is 1,463km long, and equipped with automatic fixed-block signalling.

The prototype high-speed train is fitted with an LKJ-93 automatic train protection system, used in conjunction with lineside equipment to monitor and record train speed. As the current fed to the motors can be varied continuosly, the driver is able to maintain constant speed automatically.

10.2.9 Signalling/Communications in Portugal:

Major upgrading has also been carried out on the Porto Lisbon route. Speed raised from 180 to 220 kmph. The former relay-based automatic fixed block signalling is replaced by 31 electronic and three central traffic control installations. Facilities include PA system and personal headphones at each seat, audio-visual channels, etc.

10.2.10 Signalling And Communications system in Netherland:

Signalling standards on the Netherlands high-speed line confirm to the standard European Rail Traffic Management System (ERTMS). It incorporates a high-speed communication link between trackside and train, enables continuous transmission of information from interlocking and traffic management systems directly into train cabs. Lineside and in-cab signalling control movements, and a form of automatic train protection (ATP) is fitted to trains. To further enhance safety, there is no level crossings with bridges built to take existing roads over the new rail line.

10.2.11 Signalling and Communications system in Switzerland:

Signalling systems on the routes to be used are basically unchanged over many years. The trains are governed by an absolute block system, and run under multiple (three or four) aspect colour signalling.

A pilot ETCS train control system is being installed on the Olten-Luzern route, as well as on several major new lines planned for the country, such as that from Mattstetten to Rothrist.

10.2.12 Signalling/Communications system proposed for Indian High Speed Corridor:

The new system is to involve the adoption of a modern system of SSI-type interlockings, which will allow route-setting and locking functions to be performed at the various stations and depots along the route. A network of axle counters are being installed at the trackside, in the vein of a similar system used on the German ICE high-speed network. A central control centre will monitor the entire line and its systems, and will use artificial intelligence and a modern, efficient communications network to manage and supervise all train movements.

10.3 Electrification

10.3.1 System of electrification:

While a majority of Indian Railways electrified network is at 25 kV AC booster system, 2x25 kV AT system is also in use over about 400 track kms and 1500 V DC system in and around Mumbai.

As the power requirement of high-speed trains is very large- P=f (V^3), the system of electrification has to cater to these high power requirements. The indicative power requirement of three typical high speed routes catering to speeds of 270 kmph, 300 kmph and 350 kmph are shown below

Maximum speed	Headway	Installed Power per route km of line
270 Kmph	5 Minutes	0.7 MVA
300 Kmph	3 Minutes	1.2 MVA
350 Kmph	3 Minutes	2.0 MVA

The high-speed trains are characterized by high peak power demand and low load factor compared with conventional lines. While various traction system voltages and frequency have been in use with AC as well DC system, most can be broadly classified into 1500 V DC or 3000 V DC, 25 kV AC and 2x25 kV AC system. Apart from these conventional systems magnetically levitated train technology is capable of achieving speeds beyond 500 kmph.

(a) DC System:

Figure 10.3.1.1 shows the basic configuration of such a system. The 1500/3000 V DC systems because of lower voltage compared with 25 kV systems have to handle very large currents for a given power demand. This results in large voltage drops and very close spacing of the feeding points. Such a system is characterized by heavy conductors and structures. The DC system also results in galvanic corrosion requiring elaborate safety measures to be taken by the utilities near the rail corridor. This system is therefore considered suitable for speed upto 200 kmph only where it existed prior to introduction of high-speed services.

On all new high-speed routes only AC system is being generally used.

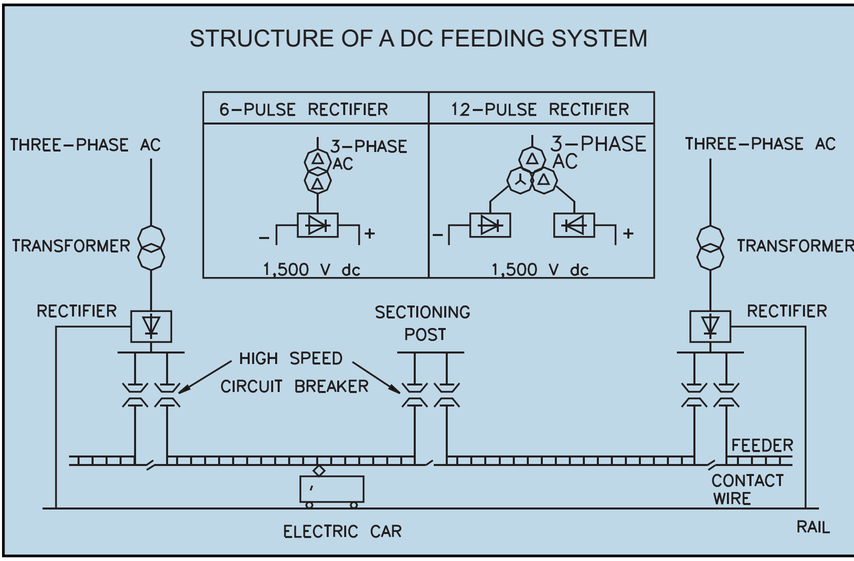

Fig. 10.3.1.1 : D.C. System

(b) 25 KV Booster System:

Figure 10.3.1.2 shows the basic configuration of such a system. The conventional 25 kV booster systems are not designed to cater for very high power requirements associated with the high speed trains. This system also suffers from some infirmities when adopted for high-speed trains.

Though the conventional 25 kV system can cater to the power requirements of the high speed trains under limiting conditions upto around 250 Kmph, the voltage profile of such systems is not suitable for high speed trains as the train would lose time due to adverse voltage profile for such large drawl of power.

Trains running at high speed drawing large power results in arcing at booster overlaps as the train pantograph temporarily short circuits the boosters while negotiating the overlap. While this is not a serious problem at lower speeds and comparatively lesser power, special arrangements have to be provided at booster locations to overcome this problem for high-speed operation.

The booster system has high impedance compared to the conventional simple feeding system thus resulting in higher voltage drops. The voltage regulation of the line is therefore poor with 25 kV Booster system in view of the very high power demand, which adversely affects the train running. To provide for acceptable voltage levels, traction sub stations in the conventional system have to be placed close to each other thus neutralizing any cost advantage which conventional system might have over 2x25 kV AT system. Series compensation to improve the voltage profile of the line is not considered desirable as this results in increased fault current.

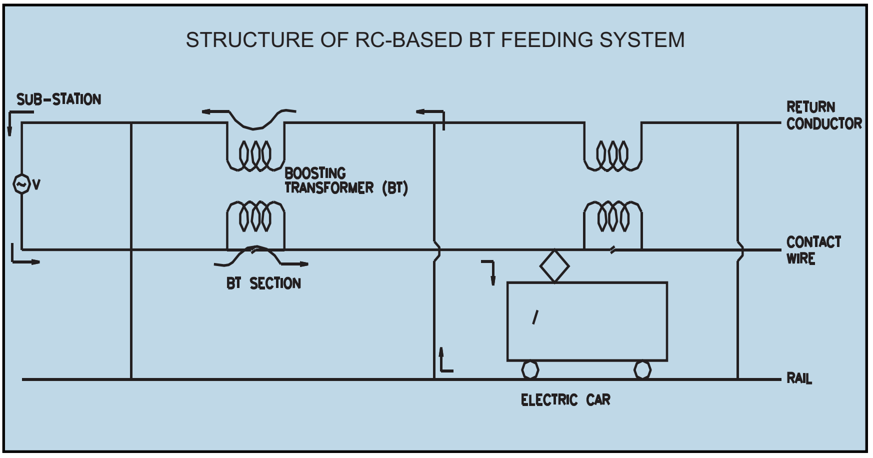

Fig. 10.3.1.2 : 25 KV Booster System

Large AC currents associated with high-speed line results in strong magnetic field in the vicinity of the OHE for which special measures have to be adopted.

(c) 2x25 KV Auto transformer (AT) system:

Figure 10.3.1.3 shows the basic configuration of such a system. The 2x25 kV AT system employs a negative feeder through out the section and Autotransformers at an interval of 10-15 kms. As a result of effective 50 kV network, the voltage profile of the line is very good and the negative feeder is quite effective in suppressing the magnetic field of the line. Most countries particularly where high speed has been introduced recently have therefore opted for 2x25 kV AT system of electrification which offers a better voltage profile and interference level.

It has following characteristics compared with other forms of traction for high-speed routes:

(i) Lower impedance levels of around 0.12 Ohms/km compared to around 0.3 Ohms /km for conventional BT system leading too considerably lesser voltage drops and consequently longer sub station spacing.

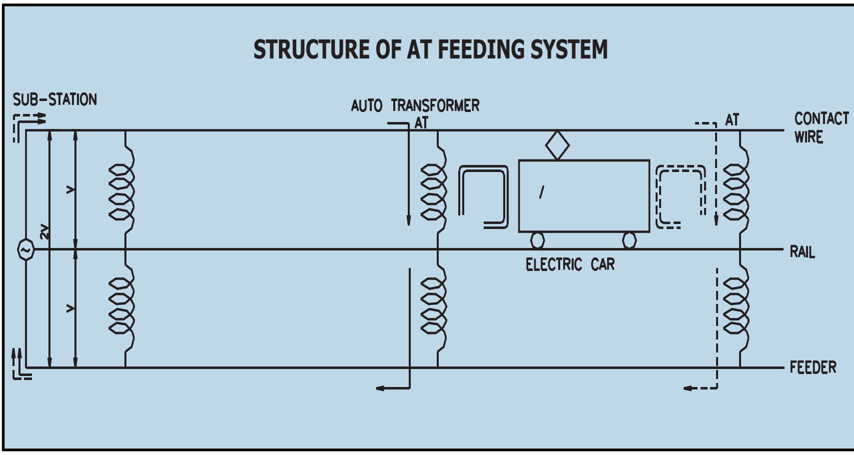

Figure 10.3.1.3: 2x25 KV Auto transformer

(ii) Less EMC Disturbance

(iii) Reduced longitudinal induced e.m.f.

(iv) More symmetrical loading

(v) About 30% higher cost of Overhead equipment

(vi) More complicated to construct and operate compared with BT feeding system

(vii) Ability to provide for very high power demands

(viii) Better voltage balance

(d) Feeding Scheme:

In both the BT system as well as the AT system, several feeding schemes are possible. Figure 10.3.1.4 shows the scheme of feeding adopted by some of the Railways and the scheme of feeding adopted for conventional BT feeding section on IR.

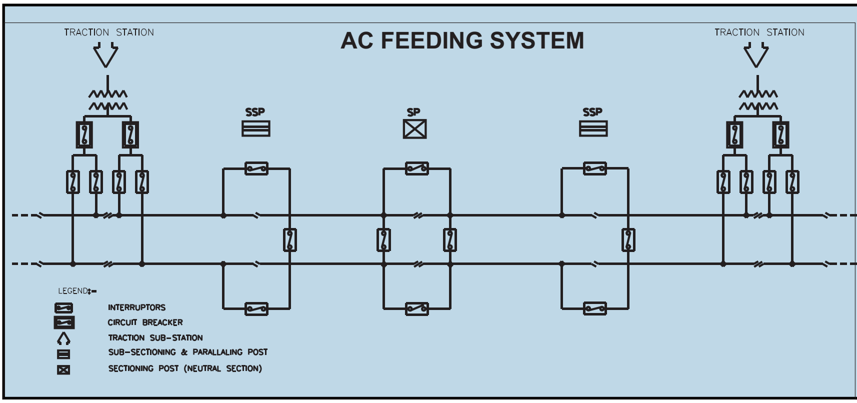

Fig. 10.3.1.4 : AC Feeding Scheme

10.3.2 Type of overhead equipment :

Figure 10.3.2 shows the basic configuration of various Overhead equipment used in high-speed routes. The OHE configuration adopted for conventional AC electrified lines of Indian Railways generally corresponds to that shown for French TGV except that a maximum span of 72 meters is permitted for green wind zone.

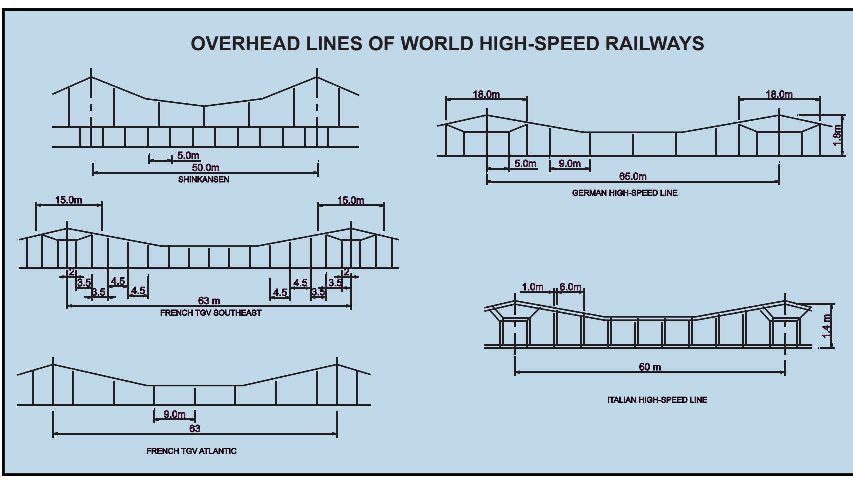

Fig.: 10.3.2 : Type of over head equipment

The type of overhead equipment to be adopted is dependent on the requirement of power transfer, maximum operating speed, spread of speed among various trains in the corridor (i.e. whether the high speed corridor is being used for mixed operation or for dedicated high speed running), number of pantographs per train and their spacing. If a majority of the line passes on via ducts, running an earth wire becomes a necessity. Following general comments apply to the overhead equipment configurations:

- The net copper cross section under contact wire worn conditions should correspond to the thermal capability of the overhead equipment arrived from the traction power simulations.
- Wave velocity: The train speed should generally be lower than 80% of the wave velocity.
- Uniform elasticity of the overhead equipment results in better current collection performance. Therefore the change in elasticity should be minimum.
- Higher tension in conductors result in better current collection performance.
- Multiple pantograph operation results in deterioration in current collection performance of second and subsequent trailing pantographs, results in more contact wire wear for the same number of trains but results in lower localized wear of the contact wire compared to single pantograph operation.
- The percentage contact loss should be limited to less than 1% with maximum uplift not exceeding 30 cms.
- Fm - 3 > 0 Newton's where Fm is the mean contact force and is the standard deviation.

The system height, tension and configuration of the overhead equipment govern the basic performance of the overhead equipment at high speeds. The tension in contact wire and catenary are in the range of 15 kN (In French high speed lines) to 20 kN (In Shinkansen lines). The contact wire material is either tin copper, silver bearing copper or copper clad steel wire (For tensions of 20 kN). Most lines adopt a 3-pulley arrangement with a mechanical advantage of 5.0 for auto tensioning equipment employing a wire rope break safety latch. Some high speed designs employ separate tensioning equipment for catenary and contact wire to prevent the change in geometry from changing with the change in temperature and wear of the contact wire.

The various configuration of the overhead equipment in use in various countries is given in the Table 10.3.2.

Table 10.3.2 :Comparison of Overhead Line Constants on Dedicated High-speed Lines in the world

Item		Japan	France		Germany	Italy	India (Conventional)
			TGV Southeast	TGV Atlantique			AC Area
Catenary type		Heavy compound type	Stitched and simple	Simple	Stitched and simple	Twin stitched and simple	Simple Polygonal
Standard span (m)		50	63(Stitched wire 15)	63	65(Stitched wire 18)	60(Stitched wire 14)	72 m (Max.)
Standard wire height (m)		5.0	4.95	4.95	5.3	4.85	5.5
System height (mm)		1,500	1,400	1,400	1,800	1,400	1,400
Wire grade	Suspended	St 180 mm^2 (1.450 kg/m)	Bz 65 mm^2 (0.59 kg/m)	Bz 65 mm^2 (0.59 kg/m)	Bz11 70 mm^2 (0.63 kg/m)	CdCu 153.7 mm^2 (1.42 kg/m)	CdCu 65 mm^2 (0.6 kg/m)
	Auxiliary suspended	Cu 150 mm^2 (1.375 kg/m)	Bz 35 mm^2	–	Bz11 35 mm^2 (0.31 kg/m)	0.30 kg/m	NA
	Contact wire	Cu 170 mm^2 (1.511 kg/m)	CdCu 120 mm^2	Cu 150 mm^2 (1.33 kg/m)	CuAg Ri 120 mm^2 (1.08 kg/m)	CuAg 151.7 mm^2 (1.35 kg/m)	HDCC 107 mm^2 (0.96 kg/m)
Contact line total density (kg/m)		4.34	1.65	1.92	21.71 x	2.77	1.6
Cate-nary wire tension	Suspended [N]	24,500	14,000	14,000	15,000	18,400	10,000
Cate-nary wire tension	Auxiliary suspended [N] (Total tension) [N] (Total tension) [N]	14,700 (53,900) (53,900)	4,000(Stitched wire) (28,000) (28,000)	– (34,000) (34,000)	2,800(Stitched wire) (30,000) (30,000)	2,900(Stitched wire) (33,100 x 2) (33,100 x 2)	20,000
Wave propagation velocity of contact wire [km/h]		355	414	441	424	376	369
ß (train speed/wave propagation velocity)		0.68, 0.76 (=240, 270/355)	0.65 (=270/414)	0.68 (=300/441)	0.59 (250/424)	0.66 (250/376)	0.43 (160)
Pre-sag		None	1/1,000	1/1,000	1/1,000	1/1,000	1/1000

Belgium Railway have used 2 x 25 KV A.C. current for new high speed lines, with catenary cable of Cu-Ag (Vmax < 300 kmph) and Cu-Mg (Vmax >=300 kmph)

Almost all high speed electric rolling stock now employ AC-AC system of electric traction with asynchronous traction motors, VVVF control and IGBT's / GTO employing extensive regenerative braking and eddy current disc brakes with low unsprung mass and low power to weight ratio (of the order of 1.5kg/kw). Most traction equipment is under slung to provide for most optimum utilization of floor space.

With the exception of Germany, where the voltage is 15 KV at 162/3 Hz, other main countries have decided to adopt the system of 2 x 25 KV, at 50 Hz. Both these power systems can be used to increase the train speed up to 350 km/h.

The mechanical force necessary (in the catenary) varies between 15 KN at 250 km/h and 30 KN at 350 km/h, passing through 20 KN at 300 km/h. This increase in the mechanical force is possible due to the development of new alloys.

The height of the contract wire in the various countries is within the values specified by the Technical Specifications (STI), either 5.08 or 5.30m.

To run at higher speeds, the power must logically be greater, and as a result in certain cases, it is essential to plan for a reduction in the distance between sub-stations.

The overhead system installed on most sections of IR is regulated conventional. For speeds in excess of 180 Kmph current collection performance deteriorates considerably for such a suspension arrangement. Therefore a stitched catenary system and higher size 150 sq. mm silver bearing or copper clad steel contact wire tensioned at 20 kN, with deep curved registration suitable for a speed potential of upto 300 Kmph has been proposed for the high speed corridor.

Automatic neutral sections (Track side and locomotive borne equipment based) have been proposed to avoid manual switching of locomotive power while negotiating the neutral sections.

The distributed power based electric traction is considered superior to concentrated power based (Push-pull arrangement) traction due to the flexibility it offers, smaller axle loads leading to less track maintenance, superior traction and braking characteristics even under adverse weather conditions, better space utilization, more reliability and better energy efficiency on account of improved regeneration characteristics.

Taking a long-term view with possibilities of further increase in maximum speed, the traction sub-stations are proposed to be equipped with 50 MVA transformers. Since the conventional superfast trains are contemplated to run over the high speed corridor.

Though at lower speeds this distinction generally blurs as the powering ratio required is low-around 25% for 250 Kmph, however at higher speeds above factors assume considerable significance. Thus from the stand point of reliability, improved traction and braking characteristics and better space utilisation distributed power system is considered more appropriate for high speed trains.

10.3.3 Pantographs:

Pantograph design is dictated by following considerations:

- Maximum power transfer per pantograph
- Maximum speed
- Type of Overhead equipment configuration
- Noise, and
- Number of pantographs per train

As pantograph and insulators installed on the roof of the car are major source of noise at high speed, simple light weight single arm pantographs or wing shaped current collector which significantly contribute in the noise reduction are employed. Suitable pantograph cover has also been used to reduce the airflow around the pantograph thereby restraining the occurrence of aerodynamic sound from the pantographs. Reducing the number of pantographs by employing 25 kv bus couplers also results in better current collection as well reduction in the noise. In French-TGV's the trailer power car collects current from the overhead line equipment and feeds power to the leading power unit as well through a power cable running along the roof. The single pantograph arrangement prevents the leading pantograph from disturbing the contact wire for the following pantographs and thus improves the current collection performance. Some of the pantographs in use for high-speed trains are quite sophisticated employing active damping. Active pantographs have recently been tried out in Germany enabling higher speeds to be achieved on conventional catenary system.

10.3.3.1 Power Supply on French railway:

LGVs are all electrified at 25 kV 50 Hz AC. Catenary wires are kept at a greater mechanical tension than normal lines because the pantograph causes oscillations in the wire, and the wave must travel faster than the train to avoid producing standing waves that would cause the wires to break. This was a problem when rail speed record attempts were made in 1990; power wire tension had to be increased further still to accommodate train speeds of over 500 km/h. On LGV, only the rear pantograph is raised, avoiding amplification of the oscillations created by the front pantograph. The front power car is supplied by a cable running along the roof of the train.

Eurostar trains are long enough that oscillations are damped sufficiently between the front and rear power cars, so both pantographs can be raised – there is no interconnecting high-voltage cable along the 400 m length of the train.

10.3.4 Issues of Interoperability for Indian High Speed Corridor:

Since it is desirable that some passenger trains from existing sections may also run on the HS corridor, following issues need to be addressed:

a) **Traction Power Supply:** Since in India existing traction power supply arrangement is of 25 kV booster system, the location of new traction sub-stations and sub-stations at the boundary of conventional and AT System has to provide for flow of power from one system to the other. Similarly the SCADA systems of conventional line and high speed line has to provide for a fault segregation philosophy which prevents the high speed section services to remain unaffected by fault in the conventional section and vice-versa. In regard to the sufficiency of power in the normal as well as emergency feed situations the new high-speed line shall be independent of the conventional line.

b) **Overhead equipment:** The 2x25 kV Overhead equipment which has an additional 25 kv feeder and possible earth wire throughout the section shall have to be interfaced with conventional line with a return conductor and boosters. Suitable interfacing arrangements in this regard has to be done.

c) **Contact wire height:** As the new high speed corridor shall not have any level crossing gates a considerably lower contact wire height compared to the conventional system can possibly be employed depending on whether any bi-level train operation is proposed in future. However since the contact wire height of the conventional system is 5.5 meters, the contact wire will have to be graded in the interfacing zones.

d) **Pantograph:** The pantographs of high-speed trains are generally lighter and may differ in geometry compared to the pantographs of conventional electric rolling stock. If conventional stock is also to run on the high-speed corridor, the overhead equipment design particularly over the turnouts, under the bridges/tunnels and neutral sections has to cater to both the pantograph profiles and pantograph pressure. Similarly the neutral section lengths have to consider the inter-panto distance of conventional as well as high-speed trains.

e) Similarly it may not be possible to adopt carbon current collection strips for the HS rolling stock due to mixed running of HS and conventional stock.

f) Trains/Locomotives nominated to run on the high speed route shall be equipped with all the cab equipment in regard to cab signaling, automatic neutral section switching, ATP transponders and communication equipment to enable the stock to run on the high speed line.

g) The high-speed stock may be wider and have different kinematic profile compared with conventional stock. Therefore the platform design has to cater for both type of stock.

10.3.5 Suggested parameters by RITES are summarized in table 10.3.5.

Table 10.3.5: Proposed Key Parameters

Item Description	Existing conventional line of IR	Proposed
Net copper area of OLE	150 sq. mm	200 sq. mm
CW material	HDGCC	Copper clad
Catenary material	Cd-Cu	Bronze
Type of construction	Simple catenary	Stitched Catenary construction
Type of masts/Portals	Galvanized steel	Galvanized/Spun Concrete
System height	1.2 meter	1.6 meter
Normal CW height	5.5 meters	5.5 meter (Can be reduced to 5.0 meters if bi-level trains are ruled out)
Tension in CW	1000 kgf	20 kN
Tension in Catenary	1000 kgf	20 kN
Negative feeder	Existing conventional OHE is without 25 kV negative feeder	Aluminum steel 288 mm^{2}, 9 kN at 15^{0} C
Normal electrical clearances	320 mm/270 mm	320 mm/270 mm

Item Description	Existing conventional line of IR	Proposed
CW gradient/relative gradient on main lines	3mm per meter/1.5 mm per meter	1:750 in central spans and 1:1200 in terminating/bridge approach span
Regulation	5:1 combined regulation	5:1 Separate regulation
Pre-sag	103 mm corresponding to 72 m span	1/1000
Type of feeding system	BT system	2 x 25 kV Auto transformer
Approximate spacing of feeding points	40-60 kms	100-130 kms
Approximate rating of main X-er	20 MVA	50 MVA
Approximate raring of BT's/AT's Approximate interval of BT's/AT's	100 kva/2.6 kms	15 MVA/20 kms
Type of neutral sections	Overlap type/BB type	Overlap type/High Speed type
Switching arrangement at neutral section	Manual by driver of the train	Automatic switching using track/Loco born equipment
Cab equipment	None other than MP related	• Cab Signalling • ATP • Communication Antenna
Driving traction system	Concentrated for main line trains/Distributed for sub-urban trains	Distributed
Formation	Varies	3M+5T: For 250 kmph 8M+2T: For 300 kmph or more
Seating capacity	Varies	Around 800
Axle load	18 T/22 Tonne	17 tonne (Approx.)
Maximum operating speed	90/140 kmph	250/350 kmph
Maximum power	< 4 MVA per Train	4MVA/10 MVA per Train
Type of pantograph	Passive	Passive with wind deflector/Active

❑ ❑ ❑ ❑ ❑

Chapter - 11

Rolling Stock & Operating Conditions

11.1 Review of High Speed Rolling Stock:

The major brands of rolling stock developed in connection with High Speed Railways around the world are reviewed in this section. The major brands of rolling stock are as follows:

ICE, KTX, Shinkansen, TGV, THALYS

Talgo and Other Tilting Trains

11.1.1 ICE:

In the summer of 1991 Germany introduced the concept of "ICE" (InterCity Express) high speed lines.

DB introduced its first ICE-T tilting trains in 1998. Developed with the involvement of Siemens Transportation Systems, the trains have a top speed of 230km/h even over rough terrain. Diesel and electric versions of the tilting ICE have reduced journey times and drastically improved passenger comfort on several 'classic' routes.

To introduce ICE comfort and speed to non-electrified routes, DB has acquired a small number of four-car tilting DMUs, known as ICE-TD.

The first experimental ICE train, introduced in 1995, ICE-2, was ordered in 1994, ICE3, introduced from 1999, ICE3 features a distributed traction package with every second vehicle powered, rather than the end power cars used for ICE1 and 2.

A consortium of Bombardier Transportation and Siemens in May 2000 delivered ICE 3 electrical multiple units to German Rail (DB AG) and Dutch Railways.

Each ICE3 trainset consists of two eight-vehicle half sets. Eight of each train's 16 bogies have both axles powered. Although ICE3 is single voltage, the ICE3M version can operate on any of the four main power supply systems on the European mainland: 15kV 16.7Hz; and 25kV 50Hz AC, 1.5kV DC and 3kV DC.

These multiple unit trains are being used primarily on German Rail's new high-speed lines, e.g. Frankfurt-Cologne, and run at speeds up to

330 km/h. The four-system units are intended for operation on the DB AG railway network and for cross-border service with the Netherlands, France, Belgium, and Switzerland as well as for operation on the European High-Speed Network.

The ICE 3 is a multiple unit train, which means the traction equipment is distributed over the full length of the train; it is possible to obtain a high acceleration as well as low adhesion coefficient. The extensive under floor electrical equipment allows for more space available for passengers. A lounge in each of the two end cars gives passengers a clear view of track ahead and is a clear deviation from conventional designs. Features of a typical system are as indicated in Table 11.1.1

Table 11.1.1: Features of ICE Stock

Parameter	Value
Length	200,000 mm
Width	2,950 mm
Max. Speed	330 km/h
Seated Passengers	416

11.1.2 Korean High Speed Train KTX: Rotem's high speed trains christened "Korea Train Express" (KTX) is running with maximum speed of 300km/h on the nation's main trunk line from April 2004.

The technological features are as in Table 11.1.2

Table 11.1.2: Features of KTX Stock

Parameter	Value
Train Composition	PMC-M-16T-M-PMC
Max. Speed	300 km/h
Main Power Supply	25,000V AC
Max. Weight (PMC)	74 tons
Train Control	ATC
Traction Rating	1,130 kW
Brake System	Pneumatic + Regenerative + Rheostatic

11.1.3 Shinkansen: The series 500 trains has now a top operating speed of 300 km/hr.

In the development of the Tokaido Shinkansen, the EMU system was adopted employing a distributed traction system, in which all the cars of a train are equipped with traction motors, in order to lighten the axle load, reduce noise and vibration, cut the maintenance cost (because of less impact on the tracks) and increase the reliability of train operation (at speeds exceeding 200 km/hr).

By employing the EMU system, trains can be split up or joined together, and formed into long or short trains, all the while ensuring top running performance.

For a high speed railway, decreasing the vehicle weight is extremely important from the viewpoint of reducing ground vibration and improving the acceleration/ deceleration performance of the train.

The car body of the Shinkansen meets safety requirements in both its strength and durability, while being lightweight enough for a high speed train.

The car body has a larger cross section than the world's other high speed rail systems. The car body is 3,400 mm in width and 4,500 mm in height from the rail top and therefore permits a layout of 5 seats (2 + 3) per row. The variation is reflected in Table 11.1.3.1 and 11.1.3.2.

Table 11.1.3.1: Seating Configuration

Country	Type	Width (m)	Height (m)	Seat interval (mm)
France	TGV-PSE	2.814	3.42	
	TGV-Atlantique	2.904	3.48	850
	TGV-Duplex	3.91	4.50	
Germany	ICE-1	3.02	3.84	
	ICE-2	3.02	3.84	900
	ICE-3	2.95	3.85	
Japan	Series 0	3.38	3.975	
	Series 500	3.38	3.69	
	Series 700	3.38	3.65	1,040
	Series E2	3.38	3.70	
	Series E4	3.38	4.485	

The most common car body of the Shinkansen is made of hollow, extrusion-formed aluminum alloy members. This car body does not require any support pillars. Since the aluminum car body is comparatively easy to build with being light weight, which reduces car body weight and increases car speed, and has good soundproofing performance, it has come to be widely used for many new Shinkansen cars (the 700 and subsequent series).

Much consideration is given to aerodynamics when designing the car body of the Shinkansen. The entire car body is sleek wherein, the nose is shaped to minimize air resistance and pressure change when the train runs into a tunnel. Even when the train runs with the nose at the rear end it is free from rolling. Since the under floor profile also affects air resistance, it is made as smooth and flush as possible. On the roof, parts that are absolutely necessary (e.g., the pantograph cover) are installed to minimize sources of noise.

Each Shinkansen train is equipped with an obstruction guard at the front end to minimize the impact of collision with obstructions weighing up to several hundred kilograms. This guard absorbs the energy of the collision and protects the front end of the car body.

The bogies for Series 300 and later are not provided with bolsters, and the car body is supported directly by air springs. The elimination of the bolster has simplified the bogie construction, reduced its weight, and improved running performance. Other improvements made on the conventional bogie construction include the use of a smaller-diameter wheel, a hollow axle, and aluminum alloy for the axle box. As a result, the weight of a bogie, including the motor, has decreased from about 10 tons to about 7 tons.

The introduction of a controlled bogie and the control of rolling and the yawing by dampers installed between car bodies have improved the riding comfort of the Shinkansen. A car-end damper is installed in Series 300 and later to prevent rolling, a damper to restrain yawing is installed in Series 700, E2 and E3, a pre-compressed outer bellows is installed in Series E2 and later and a car body tilting device will be introduced in Series N700.

The series 300 (developed in 1992) and subsequent Shinkansen cars use asynchronous (AC) motors. An AC motor is more compact, higher output, less than half in weight than a DC output and is easily maintainable. The AC motors in use now require overhaul about every 3 million km.

The present Shinkansen cars use air supplement control that controls the brakes of the motorcars and trailing cars simultaneously. In the high speed range, the regenerative brakes of the motor cars are fully utilized, whereas the mechanical brakes of the trailing are not used. In the low speed range, the mechanical brakes of the trailing cars are applied only when the regenerative braking capacity alone is insufficient. By increasing the regenerative braking capacity, it has become possible to save energy and reduce the burden of the mechanical brakes. This in turn has reduced the wear of the lining and other parts of the mechanical brakes.

Standard class cars are equipped with five seats (2+3) seats per row and first class cars with four (2+2) seats per row. The space between seats in contiguous rows is 1,040 mm for standard class and 1,160 mm for the first class. The vehicle vestibule is level with the platform for ease of small children and elderly and the vestibule areas are equipped with toilets, washbasins, telephones, vending machines and specially designed benches, toilets, washbasins and compartments for handicapped persons.

The air conditioning system is a two-stage cooling type that does not require much duct space but is extremely energy efficient exhibiting stable performance. Salient specifications of the rolling tock are listed in Table 11.1.3.2.

Table 11.1.3.2 : Specifications of Shinkansen Rolling Stock

	Series 700	**Series 300**
Electrical System	AC 25kV, 60 Hz	AC 25kV, 60 Hz
Configuration	12M4T	10M4T
Seating Capacity	Economy Class: 1,123 First Class: 200 Total: 1,323	Economy Class: 1,123 First Class: 200 Total: 1,323
Weight Maximum Operation Speed	708 ton/train set 270 km/hr (Tokaido Line) 270 km/hr (Sanyo Line) and over	711 ton/train set 270 km/hr
Start-up Acceleration Capacity	1.6 km/hr /sec (Tokaido Line) 2.0 km/hr /sec (Sanyo Line)	1.6 km/hr /sec
Power Running Control System	VVVF Induction electoric motor drive with VVVF control	VVVF Induction electoric motor drive with VVVF control

	Series 700	Series 300
Brake Control System	AC regenerative brake system and electrically-controlled air brake system	AC regenerative brake system and electrically-controlled air brake system
Body Construction	Large-sized hollow extrusions of aluminium alloy	Large-sized extrusions of aluminium alloy
Bogie	Bolsterless bogie Wheel diameter: 860 mm Wheel base: 2,500 mmGear ratio: 2.93	Bolsterless bogie Wheel diameter: 860 mm Wheel base: 2,500 mmGear ratio: 2.93
Traction Motor	AC 3-phase cage asynchronous motor 48 motors/train set 275 kW/motor Total Output 13,200 kW /train set	AC 3-phase cage asynchronous motor 40 motors/train set 300 kW/motor Total Output 12,000 kW /train set
Pantograph	Single-arm pantograph 2 pantographs/train set Single collector shoe	Diamond-shaped pantograph 2 pantographs/train set Double collector shoe
ATC	Double frequency system	Double frequency system

11.1.4 TGV (Train à Grande Vitesse):

The most striking aspect is the aerodynamic styling of the nose. Perhaps the most interesting feature of a TGV trainset is its articulation. The cars are not merely coupled together; instead, they are semi-permanently attached to each other, with the ends of two adjacent cars resting on a common two-axle truck. It is thus more appropriate to speak of 'trailers' than of 'cars'.

Fig. 11.1.4 French TGV Double Decker

TGV trainsets are essentially symmetric and reversible, with a locomotive, also called power unit or power car, coupled at each end. The trailing power unit collects power from the overhead electric catenary, and feeds power to the leading power unit through a cable running along the roof of the train. This single-pantograph arrangement prevents one pantograph from disturbing the wire and thus disrupting the contact for the following pantographs. The pantographs themselves are among the most sophisticated, some featuring active damping.

The brakes are suited for running at high speed. They are capable of dissipating a very large amount of energy. The locomotives each have dynamic brakes, in addition to brake shoes for emergency stops. The trailers are equipped with four disks per axle, and in some cases backup brake shoes. Future models might include magnetic induction track brakes.

11.1.5 Talgo :

Some of the Technological Principles of Talgo systems are:

- Lightweight construction
- Articulated connections between coaches
- Single-axles wheel sets equipped with independent wheels
- Steered axles on track at zero angle and
- Low height.

Talgo has also made four technological developments for improvements and better performances for this type of transport.

- The "Talgo RD" system for automatically changing the distance between wheels on axles
- Talgo Tilting suspension for naturally tilting the carbodies on curves,
- Damper system between carbodies and
- Talgo XXI with integrated traction and variable gauge axles.

The passenger carbodies are made from large sections of light aluminum alloys welded together. It can be claimed that, nowadays, weight per seat in Talgo trains is possibly the lowest of all trains in their class, which means major reductions in railway operating energy consumption. This reduction favours economic operating results and from an ecological point of view, diminishes consumption of energy resources.

With this type of connection, standardized and easily identified on all generations of Talgo trains, wheel set components are installed between the car bodies instead of "under" them as in classical design cars, thereby providing a series of very important structural and geometric benefits for development of other Talgo technological features.

Among these it should be emphasized that Talgo technology makes use of available space in coupling between coaches for installation of some simple, but very sturdy components, whose effectiveness has been demonstrated in several unfortunate accidents and which, to the benefit of safety, resists isolated overturning and overlapping of coaches.

Talgo railcars are shorter than conventional design rolling stock. The Talgo Tilting, Talgo XXI and Talgo High Speed generations, in particular, are approximately half the length than conventional cars.

Due to this characteristic and their light construction, Talgo trainsets only have one axle per coach, with the subsequent economic benefit this represents by halving the number of axles per train length unit. These axles also have independent wheels, a practical solution, unique in the world, which has the great advantage of eliminating dangerous axle hunting movement, with all the corresponding benefits this implies for operating safety, especially at high speed, and for reducing wheel-rail friction.

From a maintenance economy viewpoint this feature is also very favourable since on these axles it is not necessary for the two wheels to have the same diameter nor the same wheel profile, which is the case for conventional integral axles.

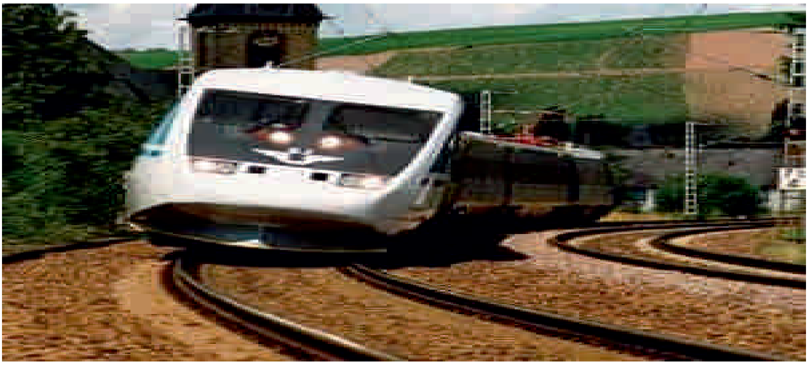

Fig. 11.1.5.1 Talgo tilting train

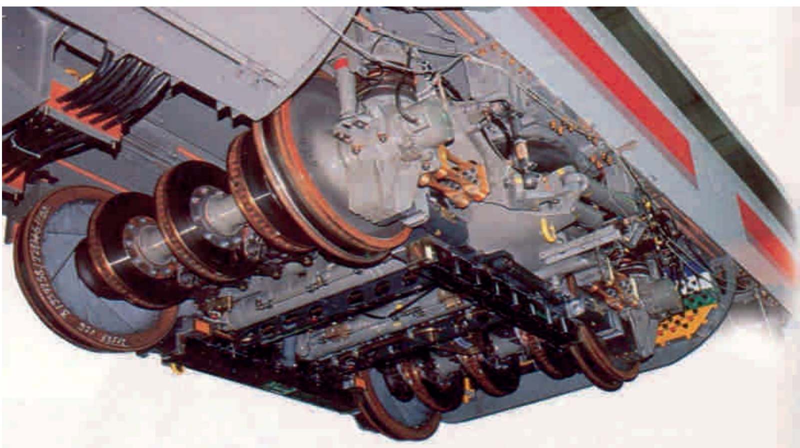

Fig. 11.1.5.2 High Speed bogie

A robust mechanism, formed by articulated rods, maintains the axles equidistant from the carbodies they are integrated into, in such a way that the wheels, both on straight track as well as on curves, remain constantly parallel to the rail. These features increase operating safety levels whilst also reducing wear on wheels and rails.

The location of wheel unit components and the reduced space occupied by the axles enable the railcar level to be lower benefiting dynamic operating stability and preventing them moving forward. Coach floors are also moved closer to platform level, facilitating passenger access to coaches.

11.1.6 Talgo Tilting suspension for naturally tilting the carbodies on curves:

Since 1980, all Talgo rolling stock is equipped with original Tilting type suspension, developed by Talgo for the Talgo Tilting family of trains, which entered commercial service.

All vehicles, when travelling along a line on curved track, are naturally pushed sideways to the outer part of the curve which, in the case of railway vehicles, is translated into a tendency to lean outwards and for the carbodies to turn in the same direction. With Talgo Tilting suspension this movement is reversed, so that on Talgo Tilting trains, the cars lean naturally "inwards" when negotiating curves.

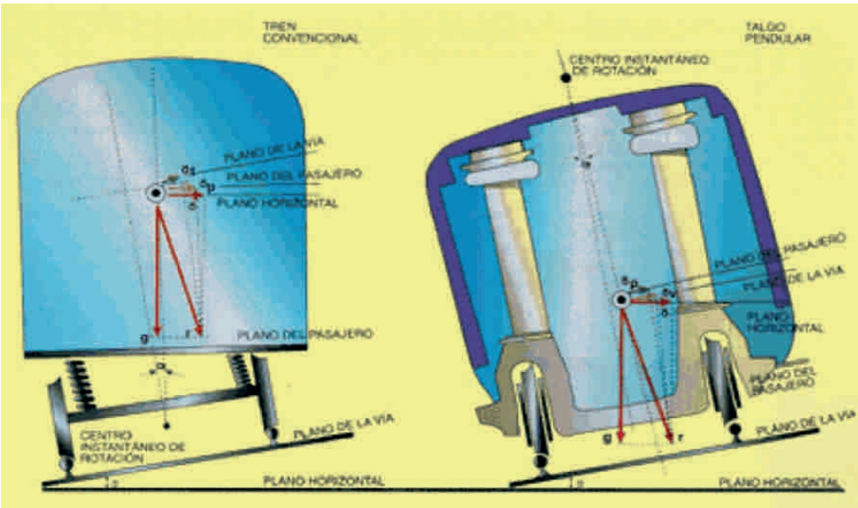

Fig. 11.1.6 Talgo tilting arrangement

This inclination, which on other "tilting car bodies" is forced, artificially produced by means of complicated equipment and systems, favours passenger comfort considerably since lateral forces when negotiating a curve are greatly reduced.

Due to this improvement, it is possible to increase operating speed of vehicles equipped with this feature, always bearing in mind the track infrastructure quality and vehicle operating conditions. In the case of Talgo trains, the axle guidance system together with other notable dynamic features, makes it possible to increase operating speed by as much as 25% with respect to authorised speeds for conventional design vehicles.

Compared with other forced carbody tilting systems, the Talgo natural Tilting, produced by centrifugal forces has the advantage of being completely reliable and at low functional cost, as well as naturally comfortable and economic to manufacture and maintain, since the system is essentially based on a simple elevation of car support levels above the Centre of Gravity, which does not involve any cost.

11.1.7 Other Tilting Trains:

Tilting trains were developed by British Rail in the 1970s and led to the creation of the Advanced Passenger Train. Prototypes of these operated on the West Coast Mainline in the 1980s, before the project was abandoned in 1986. But the concept was taken up, notably in Italy and Sweden, which went on to develop successful tilting trains.

It costs many times more per unit distance to build a dedicated high speed line than it does to upgrade existing lines for tilting trains. This is what makes tilting trains option attractive. However there are disadvantages too. The speed of 230km/h is about as fast as trains go when not on dedicated lines and then they have to be fitted in with slower moving traffic. Problems of railways reaching saturation point has forced new lines to be built. This is why despite the success of the Italian Pendolini, a new high speed line with 300 km/h trains were built, because existing lines were at saturation point.

11.1.8 Switzerland's ICN:

Swiss Tilting Train is as InterCity Neigezug (ICN) or InterCity tilting train.

Swiss Federal Railways has undertaken a co-ordinated modernisation programme in an effort to ensure that standards are lifted uniformly across the whole network under which Swedish X2000 and Italian 'Pendolino' high-speed trains for use on the twisting, undulating terrain of the Swiss rail system have been introduced. The new tilting trains are supplied by a consortium of major manufacturers comprising Adtranz (now Bombardier), Fiat-SIG and Schindler Wagon.

The chosen rolling stock design is a sleek, streamlined seven-car EMU, with a seating capacity of 463 and a top design speed of 200km/h

Each trainset weighs 355t and is 188.8m long. Power is supplied at 15kV AC, with the transformer accommodated in the third vehicle. The only vehicle not to carry any traction equipment is the centre car, the only one containing exclusively first class accommodation.

Monocoque aluminium bodies are used to minimise weight, and the vehicles' dimensions are carefully designed to ensure there is no resonance with the running gear and underfloor-mounted equipment, so ensuring a smooth ride.

Each vehicle is mounted on an H-frame bogie, including Geneva-Biel/Bienne-Basel from 2004 driven tilting mechanism, centrally-located secondary suspension, and radially-steered wheelsets. The transformer in each three-car section feeds a GTO converter, powering four self-ventilated

171traction motors. Power for auxiliary and passenger accommodation is supplied at 1.4kV 50Hz from an inverter in the train's traction converter. Data between the two halves of each trainset is transferred via a wired train bus, using a system based on that used in the IC-2000 double-deck inter-city rolling stock.

The tilting equipment specification has very tight parameters. The leading cab has a processor, which calculates the degree of tilt needed as the train enters each curve. The interior design incorporates novel features. There are no car-end doors between passenger seating areas and the gangways, which are pressure-sealed. The first-class seating is located in the centre of the train, and a 26-seat dining car with serving area in the third car.

Fig. 11.1.8.1 WCML - Pendolino

Fig. 11.1.8.2 Korean High Speed Train

11.1.9 United Kingdom :

West Coast main line pendolino tilting trains: Franchised train operator GNER operates a fleet of 31 6,090hp (4,540kW) Class 91 locomotives built by BREL (now Adtranz) at Crewe Works. These work in push-pull mode with 31 nine-car Mk4 coaches plus driving van trailers built by Metro-Cammell (Now Alstom). The trains were introduced from 1991; designed to run at (225kmh) and could be retro-fitted with tilt because they have chamfered bodysides.

11.1.10 Eurostar :

The Eurostar launched in 1994, was Europe's first international train, designed to take advantage of the Channel Tunnel, to provide a high speed rail service between London and the UK to destinations in Continental Europe.

- Top Commercial Speed 300 km/h
- Top speed in England 160 km/h
- Top speed in the Channel Tunnel 160 km/h

Fig. 11.1.10.1 Euro Star Train

The train is 20 cars long, some 400 meters long with a passenger capacity of 800. It is made up of an engine at each end and 2 buffet cars with 2nd class at each end, and the 1st class sandwiched in between the buffet cars and 2nd class in the centre. Like the TGV it is a fixed trainset, and the coaches all share a common bogie. However unlike a TGV the two coaches in the centre of the train do not share a bogie so that it can be broken up in the middle. This is for safety reasons when running in the tunnel.

The traction motors were assembled in the UK and use British asynchronous traction drivers instead of synchronous traction motors as used in France to cope better with the 3rd rail power supply. Also various signalling controls of the train are British, necessarily to cope with the British signalling system. In fact, the Eurostar is capable of operating under 7 different signalling systems. Also the Eurostar had to be built to British specifications which are more strict than in France, which meant the TGV design couldn't be used it had to be completely started from scratch.

The Eurostar has a very small windscreen for the driver, and has no side windows at all. Infact inside the car the driver sits quite far back from the small windscreen. This is because it was found that going down a tunnel at a fast rate for several minutes induced a hypnotic effect on the driver

The Eurostar is the only high speed train to have shoes which are needed to pick up electricity from the 3rd rail in England. It has two pantographs on top, one for French 25kV AC systems and one for Belgium 3kV DC systems

The nose of the Eurostar has been specially designed for operation in the Channel Tunnel, where aerodynamics is of greatest importance.

In the UK, the Eurostar runs on existing Kent Lines but is limited to 160kmph. The lines in Kent are extremely good straight and flat but there is a fundamental problem that the double track lines are spaced very close to each other. Often when two trains pass each other there is as little as 30 cm or a foot between them. This means there is an overall speed limit of 160kmph. If two trains pass just a few centimetres from each other at a relative speed of significantly greater than 320kmph, then there is a risk that the resulting pressure wave could blow out windows in the train.

In the Channel Tunnel the train runs at about 160kmph which is the speed also of the "le Shuttle" trains which ferry cars across the tunnel. In France and Belgium the Eurostar is free to run at up to 300km/h.

Eurostar is the costliest train system in the world. It works out at £30,000 per seat or US $40,000 which is a world record for a train. Having said that, for an average airliner it is about £150,000 per seat or US $200,000.

11.1.11 Active Tilting Technology:

The active tilting technology is more complicated than the passive tilting technology, nevertheless more popular. In this, the inclination of the car frame is managed by electromechanical or hydraulic systems that get data and orders from an electronic component. To calculate the optimal tilting angle, the following variables, put at disposal by acceleration sensors and gyroscopes, have to be put in consideration: actual speed, curve radius, centrifugal acceleration and track level. In early tilting systems each car had its own sensors and computer that calculated the values only for itself. As mainly multiple units are equipped with active tilting systems, newer models of tilting systems only have sensors in the first and last car. The computer calculates the delay on which the orders are forwarded to the following cars (Master - Slave - principle). Older models of hydraulically tilting systems took much space away, in newer models the whole tilting system is located in the bogies and allows the usage of the whole space in the passenger cell. There is a special problem on electrical powered tilting trains, especially electrical multiple units (EMU), with the pantographs. If the pantograph were installed in a solid way on the roof it would loose the contact with the catenary in curves. To avoid this the pantograph can be coupled solid with the bogie or a special hydraulic system can be added to compensate the inclination of the car frame.

Some of the popular tilting sub-systems are made by Alstom and Fiat.

a) Alstom System :

Alstom has developed his own tilting system, which - comparable with the system by CAF, initiates the inclination of the car frame before reaching the curve. The train is located only by gyroscopes and accelerometers. In practice this means, that the on board computer has to know the geometry of the whole line. If a train, equipped with the tilting system by Alstom, runs for the first time on a line it does not even know the geometry of the line. In this case the tilting technology works reactively (penduler réactif) and the data is saved in the on board computer. After this first run each time the tilting train enters this specific line the computer recognizes the line geometry and the tilting system can work in advance (penduler anticipatif). This is much more comfortable to the passengers.

b) Fiat System :

The most popular tilting system is developed by Fiat Ferroviaria. As most other tilting systems it works reactively. Tilting trains equipped with the Fiat-System are called Pendolino.

11.1.12 Spain :

AVE brand (Alta velocidad española) owned by the Spanish National Railways, RENFE.

The different technical features of the high speed line as compared to the conventional network mean that the AVE trains are "captive", i.e. completely restricted to these lsections.

11.1.13 Italy: Eurostar:

The first generation of new rolling stock was the ETR450 Pendolino, built by Fiat Ferroviaria. However, the latest derivative, the ETR500 non-tilting variant, has been designed and built by Gruppo Ferroviario Breda at its factory in Pistoia.

The later ETR460/480 trains were the first to offer restaurant facilities in a tilting train. and capable of speeds up to 250km/h. The ETR500 is a 13-vehicle unit seating 590 passengers. Introduced in 1996, this is capable of 300km/h.

11.1.14 Belgium - Thalys PBKA High Speed Network:

Running standards are similar to French National Railways (SNCF) with 17t axleloads, 25kV AC electrification and cab signalling.

It is provided with 17 four-voltage trains known as TGV PBKA Thalys trains were built by Alstom in the late-1990s.

11.1.15 Sweden :

X 2000 Tilting Trains The first X2000 tilting train was delivered from ADtranz in 1990

Each X2000 formation consists of one 4400hp power car, powered at 15kV ac. Each unit can be made up of up to 16 intermediate vehicles with a maximum capacity of 1,600 passengers, but a typical train has only five intermediate trailers.

The secondary routes are served by a second generation of X2000, the X2-2. While the current network is geared for 200km/h, there are long-term plans for upgrading to allow 300km/h operation.

Each X2000 trainset is mounted on 'soft' bogies, which adjust automatically on curves and mean a train can run up to 40% faster without exerting extra stresses on the track. An accelerometer measures lateral acceleration on curves and the main computer in the leading vehicle calculates the amount of tilt required and sends instructions to the computer in each coach.

X2000 is fitted with an advanced system of Automatic Train Control (ATC), which provides a series of information about the line up to 4km ahead of the driver. If there is no response, the train brakes are automatically applied.

Each train also has three independent braking systems, an electric regenerative brake for speed adjustments down to standstill; air-operated disc brakes for normal and hard braking, and a magnetic track brake for use in emergencies.

Electronic anti-slip devices and parking brakes are also fitted. The standard train brake gives stopping distances of 1,750m from 200km/h, (1,100m) from 150km/h, and (700m) from 130km/h. A full emergency application of the magnetic brake will bring the train to a stand from 200km/h in 1,100m.

11.1.16 Train Formation suggested by RITES for Indian High Speed B.G. Corridor:

The computer simulations carried out suggest that 2M+6T configuration with passenger capacity of around 766 with design similar to E-2-1000 Shinkansen series is able to achieve 250 Kmph. However a formation of 3M+5T with a cost index per passenger marginally higher (107.59 compared to the base 100 for 2M+6T and 138.61 for TGV type push-pull formation) is recommended for adoption in view of greater allowance for make up margin and no deterioration in run time even under conditions of failure of one of the motor coach.

As the energy consumption forms a significant component of operating costs, possibility of accommodating the maximum number of passengers has been explored. In this context it is noted that the duplex TGV has a width of (3.886 m) and the Shinkansan E-2-1000 has a width 3.354 m leading to a considerable increase in the passenger capacity compared to 2.946 m wide German ICE's. Thus considering our wider gauge, running of bi-level 3.886 m wide stock (similar to Duplex TGV's) may be considered for above formation to further reduce the operating cost per passenger.

11.2 Operating conditions:

Details of maximum axle load, maximum design speed and maximum operating speed in different countries pioneer in high speed operation is given in table 11.2 below:

Table 11.2: Operating Conditions - Axle load maximum design speed & operating speed.

Country										
PARAMETER	**France**		**Germany**			**Italy**		**Spain**		**Belgium**
(Km/h)	300	350	300	300	350	300	350	300	350	300
Type of traffic	Pass-enger	Pass-enger	Pass-enger freight	Pass-enger	Pass-enger	Pass-enger freight	Pass-enger	Pass-enger	Pass-enger	Pass-enger
Maximum Axle load for the maximum line speed, high speed trainsets (t)	17	17	17	17	16	17	17	17	18	17
Maximum Axle load for locomotives (t)	None	None	20	None	None	22.5	22.5	22.5	22.5	22.5
Maximum Axle load for freight wagons (t)	None	None	22.5	None	None	22.5	22.5	None	None	22.5
Maximum design speed of the lines (km /h)	350	350	300 (tunnels 330	300 (tunnels 330	350	250-	350	270	350	320
Maximum operating speed of the lines (km/h)	300	320	300	300	330	300	350	270 (300)	>300	300

11.3 Train dimension and seating capacity:

Train dimension and seating capacity of a few high speed system is given in the table 11.3 below:

Table 11.3: Train dimension and seating capacity

Equipment type	Top speed	Seating capacity	Overall length	Width	Weight	Power	Power to weight
TGV Sud-Est	270 km/h as built 300 km/h rebuilt	345	200.2m	2.81m	385 t	6,450 kW	16.7 W/kg.
TGV Atlantique	300 km/h	485	237.5m	2.90m	444 t	8,800 kW	19.8 W/kg
TGV Reseau	300 km/h	377	200m	2.90m	383 t	8,800 kW	23.0 W/kg
EurostarThree Capitals	300 km/h	794	393.7m	2.81m	752 t	12,240 kW	16.3 W/kg.
Eurostar North of London	300 km/h	596	318.9	2.81m	665 t	12,240 kW	18.4 W/kg.

11.4 Meteorological conditions:

Other things being equal the vulnerability of trains (from the point of view of the stability) to side winds increases with the speed. In addition, wind has an effect on the catenary, and in order to increase its resistance to the side wind, it is necessary to increase the mechanical tension.

DB AG imposes speed restrictions when the lateral component of the wind speed exceeds 90 km/h and traffic is discontinued, due to the catenary, when that component exceeds 120km/h.

SNCB limits the speed to 170 km/h when the wind speed is more than 108km/h, in whatever direction.

In certain cases, anti wind screens can avoid a speed restriction in order not to risks overturning high speed train sets. SNCF has introduced a software programme on the new TGV Mediterranean line, to examine the wind parameters.

11.5 Disaster Protection:

(a) Speed reduction during maintenance:

Depending on the choice of the distance between track centre lines and the definition of the dangerous zone for the staff (variable depending on the country), when maintenance staff are working on the line the speed in service may have to be reduced below 350km/h.

(b) Safety precautions on Shinkansen:

(i) The Shinkansen has no level crossings with roads. The tracks are laid out exclusively on the right of the way (on an embankment or viaduct), or in each cut section, an overpass has been created. In addition, entry of unauthorized persons onto tracks is completely prohibited by law. Also, a protective fence is installed on each side of the line, excepting tunnels and viaducts and over passes have fences to prevent automobiles and the like from falling onto the tracks.

(ii) Effective measures for prevention of slope collapsing, installation of anemometers, and rainfall measurement gauges are provided along Shinkansen routes.

(iii) For snow protection, Sprinklers for melting snow, snow plow along front skirt of the leading car, and a body mount system in which the underfloor equipment is housed inside the carbody are adopted.

(iv) In the Shinkansen system, a seismograph is installed in each of the substations and sectioning posts erected along the line at interval of 20 km. If any of the seismographs detects an earthquake of 40 gal or more, it automatically shuts off the power supply and the train running in the section stops completely. An ingenious system, which utilizes the seismic mechanisms called the Urgent Earthquake Detection and Alarm System (UrEDAS), has been developed for the early detection of earthquakes, in order to enable proper control of train operation during an earthquake.

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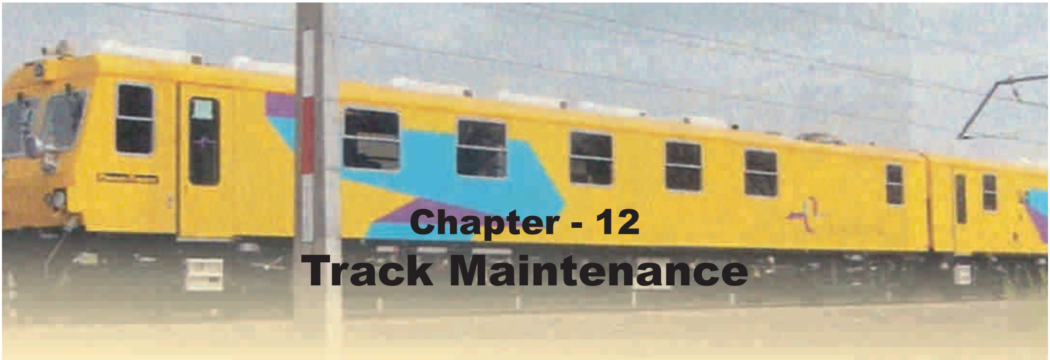

Chapter - 12
Track Maintenance

12.1 Life cycle of the Track components:

The life cycle of the track components is limited, depending on stress and length of use. They have to be replaced after this period has elapsed.

The following maintenance cycles/service life periods approximately apply to normal main-line tracks of high speed track components:

Tamping	40-70 mio. t	4-5 years
Grinding	20-30 mio. t	1-3 years
Cleaning	150-300 mio. t	12-15 years
Rail replacement	300-1000 mio. t	10-15 years
Replacement of concrete sleepers	300-700 mio. t	30-40 years
Rail fastenings	100-500 mio. t	10-30 years
Replacement of ballast	250-500 mio. t	20-30 years
Rehabilitated subsoil	> 500 mio. t	> 40 years

Nowadays, the DB AG expects maintenance cycles of 8 years of primary track. Cleaning is performed only during renewal (about every 30 years for tracks on concrete sleepers). The lifetime of the rails is about half the lifetime of the track (approx. 15 years) and this limit is usually not caused by rail wear, but by defects on the rail surface. The ballast is usually replaced during track renewal (i.e., after 30 years).

12.2 Theoretical wave length criteria:

Track geometry is described by track profile, cross level, alignment and gauge. As a vehicle travels, it responds to track geometry variations and irregularity. The chord length of 9.6 m and 7.2 m for measurement of top and alignment respectively are grossly inadequate in correctly assessing the track irregularity for high-speed operation.

The wavelength of track irregularities, which leads to sway the coach, depends on the natural frequency of the vehicle and speed. The relation among these three parameters can be expressed mathematically in the following form:

$V = f\lambda$

Where

V = Speed of vehicle in meter/second

f = Natural frequency of the vehicle in hz

λ = wavelength of the track irregularity causing sway/resonance in the vehicle in meters.

For natural frequency value of one, the vehicle proposed to run on the particular line, the wavelength for different speeds are as follows:

(a) For high speed v=200 kmph & f=1Hz

λ = **55.55m**

(b) For high speed v=250 kmph & f=1Hz

λ = **69.45m**

(c) For high speed v=300 kmph & f=1Hz

λ =**83.33m**

(d) For high speed v = 350 kmph & f = 1Hz

λ =**97m**

Hence, track defects of wavelength 80-100 m are prone to create resonance for very high speed.

All the vehicles plying on any line will not have a uniform natural frequency and speed on whole route can not be uniform due to various reasons the wavelengths to be controlled remain in a band width. On IR, the frequency of ICF coaches is 1 Hz approximately. On Japanese Railway passenger rail vehicles tend to sway at natural frequencies between 1.0 to 1.5 hzs.

Since the natural frequency of carriages designed for high-speed is low, generally less than 1 Hz long wavelength anomalies provide dynamic input to the high-speed passenger vehicles and can excite car body modes at high speeds. At speeds of 350 km/h track irregularity up to 100 m wavelength would be important.

12.3 Standard values of track tolerances for maintenance and danger limits for High speed on standard gauge:

For high speed routes it is very necessary to know the limit of track parameters in the form of tolerances, so that track can be maintained accordingly.

If the standard values for maintenance are exceeded, maintenance should be planned and carried out. If the danger limit is exceeded, the defect has to be remedied immediately or a speed restriction has to be applied. Standard value for maintenance and danger limits concerning the track position are given in table 12.3.1, 12.3.2 and 12.3.3.

Table 12.3.1: Standard value for maintenance and danger limits concerning the track position on standard gauge.

Track geometry values	Chord (m)	Standard maintenance value (mm)					Danger limit (mm)		
		v (km/h)					v (km/h)		
		v≤ 80	80 <v≤ 120	120 <v≤ 160	160 <v≤ 230	v≥ 230	120 <v≤ 160	160 <v≤ 230	v> 230
Longitudinal level	2.6/6	12	10	8	6	5	14	11	9
Cross level		10	8	7	6	5	11	10	9
Versine	4/6	12	10	8	6	5	14	11	9
Track gauge		+20	+10	+10	+8	+5	+25	+20	+15 -4

Table 12.3.2: Standard maintenance values for defects on the rail surface on standard gauge.

Type of defect	**Wavelength** range (mm)	**Standard** maintenance value (mm)	**Max.** admissible (mm)
Corrugation	10-100	0.05	0.15
Short waves	100-300	0.1	0.3
Long waves	300-3000	0.4	-

Table 12.3.3: Standard maintenance values – cross profile of the rail head.

V (km/h)	Admissible radial deviations (mm)
120 < v < 140	+ 1.5
140 < v ≤ 160	± 0.7
> 160	± 0.5

12.4 Accuracy of acceptance:

After maintenance the track geometry has to meet the following requirements:

Table 12.4.1: Maintenance Tolerances for high speed corridor

Type Class		IV	III	II	I	0
Speed Range Km/h		>250 to 300	> 200 to 250	>120 to 200	>80 to 120	<80
Gauge (mm)		±2	±2	±2	±3	±3
Cant (mm)		±2	±2	±2	±3	±3
Longitudinal level (mm)	Chord 10m	2	3	3	4	5
	Chord 20m	3	4	5	-	-
Alignment (mm)	Chord 10m	2	3	3	4	5
	Chord 20m	3	4	5	-	-
Twist 3m basis	(0/00)	1	1	1	1.5	1.5

The following tolerances apply to tracks with marked survey points and have to be observed:

Track level allowance referring to the marking: + 10mm / - 20 mm

Allowed track distance referring to the marking ± 10mm

Besides, the following tolerances apply:

Sleeper spacing: Loose sleepers + 20mm < 5%

Level of track joints (1.5-m basis) + 2.0 mm upwards,
0 mm downwards

Table 12.4.2: Acceptance limits – longitudinal profile after grinding

Type of defect	Range of Wavelengths (mm)	Acceptance limits (mm)
Roughness	< 10	0.01
Corrugation	10-30	0.01
Short waves	30-300	0.02
Long waves	300-1000	0.13
	1000-3000	0.30

Table 12.4.3: Acceptance limits – cross profile of the rail head

V (km/h)	**Acc eptance limits (mm)**
V < 140	+ 0.7 / - 1.0
140 <= v < 160	0.5 / - 0.3
V >= 160	0.3 / - 0.3

12.5 Existing Track Tolerances in IR:

The track tolerances for operation of passenger trains at a maximum speed of 160 km/h with WAP3 locomotive on Mark-IV bogie and coaching stock with IR-15 bogie coaches has been done by RDSO is described below :

Track Parameter	**Standard Deviation**	**Maximum peak Exceedences**
Unevenness (Base 9.6m)	5.0 mm	15 mm
Alignment (Base 9.6m)	3.5 mm	10 mm
Twist (base 4.8m)	3.0 mm	09 mm
Gauge	2.3 mm	08 mm

12.6 Proposed track tolerances for high speed route corridor :

Track Parameter	Standard Deviation	Maximum peak Exceedences
Unevenness (Chord 40m)	3.00mm	5mm
Alignment (Chord 40m)	2.00mm	5mm
Twist (base 4.8m)	2.0mm	5mm
Gauge	2.00mm	5mm

12.7 Ballast Cleaning:

The ballast has to be cleaned when the mean value of the specimen measured as undersized particles through a 20 mm square-mesh sieve indicates a contamination of =30 percent in weight.

12.8 Considerations on the track quality :

When the intervention threshold (desirable driving comfort) is reached, the track is tamped and the standard deviations of track defects decrease. This period is followed by a period of fast exponential growth of the track defect, before it "gets saturated" and shows a linear course of deterioration – this period is approximately 0.5-2 GMT. The rapid decrease of track quality during the first 0.5-2 GMT of operational load is called initial settlement. This rapid initial deterioration can be reduced by controlled settlement using the Dynamic Track Stabiliser.

Subsequently, the defect increased linearly. This linear rate of deterioration finally passes to exponential growth, depending on the operational load and structural design of the track grid. This happens particularly if cleaning is performed too late or in the case of subsoil problems (rising fines etc.). When the ballast gets contaminated, it loses its load-distributing effect. Then the ballast pressure under the sleepers and the pressure on the subsoil is increased and the effect of tamping does not last. At the same time the achievable initial quality decreases.

12.8.1 The initial quality:

The higher the initial quality, the higher the wear reserve and the longer it takes to reach the intervention threshold again.

The figure 12.8.1 shows the development of track quality according to the exponential law for rate of deterioration. A poor track (upper limiting value of the scatter) has a low achievable initial quality. The figure shows that the quality of a poor track deteriorates rapidly, that its position cannot be maintained even by repeated tamping, but decreases faster and faster.

The typical maintenance cycles for such tracks are between 0.5 – 1.5 years. High rates of deterioration can be found for tracks with a contaminated ballast bed, poor subsoil conditions, or for tracks where the structural design has not been adapted to the operational loads, High-speed tracks or main tracks with high bearing capacity of the subsoil (with sufficient track formation and frost protecting layers) show lower rates of deterioration – these correspond to the lower limiting line of the scatter. The initial quality of such tracks is high, their rate of deterioration is low, an unchanged, good and durable track position can be reached for long periods by tamping. The typical maintenance cycles for such good tracks are more than 5 years.

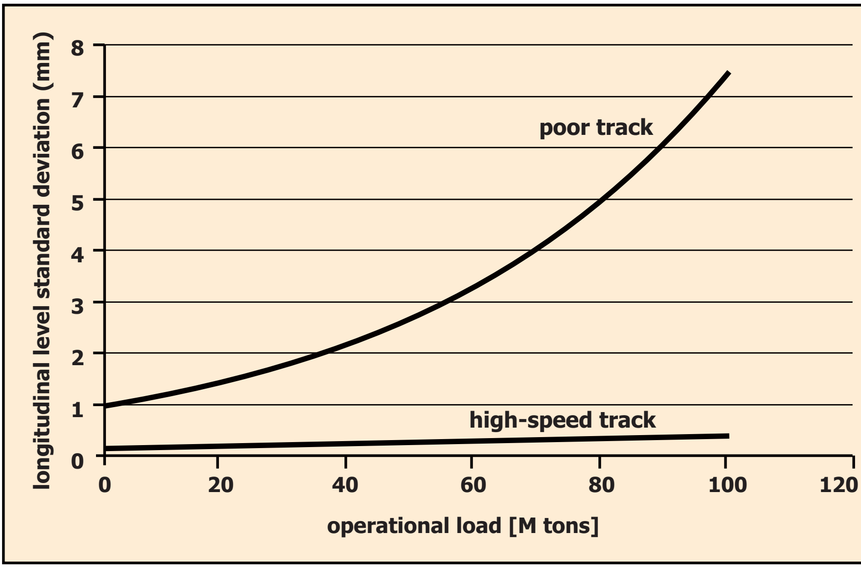

Fig. 12.8.1 Development of track quality depending on the rates of deterioration

Studies have shown that the position of a good track can be improved more in comparison to a rather poor track. The condition and high standard of high-quality tracks with good track position can be maintained more easily and economically than poorer tracks. The higher the initial quality of the track after laying, reconstruction or maintenance, the lower the subsequent maintenance cost. A precise geometric track position significantly influences the initial quality of the track.

12.9 Track Geometry Measurement through transfer function for high speed track:

Versine measurement system are linear and of invariant location. Their specific property is that for periodic defects in track position they generate in their turn periodic signals of the same frequency, but of different amplitudes and phase position.

This means that in a measurement with an asymmetrical 15-m chord (with a division relation 1:2), e.g., a long-wave defect of 70m wavelength and a maximum amplitude of 10mm is shown only with an amplitude of 3.5mm and a phase displacement of 8.5° (or a imaginary displacement of the maximum by 1.6m). This behaviour is described mathematically by the so-called transfer function of the versine measurement system.

12.10 High Speed Recoding Car:

High-speed track recording cars for high-speed lines are equipped with contactless inertial measuring system which allow long-wave track defects to be assessed in accordance with their amplitudes. Apart from the relative exactness of the track position, which is expressed by standard deviation of the measured parameter, it is necessary to record the track position absolutely in order to assess its safety in regard to track buckling.

Therefore, high-speed lines are usually surveyed tracks. The distance and the level of the track referring to fixed or reference points are monitored.

A track recording car has to record defects according to the state of the art and as far as possible in accordance with amplitudes and phases. The range of possible wavelengths, which differ from parameter to parameter, is between mm and 100m. The measured amplitudes are within the range from mm to m. Nowadays, recording cars are produced for a range of measurement speeds between 5 km/h and 250 km/h.

12.10.1 Multifunctional recording cars:

There are many advantages of simultaneous measuring and recording of various track parameters.

In order to ensure efficient maintenance and planning of track reconstruction, railway apply the method of interdisciplinary cooperation between various fields. Track work is increasingly performed in a coordinated way to ensure a minimum of operational hindrance.

Therefore it seems obvious also to carry out the recording of the individual parameters, which are important in several areas, simultaneously and with the same recording vehicle. Furthermore, this simultaneous approach offers the advantage of putting greatly varied track defects into correlation with one another in order to detect interactions. A defect in track level could, e.g., be connected to a increased wear of the overhead line. As the costs for the use of a recording car are about the same for the measurement of one or of several parameters, it is obvious that the economic efficiency increases with the number of parameter measured at the same time. Multifunctional recording cars offer the additional advantage that all measured parameters are correctly listed in real time for each location.

12.11 Measured parameters and marginal conditions:

12.11.1 Permanent way parameters :

Table 12.11.1 shows a list of the parameter which are relevant for permanent way and marginal conditions according to the state of the art.

Table 12.11.1 Relevant parameters for permanent way

Measured value	Wavelength (m)	Type of measurement	maximum recording speed (km/h)
Longitudinal level	1-100	Contacting; Contactless; inertial	250
Position / long wavelengths	1-100	Contactless; inertial	250
Absolute position	-	Contactless GPS	250
Versine	1-15	Contacting, contactless, calculated	250
Superelevation	-	Contacting, contactless, inertial	250
Twist	-	Contacting, calculated	250
Track gauge	0.25-100	Contacting, contactless, under load	250
Track gaps (joint gap, diamonds)	0.5-1	Contactless, image evaluation	160

For contact measurement, measuring wheels or sensors are used. Contactless measurement uses optical laser-aided triangulation measurement device, but also later scanners, video-systems with image evaluation, and inertial measurement system.

The absolute position of the recording car can be determined during the run by using the DGPS (Omn/STR – European service for GPS correction signals). So, nowadays, the position may be determined with an exactness of upto 0.5-1m.

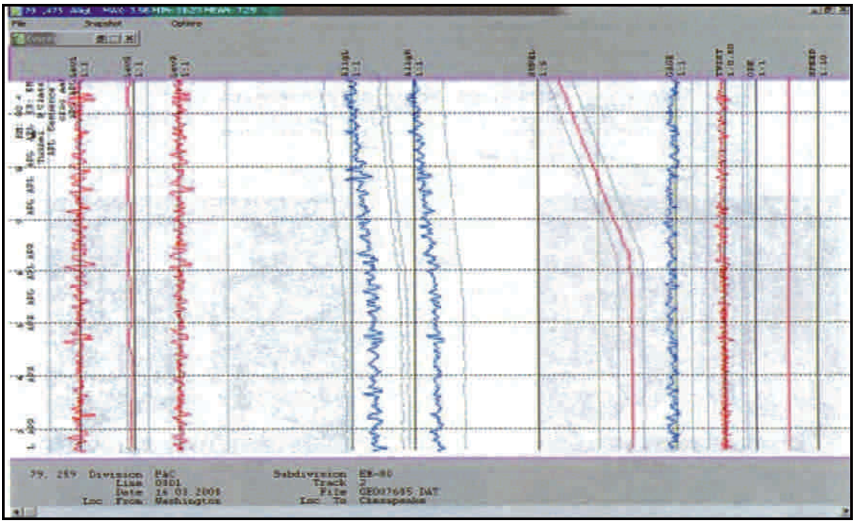

Fig. 12.11.1 : Monitor image of recorded track geometry

12.11.2 Subsoil parameter:

Nowadays, subsoil properties, like water content, statements on the layer structure, etc., can be recorded continuously only by georadar. The measuring speeds are restricted to 30-50 km/h.

12.11.3 Ballast parameters:

At the moment there are only contactless measurement systems which measure the ballast bed profile by using scanners. The thickness of the ballast bed can be determined by using georadar.

12.11.4 Rail measurement:

Table 12.11.4 shows a list of track parameters which can be recorded, as well as its marginal conditions according to the state of the art.

Video imaging and high-resolution fast digital cameras can automatically recognize and evaluate defects of the rail surface and of the rail fastenings.

Corrugation measurement is performed by inertial measurement using a softly sprung mass on which a laser distance measurement device is installed. The measurement signal of corrugation is of much higher frequency than the natural vibration of the system.

The rail profile is measured by illuminating the rail head through a laser slot and recording it digitally, usually stereoscopically. The measured rail profile is determined by comparing it to stored target profiles.

Subsequently, the measured actual profile is compared to the target profile to calculate the rail had wear. With the help of these digital photographs it is also possible to determine the rail inclination and track gauge. There are also adapted systems which are able to determine the groove width and the diamond gap of switches.

Table 12.11.4 Rail Measurements

Measured parameter	Wavelength	Type of measurement	maximum recording speed (km/h)
Material properties	0.1-10 mm	Ultrasonic	100
Surface defects	0.2-100 mm	Video image evaluation	250
Rail fastenings	-	Video image evaluation	250
Corrugation	2-100 cm	Inertial; contactless, contacting	5-250
Rail inclination	-	Contactless	250
Rail wear, rail form	-	Contactless	250
Rail temperature	-	Contactless, optical	250
Switch measurement (groove width, diamond gap	-	Contactless, optical	250

12.12 Measurement of the overhead line :

Table 12.12 below gives a lit of parameters which can be recorded for the overhead line, as well as their marginal conditions according to the state of the art.

Table 12.12 : Maximum recording speed

Measured value	Wavelength	Type of measurement	Maximum recording, speed v (km/h)
Level and horizontal position	40-100 m	Laser scanning; contacting	250
Driving dynamics	-	*Wire strain gauge* force acceleration	160
Wear of the contact wire	-	Video image evaluation	250
Pole recognition	40-100m	Contactless	250
Catenary supporting structure	-	Video image evaluation	250

Non-contact optical laser scanners are used to determine the horizontal position (zigzag) and the level of the overhead line. The measure and record in real time up to 4 contact wires. Sinusoidally modulated laser beams are used for this purpose. The light reflected by the overhead line is collected by a detector. The distance can be determined from the phase displacement between the emitted and the received light. The horizontal position and the level of the contact wires can be calculated by using the scan angle and the distance measured. Figure 12.12.1 shows the laser scanner for the determination of the contact wire position in the centre and on the left and right-hand sides the measuring equipment for the determination of the position of the masts.

Due to the use of laser radar technique for mast recognition (and the position of the contact wire bracket) the system becomes insensitive to external light (such as daylight or darkness). Therefore, measurement can be performed also in tunnels and on bridges. If two mat recognition unit are used, the position of the masts can be determined exactly even if there are interfering objects. Digital cameras are used to measure the wear of the contact wire. The resolution of the measurement is 0.1mm.

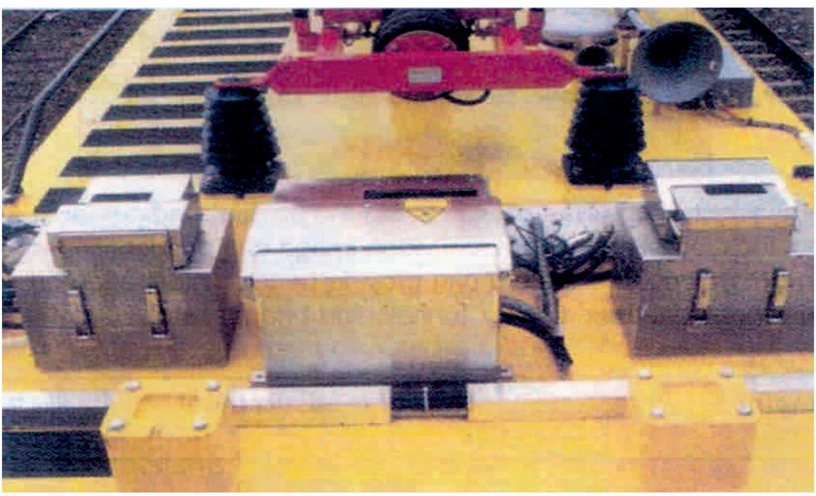

Fig. 12.12.1 : Determination of the position of the overhead line and mast recognition

The horizontal and vertical contact forces, the position of the contact wire on the slippers, the acceleration at the current collector and the position of entering and exiting contact wires of intersection catenary suspension on the current collector can be measured with contact load sensing devices. Force sensors are fitted at the ends of pantograph slippers (wire strain gauge technique) and the total of both measured signals of a slipper equals the acting contact forces. The position of the entering and exiting contact wires of intersecting catenary suspensions is measured with the help of inductive proximity sensors in the horn of the pantograph.

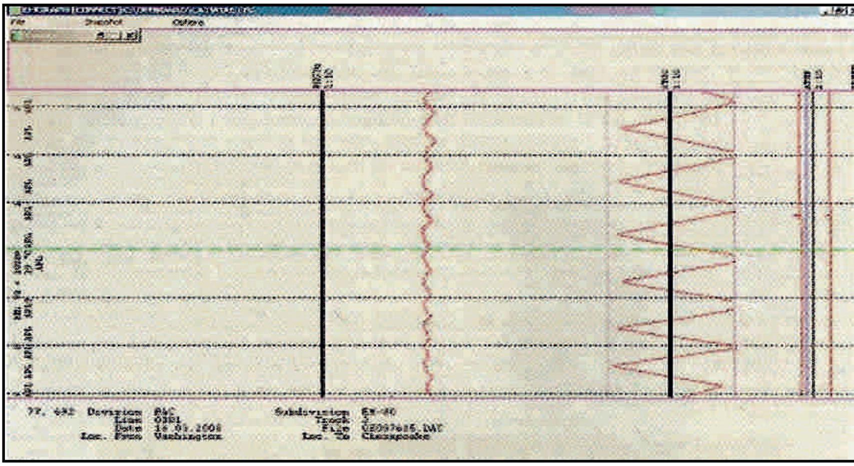

Fig. 12.12.2 : Monitor image of an overhead line determination

12.13 Measurement of the track surroundings and track inspection :

Table 12.3 Shows a list of the parameters which can be recorded during a measurement of the track surroundings, as well as their marginal conditions, according to the state of the art.

Colour video systems which record the railway track and its surroundings exist for track inspection purposes. The exact location of each individual video image can be identified by superimposition of the current position data. Thus, the system can provide general information on the track structure, the ballast bed, the vegetation, the catenary, tunnels and bridges, etc.

Table 12.13: Parameters of track surroundings and track inspection

Measured parameter	**Type of measurement**	**Maximum recording speed v** (km/h)
Clearance gauge tunnel profile	Laser scanning	250
Track inspection	Video	250
Rail fastenings	Video image evaluation	250
Radio line section strength	Field strength measurement device	250
Location of automatic train stop devices	Optical triangulation	250
Sound	Microphone	160
Conductor rail measurement	Contacting; optical; video	50-250
Ambient temperature	Electrical	250

Other video inspection systems with subsequent image evaluation determine defects of the sleepers and rail fastenings. Images showing defects are classified and stored together with track data and kilometric data.

12.14 Multifunctional recording car UFM 160:

The UFM 160, Fig. 12.14 shows a modern version of a universal recording car.

This vehicle was built for use in the German Federal Republic, the Netherlands and Great Britain. It is a recording car consisting of two vehicles. Both vehicles are connected to each other via a passage. The recoding car runs on four pneumatically cushioned bogies, a special development of Plasser & Theurer for speeds of up to 200 km/h. The bogies are equipped with disk brakes, antiskid and antislip systems. Two bogies are powered and ensure a self-propelled running speed and measuring speed of 160 km/h. The drive unit consists of two low-emission 12-cylinder underfloor diesel engines with an output of 550 kW each, two hydrodynamic turbo-gearboxes and two axle gearboxes each.

Figure 12.14 : Two-piece multifunctional recording car UFM 160

The following are the essential recording systems:

- measurement of the track geometry parameters with inertial measurement systems and GPS and 2 optical track gauge measurement systems. Measurement and recording of track gauge, super-elevation, longitudinal level, alignment, cross level and track twist,

- an additional rapid track gauge measurement system working according to the laser method of dissecting (allows track gauge to be recorded also for switches in the area of the check rails),
- GPS (OmniSTAR) location and orientation system,
- rail profile and rail wear measurement system,
- inertial corrugation measurement system with automatic rail centre follower device,
- video analysis of the rail surface and the rail fastenings,
- measurement of the horizontal position and the level of the overhead line,
- adjustment and measurement of the pantograph pressure,
- measurement of the position of the masts,
- measurement of the track surroundings by four high-resolution digital colour video cameras and one high-resolution bland-and-white digital video camera-recording on four digital tape recorders,
- measurement of the vehicle body acceleration,
- detection of automatic train stop magnets, and
- ambient temperature measurement.

12.15 Small devices for track geometry measurement:

Apart from large self-propelled recording vehicles smaller systems exist which are moved along the track by hand. These devices can record the vertical profile, superelevation, versine and track gauge. The vertical profile is recorded via a symmetric versine measurement for the left-hand and right-hand rail (chord length:1 m) and additionally via an inclinometer recording the absolute level in a longitudinal direction. Superelevation is recorded by an additional inclinometer fitted in a transversal direction. The maximum measurement speed of these devices is usually 5 km/h (75 kg dead weight of the device). Such systems are advantageous when the track condition has to be recorded after accidents, to remedy individual defects and, in general, in all cases where the use of an electronic track recording car does not make sense for time or economical reasons.

12.16 Surveyed track – measurement and calculation of track correction Values:

The DB AG, the OBB, the SBB, the SNCF, the RENFE, the FS and railways of other countries survey fixed geodetic points along their tracks.

Stable reference points are marked on both sides of the track at the distance of the catenary masts (figure 12.16).

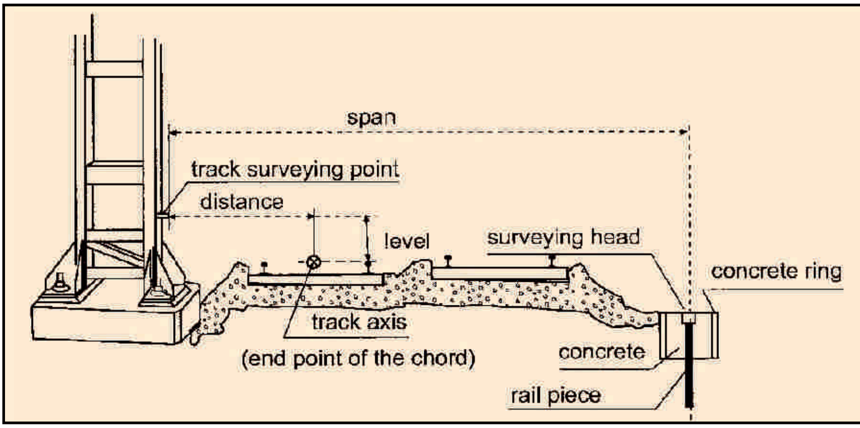

Fig. 12.16: Principal sketch of track survey points

12.16.1 Track surveying car EMSAT

The EMSAT measurement system has proven a success in practical use since 1990.

As the EMSAT uses mechanized measuring methods as against the common manual-optical method, a cost saving by more than factor 5 is achieved.

Fig.12.16.1: EMSAT (Network Rail) with on-track laser satellite

The EMSAT is used for:

- planning and determination of tamping and lining sections,
- surveying for subsequent tamping,
- surveying for the elimination of individual defects by an individual-defect-tamping machine,
- measurement during track reconstruction (checking the laid track in level and alignment) before and after the tamping / lining operations, and
- acceptance of newly built tracks in order to determine whether long-wave defects exist.

The EMSAT continuously detects particularly long-wave track defects in level and curvature (alignment). The resulting actual values are documented for technical and economic purposes in a record (analog chart) referring to target geometry and made available to the tamping machine for further processing.

Long-wave track defects are defects in track level and curvature (alignment) with larger wavelengths upto 250m.

The advantages of an EMSAT measurement compared to manual surveying are its high precision and measuring speed, the measurement and detection of long-wave defects on the basis of an extended chord, the detection and possible elimination of changes in position and level of the existing geodetic points, the high reliability of data without a media break (through data flow), safe working places for the crew where dangers deriving from railway operation are avoided.

Description of the track surveying car EMSAT:

- The EMSAT determines alignment and longitudinal level referred to an extended measuring base), a stationary laser chord,
- It determines superelevation and cross level by an inclinometer,
- It determines the curve length covered between two measurements by measuring wheel, i.e. distance, and
- Measures the track gauge with a measuring axle.

Working range and measuring accuracy:

Working range:

alignment versines:	max 1000 mm
longitudinal level versines:	max 400 mm
length of the laser chord:	max approx. 250 m
measurement output:	1.3-2.6 km/h, depending on the length of the laser chords

Measurement accuracy:

versine:	1 mm repeating accuracy
mutual cross level:	1 mm
track gauge:	1 mm
distance measurement	0.1 m/100 m

The EMSAT is available with an additional 8-channel measurement recorder and geometry measurement equipment (measuring chord with mechanical measuring axles). Due to this additional measuring and recording equipment track geometry can be documented analogously to the tamping machines.

Use of the EMSAT for track and switch renewal:

The EMSAT is also used for track renewal. Here, the described measurements are performed immediately before the passing of the tamping machine.

For tamping of newly laid track the measurement is performed immediately before the tamping machine passes.

12.16.2 Description of the Fixed-point Measurement Device:

The fixed-point Measurement Device is used to exactly determine the absolute track position, i.e. to determine the values of track lifting and displacement in the area of geodetic points (markings by bolts, of bottoms of curves, by pegs etc.).

This device is a combination of an electronic tachymeter for infrared distance measurement and angle measurement and a precision inclinometer for superelevation measurement. The frame is an aluminium light-gauge construction and can be easily and rapidly dismantled into three part. Therefore, the device can be transported in any common passenger car and operated by one person. The device is equipped with a micro-controller with report printer and data storage card for the evaluation of the measured values.

Fig. 12.16.2 Electronic fixed-point measurement device

Working range and measuring accuracy of the fixed-point measurement device:

Working range:

Distance measuring device: $\geq$ 1.3 m

Measurement output: 1.1-2.6 km/h depending on the distance of the geodetic points ad the purpose of the measurement (actual track position/span)

Measurement accuracy:

(for individual close-range measurements, according to the manufacturer):

level measurement: 1-3 mm (1.5 m – 5 m)

distance measurement: 1-3 mm (1.5 m-15 m)

The use of the EMSAT in switches

The EMSAT and the Fixed-point Device can be used for checking the outer geodetic points in switches and switch connections.

12.16.3 Measurement evaluation and decision on necessary measures:

The contractor makes the true-to-scale graphic record (measuring chart) of lifting and slewing value including cross level, which is made up by the computer system, available to the network operating organization which then determines the required measures to be taken. The operating organization of EMSAT offers technical advice. After an evaluation of the date the network operating organization chooses the start and end of tamping in such a way as to ensure a harmonic transition to the untreated sections in track level, as well as in curvature (alignment).

A zero lifting value can be accepted at high points, if the slew in this area is small and the deviation of cross level is < 5 mm. In such a case a ramp with a gradient of 1:2000 is built for cross level.

12.16.4 Transmission and storage of measurement documentation :

The contractor of the tamping works is given the target geometry values, the lifting and slewing values, as well as the nominal distance and the nominal level referring to the geodetic points on a data carrier (e.g. CD/DVD/Pen Drive).

Furthermore he is given a digital printout of the lifting and slewing values, so that he can use them, if necessary for manual control of the tamping machine (in case the computer system should fail).

12.16.5 The GPS satellite measurement technique for the measurement of surveyed tracks :

Nowadays, the Global Positioning System (GPS) offers new opportunities for measuring the current track position. Track construction usually requires accuracies which may be achieved only in relative mode (i.e. by reference like measurement).

The GPS allows relative position accuracies of approximately max. +6 mm to be achieved. The accuracy of the level measurement is lower by a factory of 1.5-2. GPS is too inaccurate to replace laser long chord measurement.

However, the GPS offers the economical solution of transferring high-precision local laser long chord date to absolute coordinates.

Fig.12.16.5: GPS aerial on the roof of the EMSAT

12.16.6 Application of the combined EMSAT-GPS system :

The actual track is measured by long laser chords ad at the same time by GPS, which enables the long laser chord (operating in a local system of coordinates) to be determined by absolute coordinates and the high-precision relative data of the long laser chord to be transformed to absolute coordinates.

12.16.7 The combination of the EMSAT with a Ballast Profile Measurement system :

The actual ballast profile on the spot is a significant parameter for the planning of the practicable lifting values on the basis of measured lift correction values. The contactless Ballast Profile Measurement System determines an excess or deficiency of ballast.

12.17 Automatic guiding computer WINALC for tamping machines :

The geometry guiding computer WINALC has to guide the permanent-way machines through the existing track geometry. Therefore, the device has to offer the possibility of entering the target geometry data by hand via keyboard or from a CD. The geometry-dependent correction values for the measurement and control systems of the machine have to be calculated. Unknown target geometry has to be measured, optimized and transferred to the track as a new target position. The displacement limits in constraints (bridges, level crossings) and reference points, as well as pre-set minimum lifting values, have to be taken into account.

The system has to offer the possibility of storing and printing the results of the measurement records and the optimization calculations. A desirable feature is the recording of the geometric position reached while the tamping machine is working. This offers the opportunity to train the personnel in the office, to prepare geometry data in the office and to transmit them on floppy discs to the geometry guiding computer of the tamper.

Functions of the WINALC :

12.17.1 Entry of target geometry data :

The target geometry data (radii, length of transition curves, shape of transition curve, ramps, changes in gradients, superelevation, etc.) are entered into a WINALC table, and this entry is immediately represented graphically. The target track geometry data can also be entered and modified in a graphical representation mode. The modification of a geometry element can be made by mouse-clicking the corresponding element; the parameter is then changed in the window that appears.

12.17.2 Electronic versine compensation and track geometry optimization :

In this working mode an existing track position is recorded during a measuring run of the working machine. It measures versine values for alignment and level, as well as superelevation (via inclinometer), represents them graphically and stores them.

This measurement is the basis for an optimization of track geometry which smoothes the course of versines for alignment and level. The correction values (displacement and lifting values) are calculated from this smoothed curve by comparing its values to the measured actual versine. Smoothing and calculation are carried out in an automatic process. The operator can set the following line classes:

0	(up to 80 km/h)
1	(80-120 km/h)
2	(120-160 km/h)
3	(160-300 km/h)

Standard deviations for a compensation length of 35 m for the track classes 0-3 are defined in the programme. Furthermore standard deviations for a compensation length of 70 m are defined for the track classes 2 and 3. during optimization, the programme continue the smoothing process, until the value remain below the preset standard deviations. Apart from the track class, the operator also has to enter the constraint conditions of the line section.

The entire calculation procedure is started at the touch of a button and performed automatically, no interaction of the operator is required.

It is possible to carry out track measurement while the machine is transiting to the work site, after optimization has been carried out the machine will start tamping in this case beginning from the end point of measurement. This is a way of saving the run back to the starting point of measurement. Wavelengths of upto 100m were recorded correctly.

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Chapter - 13
Current Scenario of High Speed Rail in India

13.1 High Speed Planning in India

The Ministry of Railways published a white-paper **'Vision 2020'** submitted to Parliament on December 18, 2009. The document envisages the implementation of regional high-speed rail projects to provide services at 250-350 km/h, and planning for corridors connecting commercial, tourist and pilgrimage hubs. It says "India is unique and alone among the major countries of the world in not having a single high-speed rail corridor capable of running trains at speeds of over 250 kmph. High Speed corridors have played a major role in revitalization of Railways in Japan and Europe. Of late, high speed-rail networks are also getting built in China, Taiwan, and USA. Indian Railways would follow a two-pronged approach in this respect. The first approach would be to raise the speed of segregated passenger corridors on trunk routes using conventional technology to 160 to 200 kmph. The second approach would be to identify a number of intercity routes, depending on viability, and build state-of-the-art high-speed corridors for speeds up to 350 kmph through on PPP mode in partnerships with the State Governments. Partnerships with the State Governments would be crucial as real-estate development would be a key element of viability of these high-cost projects. By 2020, at least four corridors of 2000 kms would be developed and planning for 8 other corridors would be in different stages of progress."

Seven corridors have already been identified for technical studies on setting up of high-speed rail corridors they are:

- Delhi-Chandigarh-Amritsar (450 km)
- Mumbai-Ahmedabad (527 km)
- Hyderabad-Dornakal-Vijayawada-Chennai (664 km)
- Howrah-Haldia (135 km)
- Chennai-Bangalore-Coimbatore-Kochi (850 km)
- Delhi-Agra-Lucknow-Varanasi-Patna (991 km)
- Ernakulam – Trivandrum (194 km)

These high-speed rail corridors will be built as elevated corridors in keeping with the pattern of habitation and the constraint of land. The routes are plotted on map of India in fig 13.1 for appreciation.

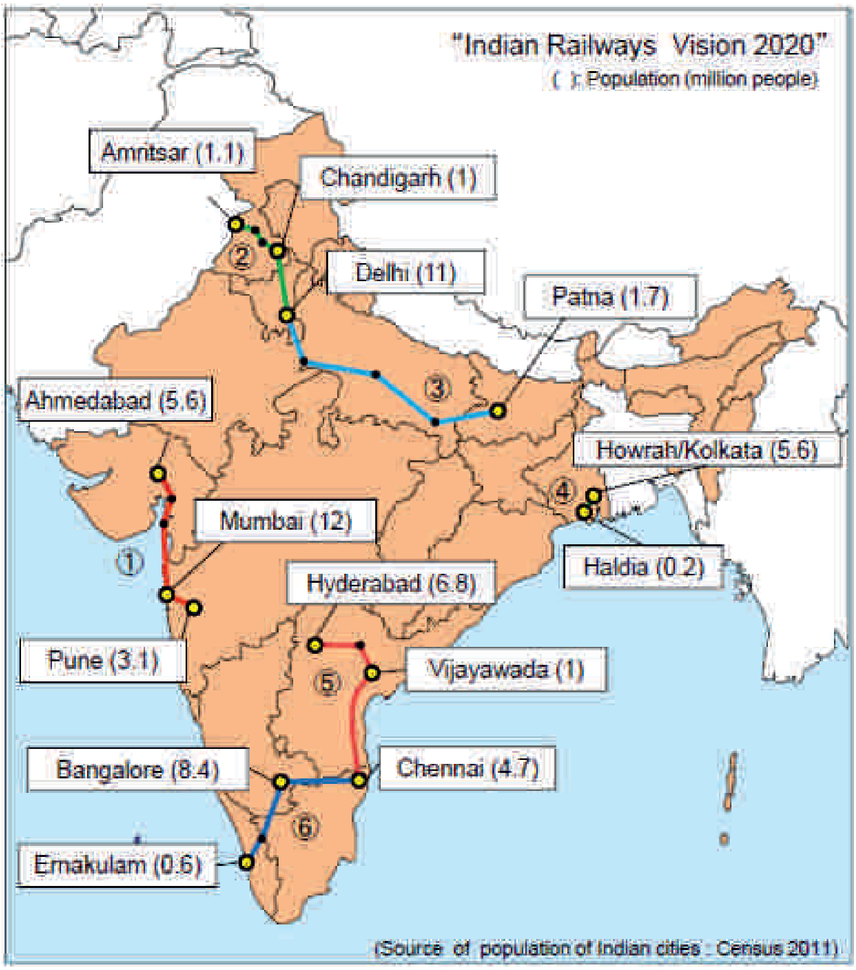

Fig 13.1 Proposed high speed Rail routes in India

Currently feasibility studies are being conducted on all these routes.

13.1 Budget Speech

Budget speech 2014

It was stated in parliament that "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:

Delhi-Agra
Delhi-Chandigarh
Delhi-Kanpur
Nagpur-Bilaspur
Mysore-Bengaluru-Chennai
Mumbai-Goa
Mumbai-Ahmedabad
Chennai- Hyderabad and
Nagpur-Secunderabad.

Budget Speech 2015

The honorable MR announced in his speech "we will continue to pursue with vigour our special projects like High Speed Rail between Mumbai-Ahmadabad. The feasibility study for this is in advanced stage and report is expected by the mid of this year. Quick and appropriate action will be taken once the report is available with us. Regarding the other high speed routes on the diamond quadrilateral, studies are being commissioned. "

"In the proposed investment plan for the period 2015-19 an allocation of Rs.65000 crore has been made for High Speed Rail & Elevated corridor."

13.2 Pre Feasibility Study of High Speed Rail Corridor between PUNE – MUMBAI – AHMEDABAD

This Pre Feasibility Study was done by a consortium of **RITES, SYSTRA and ITALFERR**. The report was submitted in Apr'2010. The scope of study included (a) Review of passenger market abroad. (b) Assessment and selection of High Speed Rail technology and construction standards. (c) Ridership forecast on the proposed route and optional route. (d) Optimized route alignment. (e) Basic drawings of various components. (f) Concept Design. (g) Costs and revenues estimations. (h) Environmental impact assessment. (i) Assessment of financial and economic viability. (j) Structures of implementation and financing the Project.

Speed: The speed considered for project is 350 kmph and commissioning period has been taken as 2021.

Traffic forecast: The outputs of the traffic forecast studies show a total number of 26.6 millions passengers per year for the whole Project at the 2021 horizon year, including 2.5 million passengers on the part of the existing network operated by the High Speed trains. Traffic and revenues are maximized for a fare of 7 Rs per Km for 75% of the traffic and 4.5 Rs per Km for the remaining 25%. The 2021 HSR traffic is estimated to double within less than 10 years and to possibly reach 104 million passengers in year 2041.

Track Gauge and alignment: The report envisages a BG ballastless track. Alignment specifications have taken into account a minimum horizontal curve radius of 6425 m which optimizes integration of the Project in the environment and minimizes construction costs .

Civil Works: The study estimated 550 km of earth work 72 kms of bridges and viaducts and 22 kms of tunnel (total three in nos with 18.3 km long Lonavala tunnel being the longest followed by vashi and Mumbai approach tunnels).

Signaling: ERTMS level 2 is recommended as the International reference signalling system for HSR worldwide.

Overhead Catenary System and Power Supply: Either the French or the German/Chinese systems in the 2x25 KV version has been recommended.

Travel Time: Travel times have been calculated for every possible case (without and with stops) . The best travel times at 350 Km/h operation speed (without stops) come at 0 H 40 min between Pune and Mumbai and 1 H 52 min between Mumbai and Ahmedabad. 80 trains circulations per day and per direction are expected on SU1 branch at horizon year 2041.

Rolling Stock: The full level of interoperability with existing network has been recommended. Therefore a wide gauge rolling stock (1676mm) with a 3300mm wide car body has been recommended. The R&D cost for such rolling stock has been envisaged to be covered with first order of 30 – 40 train sets.

Alignment: Three alternatives have been studied.

Stations: AT Mumbai station has been proposed at Wadala or Kurla. At Pune proposed station will be near to existing Railways station. At Ahmedabad either near existing Railway Station or near Bopal. Intermediate stations have been proposed at Surat, Mumbai airport and Vadodara.

Cost: The average construction cost per kilometer of double track line comes between Cr. Rs. 76 and 84 depending on alignment option (base year 2009). The total construction cost (base case) has been estimated to Cr. Rs 49,000 (economical conditions 2009) Investment in Rolling stock (base case) comes at Rs. 6,800 Cr (economical conditions 2009).

Total Investment Cost: The landed project cost for the entire project and its two major sections are given in table below. The total project cost includes rolling stock requirement for the first year of operations only.

Project Phasing: Based on the technical study, the construction period

Particulars	Pune-Mumbai-Ahmedabad	Pune-Mumbai	Mumbai-Ahmedabad
Basic construction cost (Civil, Bridge, Track, S&T, OHE, Energy and other EPC cost)	59,708 Cr	26,239 Cr	46,256 Cr
Initial Rolling Stock	8,253 Cr	4, 343 Cr	3,909 Cr
Total Sub Cost	67,961 Cr	30,582 Cr	50,165 Cr
Cost Escalation	11,133 Cr	5,010 Cr	8,217 Cr
Interest during construction	5,865 Cr	2,641 Cr	4,336 Cr
Preliminary Expenses	597 Cr	262 Cr	462 Cr
Total Investment Costs	85,556 Cr	38, 495 Cr	63,180 Cr

considered is 7 years. The project phasing is given in table:

	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7
Basic Construction Cost	2%	3%	10%	20%	33%	27%	5%

Operation and Maintenance Costs: Following is the maintenance cost at 2009 prices.

Item Description	Total Cost (2009 prices – Rs Cr/Year)		
	Pune – Mum – Ahm	Pune – Mum	Mum - Ahm
Rolling Stock Maintenance	Rs 148.6 Cr	RS 55.5 Cr	Rs 90.7 Cr
General Operation and Maintenance	Rs 210.7 Cr	Rs 85.2 Cr	Rs 135.7 Cr
Infrastructure Maintenance	Rs 254.5 Cr	Rs 81.6 Cr	Rs 186.3 Cr
Total	RS 613.8 Cr	Rs 222.3 Cr	Rs 412.7 Cr

13.1 High Speed Rail Corporation of India (HSRC)

High Speed Rail Corporation of India Limited (HSRC) has been formed on the directions of Ministry of Railways, Government of India, for development and implementation of high speed rail projects.

This Special Purpose Vehicle has been incorporated in 2012 as a subsidiary of Rail Vikas Nigam Limited which is a Mini-Ratna public sector enterprise of Government of India. The objectives of HSRC is as following

- To undertake feasibility studies and techno-economic investigations and prepare Detailed Project Reports and Bankability Reports of selected corridors for introduction of High Speed trains in India.
- To plan, design and freeze technical parameters for High Speed Rail Systems including fixed assets, rolling stock and operations.
- To develop financing models, explore PPP options, coordinate with stake holders and funding agencies and obtain various Government approvals.
- Project development, project execution, construction, upgradation, manufacture, operation and maintenance of High Speed Rail Systems on existing as well as new rail corridors.
- To enter into and carry on all businesses related to High Speed Rail Systems and other rail based traffic as may be approved by Government of India or RVNL or any other Authority created by the Government for such activities.

HSRC has awarded contract for the consultancy of feasibility study for diamond quadrilateral network of high speed rail corridors

MUMBAI-AHMEDABAD :

Rail Vikas Nigam limited/High Speed Rail Corporation of India limited have been assigned the implementation of High speed rail projects. Mumbai-Ahmedabad is the first corridor which has been undertaken for implementation.

FEASIBILITY STUDY OF MUMBAI - AHMEDABAD HIGH SPEED CORRIDOR:

An MOU has been signed between JICA and Ministry of Railways on 07.10.2013 for conducting a joint feasibility study for Mumbai - Ahmedabad high speed rail system. Railway Board has decided to associate High Speed Rail Corporation of India Ltd (HSRC) in this study. JICA has submitted its

Final Report of Feasibility Study of this corridor to Ministry of Railways in July 2015.

DELHI-CHANDIGARH-AMRITSAR :

Pre-Feasibility study of this High Speed Rail Corridor is in progress. Interim Report-II has been submitted by the consultant M/s Systra of France in Sep 2015.

Delhi-Chennai:

Delhi-Nagpur section of this corridor is being taken up as Phase I under Government to Government cooperation. Planning study report for this High Speed Rail Corridor by China Railway SIYUAN Survey and Design Group Co. Ltd has been completed. Project Feasibility Study Report is yet to be taken up by Siyuan shortly. High Speed Rail Corporation of India Ltd is the counterpart agency.

CHENNAI-BANGALURU-MYSORE :

Feasibility Study for Speed raising on this section in cooperation with China Railway Eryuan Engineering Group is in progress. China Railway Eryuan Engineering Group has submitted Interim Report in June 2015. High Speed Rail Corporation of India Ltd is the counterpart agency

DIAMOND QUADRILATERAL

Delhi-Mumbai (Package-I)

Feasibility Study Contract awarded to a Consortium of M/s The Third Railway Survey and Design Institute Group Corporation (CHINA) and Lahmeyer International (India) Pvt. Ltd, India

Mumbai-Chennai (Package-II)

Feasibility Study Contract awarded to a Consortium of M/s SYSTRA (FRANCE) - RITES- Ernest &Young LLP.

Delhi-Kolkata (Package-III)

Feasibility Study Contract awarded to a Consortium of M/s INECO (SPAIN) - M/s TYPSA- M/s Intercontinental Consultants and Technocrats Private Limited.

13.4 Kerala High Speed Rail Corporation Ltd (KHSRC)

The state government has formed a new public limited company - Kerala High Speed Rail Corporation Ltd - to implement a high speed rail network. The 630-km network will connect Thiruvananthapuram with Mangalore. The Kerala State Industrial Development Corporation (KSIDC) has been appointed the nodal agency to develop the project, and Delhi Metro Rail Corporation (DMRC) has been assigned with a pre-feasibility study.

The new company was formed on the basis of a pre-feasibility report submitted by DMRC. Further technical studies and economic evaluation are currently being planned. The proposed high speed corridor will have two parallel tracks in the standard gauge system as in the Delhi Metro Rail. The high speed corridor will have an alignment independent of the existing alignment of the Indian Railways.

The project will be implemented as a joint venture between the state government and a private partner which will be selected at a later stage. The company will undertake detailed feasibility report for the project and identify suitable rail technology to implement the high speed corridor. Steps have also been initiated for the release of a notification for the acquisition of land needed to implement the project. The width of the land required to be acquired for the rail corridor is 13 metres. The high speed corridor will use a greenfield route to keep the rehabilitation task to the minimum

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