ज्ञान ज्योति से मार्गदर्शन
To Beam As A Beacon of Knowledge

RAIL STEEL AND STRESSES








November 2019

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING,
PUNE - 411001.

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PREFACE TO THE FOURTH EDITION

The book on 'Rail Steel' was originally published in 1987. Its second and third edition was brought out in 1997 and 2007. The book has been found to be quite useful by the field engineers for developing an understanding about basic rail metallurgy and manufacturing process of the rail.

A need for familiarising the field engineers with rail stresses was felt for long. This has assumed greater importance in view of Indian Railways entering into an era of High Speed and Heavy Haul operations. Such operations will put more severe demand on the performance of the rail. Proper understanding of rail stresses is need of the hour for railway engineers. A new chapter on rail stresses has, therefore, been added in the current revision and the title of the book is revised to '**Rail Steel and Stresses'**. The book will go a long way in helping the engineers to understand the concept of rail metallurgy and rail stresses.

The book has been revised, enlarged in scope and updated by **Shri G. S. Yadav,** Professor, Bridges incorporating latest information on the subject.

I hope the book in its enlarged form will be appreciated by the engineers.

Pune
November 2019

Ajay Goyal
Director
IRICEN,
Pune

PREFACE TO THIRD EDITION

The book on Rail Steel was first published in 1987. Its second edition was brought out in 1997. The book has been found very useful by the field engineers for developing an insight in rail steel.

Rail is the most important constituent of the track structure and plays very vital role in the reliability of railway system as a whole. Quality of rail steel with reference to itschemical composition, especially the hydrogen content has been a matter of serious concern to the manufacturers as well as Indian Railways. In service failure of rail has been a big challenge to the track engineers. Various methods of rail testing and improved chemical composition are being adopted. A lot of new developments have taken place in rail manufacturing industry. Bhilai Steel plant has also done many improvements in rail manufacturing and in post manufacturing inspection process. Proper handling of rails from the stage of its manufacturing up to insertion in track is equally important especially in case of the high UTS rails which are more brittle.

The revised and enlarged edition of the book has been complied by Shri Abhai Kumar Rai, Ex. Professor/Works and Shri Atul Agarwal, Professor/Track-III. The book is now comprehensive starting from pig iron manufacturing and ending with testing of rails incorporating new developments. RDSO has recently issued 5th amendment to IRS-T-12-96 which has also been incorporated in the book.

I hope this book in the present format will be found more useful by the field engineers.

Shiv Kumar
Director
IRICEN
Pune

ACKNOWLEDGEMENT

The subject of "Rail Steel" is being taught during various courses at IRICEN. Even though a lot of information is available on this subject, yet it was not available at one place especially regarding rail manufacturing in India.

This book is an attempt to compile all the relevant information regarding rail steel starting from manufacturing of the pig iron to rail rolling including its testing and handling.

It would not be out of place to acknowledge the support and assistance rendered by IRICEN faculty and staff in the above efforts. We are particularly thankful to Shri Rajesh Kumar, Professor / Track-1, who has provided logistic assistance for printing of this book. The word processing of the manuscript and its editing has been done by Mrs. Vidya S. Jamma. We also acknowledge the help rendered by Shri Sunil Pophale, in preparing various drawings.

Above all, the authors are grateful to Sri Shiv Kumar, Director, IRICEN for his encouragement and advice for improving the book.

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Professor/Track-3

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Ex Professor/Works
IRICEN/Pune

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CHAPTER - 1

INTRODUCTION

1.1 Role of rail in permanent way :

The invention of steam locomotives which could run on rails led to the development of a transport system which has changed the life of people in most of the countries of the world. It has facilitated transportation over long distances and immensely contributed to industrial development.

Rail is the defining feature and most important component of permanent way. The primary function of the rail is to provide a smooth and continuous level surface for movement and to provide guidance in lateral direction for movement of the wheels. In process, it transfers the load from the wheels to the track structure below and is subjected to stresses. Function of the rail is shown in Fig. 1.1.

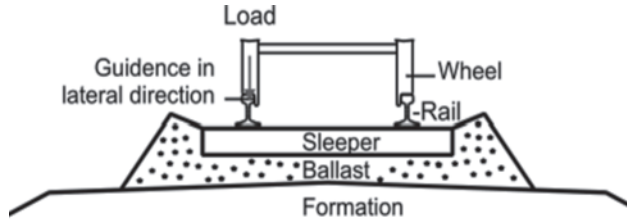


Fig. 1.1. Function of the Rail

The safety and reliability of railway system, to a great extent, depends on proper functioning of rail. Wear and tear of permanent way necessitates its periodical renewal in which, rail renewal is a major component.

The design of rail is a complex process. The features like cross section, chemistry, process of manufacturing, handling & utilization each have

bearing on its life and these aspects are to be decided depending upon the expected traffic, speed, axle load etc.

1.2 Historical background :

The history of rail transport is about 500 years old and includes systems with human beings or horses pulling wagons running on rails made of wood or stone. The wagonways were developed in Germany in the 1550s which made use of wooden rails and the wagons drawn by horse. In 1600s these were popular in Britain also. The Wollaton Wagonway drawn by horses is the earliest, proven, surface railway. It is recorded as running from Strelley to Wollaton near Nottingham and was completed in 1604. Subsequently in the late 1760s the fixing of cast iron plates through the wooden rails started. The wagons were having flanged wheels. Another system having flanged ('L') shaped metal plate fitted to the wooden rails and the wheels without flange was used. However, over a course of time it was realized that flanged wheels with flat rails worked better than the 'L' shaped rails with flat wheels. The 'flanged wheel' on 'flat rail' arrangement continues even today.

The strip iron rails having thin strip of iron fixed on wooden rails were very fragile and not suitable to carry heavy loads. However, their use continued for quite some time because of the fact that initial cost of construction was low and so the railway lines could be completed faster at a cheaper rate. The main problem associated with these rails was separation of iron strip from the wooden rails, which increased maintenance requirement making it expensive over the life cycle.

In 1767, first all iron rail was manufactured with cast iron. These rails were manufactured by casting process. These rails were three feet long.

Subsequently rolling of rails started. The steel rails were first made in 1857 and laid at Derby station in England. Steel being a better and stronger material than cast iron, in due course, it replaced the cast iron as the material for use in making rails.

1.3 Evolution of rail steel :

The first use of iron in the making of rail was in the form of a cast iron plate fitted over wooden rail. As its maintenance was becoming expensive, the next stage in development was use of cast iron rail, which was replaced by steel. As the know-how in manufacturing of steel developed, the chemical composition of rail steel also changed over the years and the percentage of various constituents particularly carbon, manganese and silicon changed. Adding of expensive alloys such as chromium etc. were also tried to improve steel quality. Carbon content in the steel has a major bearing on its properties and hence various percentage of carbon contents are tried to produce different types of rail steel. This will be discussed in detail subsequently.

1.4 Evolution of rail section :

The rail section also got evolved over time from a simple cast iron plate to today's flat footed rail. The basic principles which govern the design of section are that it should have required strength in bending, the head should provide a smooth running surface and should interact with the wheels so as to have minimum wear. It should have a base, which is wide enough to provide stability.

One of the early iron rail was double headed which has a dumb-bell type shape. The reason for using this shape was that during service one side head gets worn out and it can be turned for other side use.

However, in practice, this could not be done because of the fact that once the one side gets worn, it was not possible to re-use it. The next stage of development of rail section was bull headed rails which has two heads but the one head was larger than the other. This type of rail was difficult to fix to the sleepers. This has resulted in the development of flat footed rails which is easy to fix to the sleepers because of the shape of the foot. The use of flat-footed rails still continues. The finer point of head profile was further refined so as to match the wheel profile. Weight of the rail section also got increased over years in line with increasing axle load and speed of the trains. Currently IRS 52Kg and 60E1 rail sections are being procured by Indian Railways.

■ ■ ■

CHAPTER - 2

STEEL MAKING

2.1 Introduction :

Iron, like most other metals is not found in elemental stage. It is found in combination with oxygen or sulphur, in the form of ore. Pure iron is relatively soft material not suitable for structural purposes. Therefore, for most structural needs steel is used which is an alloy of iron. The principle ores from which iron and steel are manufactured are magnetite ($Fe_3 0_4$) and hematite ($Fe_2 0_3$). Iron is extracted from these ores by removing the oxygen.

There is archeological evidence to show that iron ore has been reduced to usable iron as early as 400 B.C. Prior to 14th century, this reduction was accomplished by heating iron ore and charcoal in a shallow hearth, which produced a spongy mass of iron, which was shaped directly by forging.

A brisk charcoal fire was sufficient for the ancient man to produce lumps of hot metal from iron ore. This can be accomplished at fairly low temperature (say 300^0C). The metal can not be produced in a liquid condition but it can be dragged out of the fire in the form of spongy mass which in hot condition can be welded to another piece of spongy mass and when enough iron mass is welded like this, then it is hammered in hot condition to convert into useful tools. This process results in production of wrought iron (worked iron).

In India, good quality steel was being produced as early as 200 A.D. by crucible technique wherein high purety wrought iron, charcoal and glass were mixed in crucible and heated until the iron melted and absorbed

the carbon. The solid pillar of rust resistant iron made in 4th century A.D. which has stood for many centuries next to the Kutub Minar in Delhi is a testimony to this.

Subsequently, it was understood that iron could be produced soft or hard, ductile or brittle, depending upon the carbon content and cooling rate. Melting temperature of iron depends on its carbon content. Pure iron melts at a temperature of about 1535^0C. When it has carbon content of 1%, the melting can begin at 1150^0C. However, the melting completes at a temperature of 1450^0C. Similarly, with 3% carbon, the melting is completed at 1320^0C. This shows that the melting temperature varies with the carbon content. The lowest melting temperature is corresponding to a carbon content of 4.25% when it melts at 1130^0C. If carbon content is more or less than 4.25% the melting temperature will be more than 1130^0C. Iron containing 3 to 4 % of carbon, which can be easily melted, and cast into mould, is known as cast iron. Because of higher carbon content it is very brittle and so could not be worked either hot or cold and any attempt to work it results in cracking. This means, the cast iron can not be wrought and wrought iron can not be casted.

2.2 Pig Iron :

Around the year 1350, a method was developed for producing molten high carbon iron in a furnace and for casting the molten iron into shaped moulds. This was the basis for the present day blast furnace process for manufacturer of pig iron. The original process utilized charcoal, lime stone and ore. The charcoal was later on replaced by coke around the year 1600 and hot blast was introduced about 200 years later. The capacities of the furnace had been increased to 100 tons a day by the late 1800's and in the present day, it has further increased to over 1400 tons a day.

Pig iron, besides being used directly in the form of castings, is the intermediate form of iron through which all commercial ferrous products must pass. The name pig iron was derived from the manner of casting molten metal from the furnace in sand. The molten metal runs from a main runner into smaller ones on both the sides resembling a sow with a litter of suckling pigs.

The pig iron is manufactured from iron ore in blast furnace. The chemical reaction which takes place is as follows:

Iron ore + Sinter + Coke + Limestone → Pig Iron + Carbon Mono-oxide

$2Fe_2O_3 + 6C \rightarrow 4Fe + 6CO \uparrow$

2.2.1 Blast furnace

The process of smelting : Extracting metal from its ore by process involving heating and melting iron ore in a blast furnace consists of charging a mixture of ore, fuel and flux in proper proportion through a specially constructed opening in the top of a tall cylindrically shaped furnace. This furnace has firebricks while heated air is continuously blown near the bottom through openings called tuyeres. A typical blast furnace is shown in Fig. 2.1. Blast refers to the combustion air being forced or supplied above atmospheric pressure.

Blast furnace is a refractory lined steel shell which is about 90 to 100 ft.high. The cylindrical bottom of the furnace is called the Hearth having a dia. of 24' to 28'. This is where the molten iron and slag are collected. The inverted truncated core above the hearth is called the bosh where the melting of iron and slag occurs. Above the bosh is the tall- truncated cone, where the burden is heated and where the reactions start. On top of the furnace, the double bell and hopper system is located for charging the raw materials without allowing

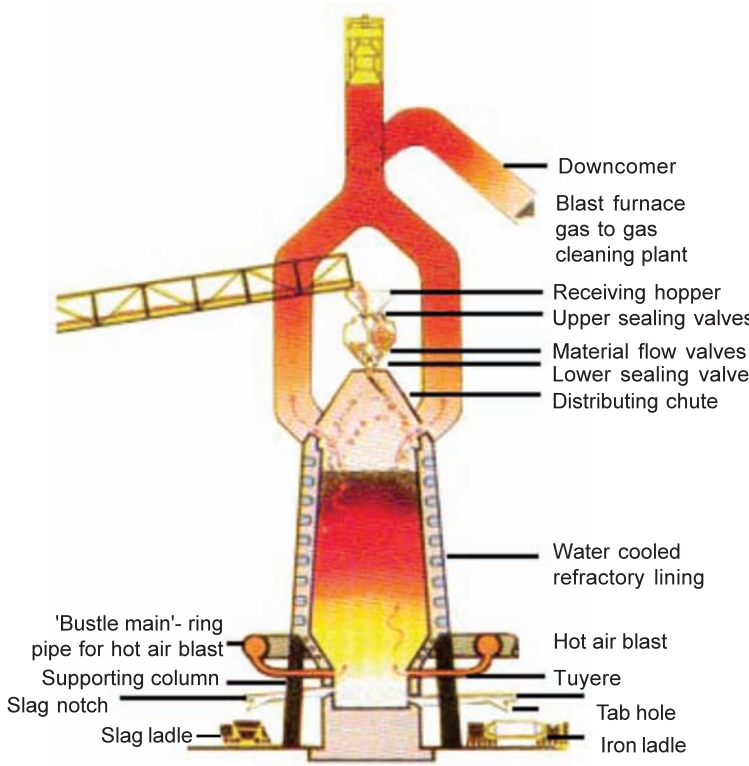


Fig. 2.1 : Blast Furnace

the gases to escape. Inside this furnace is a 90ft. column of material consisting of coke, ore and limestone in which temperatures vary from 1650^{0}C at the bottom to about 149^{0}C at the top. Average capacity of a modern blast furnace is about 1200 tons per day.

2.2.2 Modern blast furnace

A modern blast furnace for smelting iron consists of (i)blast furnace (ii) hoisting appliances for hoisting ore, flux and coke to the top of the furnace (iii) the blowers for supplying hot air blast (iv) stoves for heating the blast (v) the pumping plant for supplying the large quantities of water needed for cooling the furnace

walls and steam raising (vi) gas cleaning plant (viii) appliances for disposal of slag and pig iron and (ix) pig casting machine. The components of a modern blast furnace are shown in Fig. 2.2.

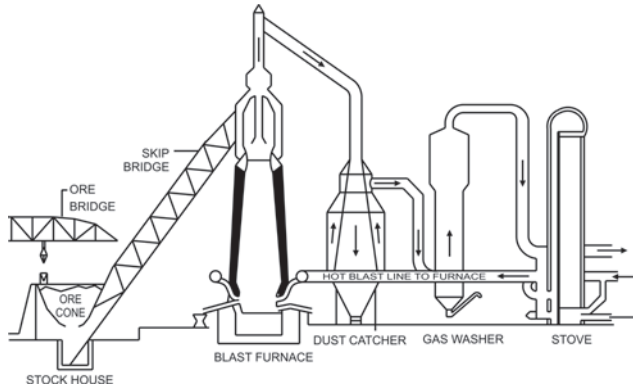


Fig. 2.2. Modern Blast Furnace

2.2.3 The reduction process

The raw materials except air are charged through the top of the furnace. They proceed by force of gravity down against rising air and gases. The reducing reactions start near the top of the furnace and increase in intensity as the charge settles in the stack. The charge remains a mixture of solids and gases until it descends to the upper region of the Bosh where the iron starts to become a pasty mass. Simultaneously, the calcium oxide in the limestone forms fusible slag with the impurities in the iron ore and the ash of the coke. The pasty mass of iron absorbs more carbon and both the slag and metal become molten and trickle down to the hearth over the remaining un-burnt incandescent coke. In the hearth, since the slag has a lower specific gravity than iron, it floats on top of the molten metal from where it is drained at regular intervals. The molten high carbon iron is tapped

regularly and is then cast in the pigs or used in the molten condition in the manufacture of steel.

2.2.4 Reaction in blast furnace

The oxygen in the pre-heated air, that is blown through the tuyeres reacts quickly with the carbon in the incandescent coke forming carbon dioxide which in the presence of excess carbon at high temperature is reduced to carbon monoxide according to the following reactions:-

$O_2 + C = CO_2$
$CO_2 + C = 2\,CO$ or
$O_2 + 2C = 2\,CO$

The first and third of these reactions are exothermic and provide most of the heat for initiating and accelerating the reactions of the furnace. They also produce the CO that is responsible for approximately 80% of the reduction in the furnace. The reduction of the ore proceeds according to the following reactions:

$3Fe_2O_3 + CO = 2\,Fe_3O_4 + CO_2$
$Fe_3O_4 + CO = 3FeO + CO_2$
$FeO + CO = Fe + CO_2$

The reduction of iron ore, therefore, occurs progressively i.e., Fe_2O_3 is first reduced to Fe_3O_4, then to FeO and finally to iron. The first reaction is predominant at 200^0C and the second begins approximately at 650^0C. The latter is not completed till the oxide is completely reduced to iron in the bosh zone.

Under the reducing conditions in the furnace, all easily reducible oxides get reduced along with the iron and produce an impure pig iron having picked up approximately 4 to 5% carbon from the coke, 0.5 to 2% silicon from the slag, 0.4 to 2% manganese from the

ore, 0.04 to 2.5% phosphorus from the ore and 0.020 to 0.2% sulphur mostly from the coke.

2.2.5 Recent development in the blast furnace technology

Blast furnace technology and operations have progressed extensively during the recent years. Improvements are mainly in relation to the furnace design and preparations of the burden. A direct result of technological advances in furnace design is the marked increase in size. The present day furnaces are about 29' hearth in dia. and produce upwards of 1400 tons of iron per day. Along with increase in size, the furnace productivity is continuously being improved by other means such as the replacement of the reciprocating blowers with turbo blowers, improving the design of the top applications and the use of high top pressures in the blast furnace. Some of these developments have been incorporated in the blast furnaces in the new steel plants in India. In the matter of burden preparation, screening of ores and washing of the coal to reduce sulphur and ash content are the most important.

2.3 Steel making :

The starting point for the manufacture of steel is pig iron. As explained earlier, the pig iron is produced by reducing iron ore (the most common ore being hematite Fe_2O_3) with the help of coke into blast furnace. Pig iron contains, carbon, silicon, phosphorous, etc. far in excess of percentage desired in steel, as will be evident from the comparison given in table 2.1.

Table 2.1

Element	Typical percentage in pig iron	Percentage usually present in steel
Carbon	3.5 to 4%	Upto 1.2%
Silicon	Upto 2%	Upto 0.3%
Manganese	Upto 1%	0.3% & above
Phosphorous	Upto 2%	0.05% max.
Sulphur	Upto 0.08%	0.05% max

By suitably altering the operating conditions in the blast furnace, silicon, manganese and phosphorous in pig iron are kept within predetermined limits to suit the subsequent steel making process.

To convert pig iron into steel, the various methods being used are as follows:

i) Bessemer Process
ii) Open hearth process
iii) Basic oxygen method
iv) Electric Arc furnace

Regardless of the process, the essential principle in the conversion of pig iron into steel is oxidation – oxidizing agent being Oxygen in air for the Bessemer process, pure oxygen in LD (Linz - Donawitz), and iron ore (which contains oxygen in chemical combination with iron) in open hearth and electric arc process. By oxidation, Carbon gets converted into gaseous carbon monoxide and escapes whereas the other elements get converted into their respective oxides in which form they combine with the fluxing materials used in the charge, such as lime, to form slag that floats on the molten steel. IRS-T-12-2009 mandates the use of basic oxygen method or electric arc furnace method. These methods are described in subsequent paras.

2.3.1 Basic oxygen method

The basic oxygen method popularly known as BOS i.e. basic oxygen steel making, is an improvement over the Bessemer process. In this method oxygen is blown through molten pig iron and the carbon content is lowered. So this process of steel making is used to convert carbon rich molten iron into steel. The basic oxygen method is used by LD converter, which has got its name from Austrian place names Linz and Donawitz, where this method was first used. This process has assumed a great importance as a steel making process because it possesses some of the economic advantages of Basic Bessemer process combined with the qualities of open hearth steels. Generally, the process is suitable for pig irons having the same composition as those used in basic open hearth practice.

In this process refining is carried out in a Basic lined converter by blowing 98% purity oxygen, vertically downward by a water cooled nozzle in the surface of the bath of hot metal. The oxygen jet impinging on the surface of the liquid bath instantaneously starts reactions leading to the formation of FeO, part of which diffuses rapidly through the bath. Carbon monoxide is immediately evolved which gives rise to a vigorous boiling action and accelerates the refining reactions. Slag forming fluxes such as burnt lime are added during the blow. The blow usually lasts 18 to 20 minutes.

Unlike the basic Bessemer process, this process employs a refining agent which is nitrogen free and, therefore, the steel produced have low nitrogen content, i.e., of the same order as in open hearth process. The steel exhibits good cold forming properties and good weldability. In Bhilai Steel Plant, basic oxygen method is used for making steel for rails.

The steps involved in this process are as follows:

I. Molten iron from a blast furnace is poured into a large container called a ladle.

II. The metal in ladle is sent directly for basic oxygen steelmaking or to a pretreatment stage. Pretreatment of the blast furnace metal is used to reduce the refining load of sulphur, silicon, and phosphorus. In desulphurising pretreatment, a lance is lowered into the molten iron in the ladle and several hundred kilograms of powdered magnesium are added. Sulphur impurities are reduced to magnesium sulphide in a violent exothermic reaction. The sulphide is then raked off. Similar pretreatment is possible for desiliconisation and dephosphorisation using mill scale (iron oxide) and lime as reagents. The decision to pretreat depends on the quality of the blast furnace metal and the required final quality of the BOS steel.

III. The BOS vessel is tilted and one-fifth filled with steel scrap. Molten iron from the ladle is added until the vessel is full. Filling the furnace with the ingredients is called charging.

IV. The vessel is then placed upright and a lance is lowered down into it. The lance blows 98% or more pure oxygen onto the steel and iron, causing the temperature to rise to about 1700^{0}C. This melts the scrap, lowers the carbon content of the molten iron and helps remove unwanted chemical elements. It is the use of oxygen instead of air that makes for the improvement on the Bessemer process, for the nitrogen (and other gases) contained in air does not react with the charge as oxygen does.

V. Fluxes (burnt lime or dolomite) are fed into the vessel to form slag, which absorbs impurities. Near the end of the blowing cycle, which takes about 20 minutes, temperature reading and samples are taken. The

samples are tested and the composition of steel is checked.

VI. The BOS vessel is tilted again and the steel is poured into a giant ladle. This process is called tapping the steel. For making steel having special properties, required alloys are added in the ladle furnace. Sometimes argon or nitrogen gas is bubbled into the ladle to make sure the alloy mix correctly. The steel now contains 0.1-1% carbon. The more carbon in the steel, the harder it is, but it is also more brittle and less flexible

VII. After the steel is removed from the BOS vessel, the slag, filled with impurities, is poured off and cooled. The basic oxygen method is explained in Fig. 2.3.

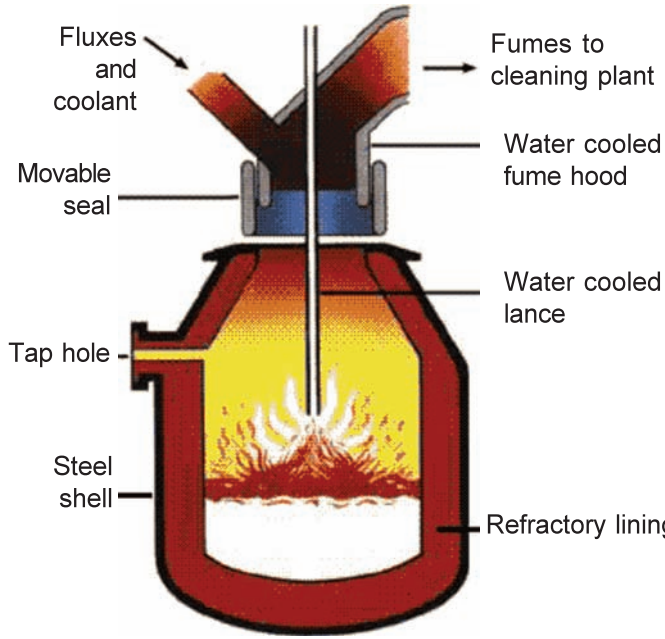


Fig. 2.3 Basic Oxygen Method

2.3.2 Electric Arc Process

The shell of a modern electric furnace is usually cylindrical and is constructed of steel plates. The shell has a circular flat bottom which is laid first with clay, magnesite or silica brick as required. The roof is a simple dome with three openings near thecenter for the electrodes. Two doors are usually placed in the shell of the furnace one the charging door diametrically opposite to the tap-hole and other the working door 900 away.

2.3.4.1 Operation

The charge generally consists of about 40% heavy scrap, 40% medium scrap and 20% light scrap. Ferro alloys, alloying oxides and virgin alloys, which are not easily oxidized, can be and usually are charged in the furnace prior to melting down. The charge usually contains excess carbon in the bath to permit proper shaping of the heat. The ore is added to lower the carbon. This ore may be added with the initial charge or when the charge is completely melted. When charging is completed, electrodes are lowered to about 1" above the scrap and with proper current setting when the arcs are struck under automatic control, the melting of the charge starts. The first period in the heat is the oxidation period during which the reactions taking place in the basic electric furnace are similar to those in the basic open hearth furnace. During this period, the phosphorus, silicon, manganese, carbon, chromium and some sulphur are oxidized and at the end of the oxidizing period, the initial oxidizing slag is removed from the furnace. This is now replaced with reducing slag by adding burnt lime fluorspar, coke and silica sand. Small amounts of crushed ferro silicon are also added. During the reducing period, a strongly reducing slag containing calcium carbide is formed and is maintained through out the refining period. Carbide cannot exist in the presence of oxides reducible by carbon and,

therefore, carbide slag is free of such oxides. Carbide slags return reducible oxides such as those of Mn, Cr, V, W, Fe, from the slag to the metal. Consequently, such oxides may be added for direct reduction as soon as carbide slag is formed. The slag also serves to reduce the oxides in the bath and facilitates the removal of sulphur as calcium sulphide. After the reducing slag has been formed, sample of steel is taken for analysis and the necessary additions for adjustment of carbon and alloys are made. When all the additions are in solution, ferro silicon is added for silicon content and deoxidation and the steel is ready for tapping.

The electric furnace provides several advantages among which the following are the most important:-

i. The electric arc is a source of pure heat, which minimizes contamination by elements normally present in the liquid or gaseous fuels.

ii. Permits temperature control within close limits.

iii. The slag can be better-controlled permitting high efficiency of recovery of alloys in scrap and additions, through slag manipulation and, therefore, can make practically all the known grades of steel and is used exclusively for the high alloy steels.

iv. The oxidizing and reducing conditions can be more effectively attained and removal of sulphur to a very low level is possible.

The disadvantage of the electric arc furnace relates to the higher cost of auxiliary equipment, power, electrodes and refractories etc. when compared to the open hearth process.

2.4 Provision of IRS T-12–2009 :

- The steel used for the manufacture of rails shall be made by basic oxygen or electric arc furnace process and continuously cast. Any other method of casting shall have prior approval of the Purchaser. For molten steel secondary ladle refining is mandatory. The manufacturer in his offer shall furnish details of the steel making process including refining, vacuum degassing.

- The cross sectional area of the bloom shall not be less than ten times that of the rail section to be produced.

- The manufacturer shall apply the best accepted code of practice throughout manufacturing process to ensure that the rails meet the stipulations of this specification. The manufacturer shall, on request, inform the purchaser of the measures adopted for ensuring the above.

- For head hardening, rails should be suitably heat treated to meet the requirements of this specification. The method of heat treatment adopted by the manufacturer should be made available to the purchaser and prior approval of the purchaser shall be taken before execution of the order.

■ ■ ■

CHAPTER - 3

RAIL MANUFACTURING

3.1 Introductionm :

Whatever process of steel making is used, the steel produced contains some residual iron oxide dissolved in the steel. In addition, molten steel can dissolve a large amount of hydrogen, the source of hydrogen being moisture in the materials added to or moisture coming in contact with molten steel. Rails fail in service by what is now well known as transverse fissure. Intensive investigation showed this type of failure to occur due to hydrogen present in steel. In the molten steel, excess hydrogen easily escapes, but in the solid state, escape of excess hydrogen can take place by the process of diffusion, which is temperature and time dependent.

The excess hydrogen produces cracks which are called flakes or shatter cracks. The harmful effect of hydrogen is well recognized and therefore attempts are made to controll all the possibilities of excess hydrogen taking place in the production of steel. It is a standard practice to take necessary precautions such as drying all materials used for manufacturing of steel. Despite such steps, transverse fissures traceable to hydrogen in steel occur, thus emphasizing the need for steps to further reduce the hydrogen content in steel.

For making the steel fit for rolling of rail, the steel so made is further processed and treated to bring various elements in the permissible and desirable limit. This is called **secondary refinement**. Earlier the reduction in hydrogen content was being achieved through controlled cooling. Subsequently, the use of vacuum degassing and argon flushing started which made the

process of slow cooling as avoidable. The latest of the degassers is RH (Rushstahe Heraeus) degasser and the same is being used at Bhilai steel plant for rail steel making.

The process of controlled cooling and various types of degassers are discussed below:

3.2 Controlled Cooling :

From solid steel, hydrogen can be removed only by diffusion, which is dependent both on time and temperature. In the controlled cooling method, excess hydrogen is sought to be removed by choosing a high enough temperature at which the hydrogen content normally present in steel does not cause cracking and cooling the rails from this temperature to room temperature very slowly thus allowing sufficient time for hydrogen to diffuse out. Controlled cooling came into general practice in 1937 and was especially developed to prevent formation of shatter cracks, also called internal thermal ruptures, flakes or internal thermal cracks. Rails from the hot saw are allowed to cool to about 500^0C on the hot banks and then are transferred to the insulated containers. The containers are such that the rails cool from 500^0C to nearly room temperature in a period of about 15 hours.

3.3 Vacuum Degassing :

Like the controlled cooling process, this process also aims at solving the shatter crack problem. Its approach however is to reduce the hydrogen content in the liquid steel to a harmless level by exposing the liquid steel to a low pressure atmosphere created by vacuum treatment. The time consuming controlled cooling method can therefore be dispensed with resulting in corresponding saving. An accidental advantage is that the mixing action taking place during vacuum treatment gives greater uniformity of composition.

In vacuum degassing process, a vacuum chamber is made above ladle containing liquid molten metal. Low pressure in the evaporation chamber allows the entrapped gases to expand and rise to the surface.

There are several processes for carrying out vacuum degassing. However RH degassing is the latest and generally preferred owing to the metallurgical advantage of downstream refining processes to produce large tonnages of high quality low cost continuously cast steel.

Various methods of vacuum degassing are discussed below:

3.3.1 Ladle degassing

The Ladle containing the molten steel to be degassed is kept inside a gas-tight tank, the outlet of which is connected to a vacuum pump. Evacuation of the space within the tank causes hydrogen from molten metal to escape with accompanying boiling action. It is necessary to agitate the molten metal to hasten removal of hydrogen and this is done either by induction stirring (which will necessitate use of non magnetic stainless steel for construction of the ladle) or by bubbling an inert gas such as helium or argon, into the molten metal. On completion of degassing and before the tank is opened to atmospheric air, the tank is purged with an inert gas in order to avoid the possibility of ignition of flammable gas and metallic dust that may have collected inside the tank. The degassed steel is teemed in the usual manner. Fig. 3.1 shows the sketch of ladle degassing.

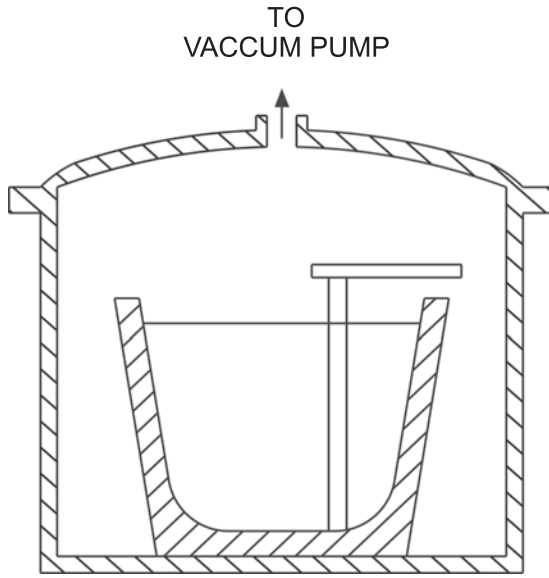


Fig. 3.1 Ladle degassing

3.3.2 Steam degassing

A bottom pour ladle, containing the molten metal is set on the top of the vacuum tank to which it is sealed to prevent entrance of air. A second ladle to receive the degassed steel is set inside the tank. After creating vacuum inside the tank, the stopper of the ladle containing the molten steel is lifted when molten steel flows down, it melts the metal diaphragm that seals the opening to the tank and falls into the ladle inside the vacuum tank. Because of the vacuum, the molten steel breaks up into the droplets, thus exposing a large surface to the degassing action of vacuum. After letting in an inert gas to replace inflammable gases inside the tank, the tank is opened to atmospheric air and the ladle metal teemed in the conventional manner. Fig. 3.2 shows the sketch of steam degassing.

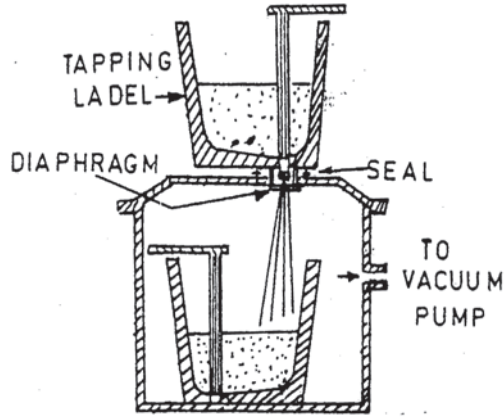


Fig. 3.2 Steam degassing

3.3.3 Dortmund-Horder Degaser (D-H Degasser)

To start with, the vacuum vessel is lowered until its nozzle extends through the slag into the molten steel in the ladle (Fig. 3.3A). Pressure is lowered to the order of 1mm of mercury when the liquid steel rises into the chamber with violent evolution of gas, on account of which the molten steel entering the vacuum vessel is in the form of the droplets, thus exposing an enormous surface to the influence of vacuum.

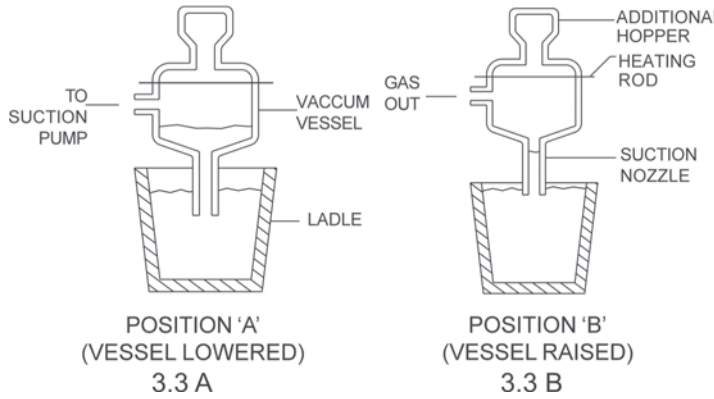


Fig. 3.3 D. H. Degassing

The vacuum vessel is then raised (Fig. 3.3 B) without removing its nozzle from the liquid metal which permits the degassed metal in it to flow back into the ladle. The vessel is again lowered and metal degassed. By repeating the operation sufficient number of times, the entire contents of the ladle can be degassed to the required level. A graphite electric resistance heating element is provided at the top of the vacuum chamber which can be used to offset any heat losses. Additions to the molten steel to bring it to the desired composition may be made without destroying the vacuum by using the addition hopper provided at the top of the vacuum vessel. After degassing is completed, the vacuum vessel is purged with nitrogen before lifting it from the molten steel.

3.3.4 Ruhrstahl-Heraeus Degaser (R.H.Degasser)

The vacuum vessel has two tubular extensions, on one of which there is an inlet for injection of an inert gas. The vessel is lowered to have the ends of both the tubular extensions submerged in the molten steel to be degassed. On evacuation of the vessel, molten steel rises in both extensions. Argon, an inert gas, is now continuously injected into one extension, on account of which, in that extension, the density of liquid steel is decreased and therefore, the level of molten steel rises. Because of the imbalance in the liquid levels thus created molten steel flows from this extension into the other, thus producing a pumping action. By the action of vacuum and the argon bubbles, hydrogen leaves the metal with boiling action and the degassed metal returns to the ladle by way of the other extension. Thus there is continuous circulation of the metal from the ladle into the vacuum chamber. When the dissolved gases have been brought to the desired level, the molten metal is teemed in the conventional manner. Bhilai Steel plant is using RH degasser since March 2000. The schematic diagram of R.H. Degasser is shown in Fig. 3.4.

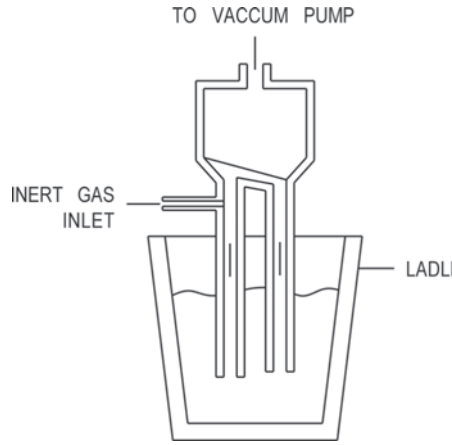


Fig. 3.4 R.H. Degasser

3.4 Casting :

After the steel of desired quality for making rails is prepared at the end of degassing process, its casting is done. Earlier, ingot casting was being done which had many disadvantages.

A pre-requisite to faultless finished material is perfect ingots, free from all cavities or openings and made up of material, that is uniform. Unfortunately, the natural process that govern the solidification of the liquid metal operate against both these requirements and defects called piping, blow-holes, segregation, columnar structure and internal fissures are pesent in ingots. To these may be added defects such as checking, scabs and slag inclusions attributable to the incorrect pouring practice. A number of defects in the finished products can be directly traced to the defective ingots. So the ingot casting method has been subsequently replaced by continuous casting. IRS-T-12-2009 mandates use of continuous casting method for rail manufacturing continuous casting method is described below.

3.4.1 Continuous casting process

This process comprises the direct solidification of liquid steel into a solid bloom which is continuously extracted from the casting machine and cut into required lengths.

Figures 3.5 A, B, C show the arrangements of the principal components of a continuous casting machine. While the arrangement in A will require a tall structure of height above 21m with attendant material handling difficulties, B & C show arrangements where a structure of shorter height will suffice.

3.4.1.1 Working

In order to conserve heat and to control the temperature, insulated ladles are used, and these, as also the pouring vessel are preheated. Where more than one billet production stand are in operation, the same pouring vessel may be used for pouring the moulds simultaneously by providing as many nozzles in the bottom of the pouring vessel. During casting, the mould oscillates over a small predetermined distance and this prevents sticking of the solidifying steel on to the mould. Molten steel is continuously poured from the ladle through the pouring vessel into the water-cooled mould. The withdrawal rolls control the speed of withdrawal of the billet. Because of the high melting point, high specific heat and low thermal conductivity of steel, only partial solidification occurs at the mould stage and much of the steel inside is still in molten condition. Solidification is completed as the steel mass passes through the vertical cooling chamber which is cooled on the outside by water sprays. The billet is flame cut to the required length, as it emerges out of the withdrawal rolls and received by the tilting mechanism and rolled out.

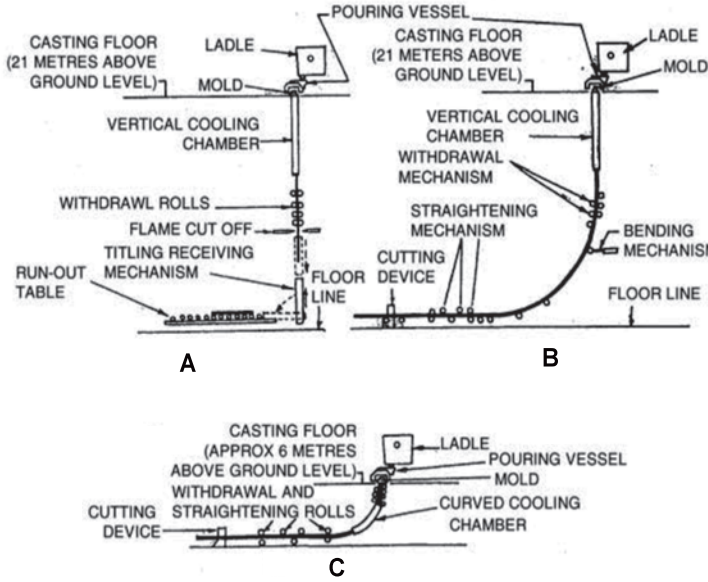


Fig. 3.5 Continous casting

3.4.1.2 Advantages

i) This process produces blooms of required length straight from liquid metal and thus eliminates the necessity to pour the liquid steel into ingot, stripping the solidified ingot from the mould, reheating it for rolling, rolling into blooms and cutting the blooms to the required length. Thus economy is achieved.

ii) Pipe, large and numerous inclusions and segregations are known to give rise to cracks during upsetting in flash butt welding and similar processes. The faster and more uniform bloom cooling rates which occur during solidification in this process greatly reduce the occurrence of macro segregation and minimize the occurrence of pipe. Therefore, troubles during welding arising from these factors are eliminated.

iii) Since there is no need to discard a portion of ingot to remove the piped portion, steel yield from molten metal is greater.

According to para 5.2 of the IRS-T-12-2009 "Standard Specification for flat bottom rails", all blooms used in the manufacture of rails shall have a cross sectional area not less than ten times that of the rail to be produced.

3.5 Rolling of Rails :

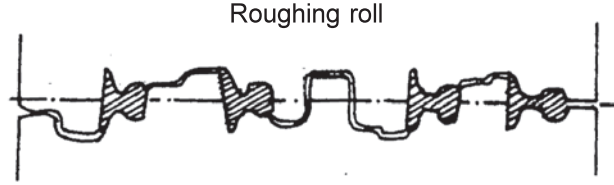
From pig iron to bloom making it is a continuous process. After blooms are prepared, these are rolled into the rails. For this, the cut blooms which are still hot are taken for rolling into rail lengths. Alternatively, these are allowed to cool and stored to be taken up for rolling later, in which case the pieces are reheated before rolling.

In Bhillai Steel Plant, the blooms are allowed to cool and are reheated to 1250^{0}C before rolling of rails.

The blooms are rolled in a series of roll passes to form the rail to template dimensions. In the first few passes, called roughening, a large amount of work is done to reduce the section size and elongate the piece. In the next stage known as first finishing, actual shaping of the rail takes place in a few passes. The third stage is the finishing pass in which the rails are formed exactly to template dimensions without reduction in section. A typical series of section changes occurring during the rolling process is shown in figure 3.6.



Roughing roll



Finishing roll

Fig. 3.6

While rolling is done, spraying of water at 200 bar pressure is done to remove furnace scale. By the time, rolling is complete, the temperature of rails comes down from 1250^{0}C to 800^{0}C. Rolling of rails have many advantages as detailed below :

(i) To break down coarse grains

In the as-cast condition, the ingot/billet shows columnar structure towards the mould surface to varying depths and very coarse grained structure in the interior. Both are undesirable structures and in order to develop the mechanical properties to the maximum extent, the structure should be broken, mixed and refined. When the rail is rolled, the change in section size elongates the grains, of which the ingot is made up, in the direction of rolling by shear along characteristic atomic planes. The shearing force increases the internal energy of the grains and immediately therefore, the elongated grains recrystalise giving rise to a new sort of grains. This process of elongation of grains and recrystallisation occurs every time the process of rolling changes the section size. The facility with which grains grow

depends on temperature. At a high temperature, several small grains initially formed during recrystallisation form large grains. At a lower temperature, however, this is limited and therefore, the grain size is smaller. Because of the lower temperature at the time the rail is finally rolled, the recrystallised grain tends to be much smaller than in the ingot.

(ii) To make composition uniform

When steel is in liquid state, carbon, manganese silicon, etc. are uniformly distributed throughout. When the steel solidifies from liquid state, the composition of nucleus is different from the liquid from which it crystallizes. Also, the composition of different layers of solid crystallizing on the nucleus progressively differs. In other words, there is difference in concentration of elements in each grain and this is called “micro segregation”. Though some equalizing of concentration occurs due to diffusion even as the ingot solidifies, complete uniformity is not achieved. With micro-segregation optimum properties cannot be achieved. The high temperature employed and the work put in during rolling facilitates diffusion of the elements to result in uniformity in concentration.

(iii) To close down internal blow holes

Blow holes are formed by evolution of gases during solidification of steel. Unless the blow holes are exposed to atmospheric oxygen, their walls remain clean. During rolling, the blow holes elongates, the clean walls come together and weld up. Thus the blow holes are completely eliminated.

(iv) To break down inclusion and render them harmless.

Inclusions are non-metallic materials, such as, sulphides, complex silicates, etc.

Steel making process is essentially oxidizing process. When the elements have been brought down by oxidation to the level planned, even though no further oxidation occurs, some oxygen still remains in equilibrium in the molten steel. When the steel solidifies, because of the lower equilibrium concentration, oxygen reacts with carbon to give carbon monoxide gas and so makes the solid steel full of blow holes. The oxygen in the molten steel has therefore to be removed (deoxidization) before the steel can be taken for pouring. Ferro manganese, ferro silicon and aluminum are used for this purpose, which by reaction with oxygen produce their respective oxides. This is one source of inclusion of steel. Other sources are accidental entrapment of slag or refractory particles from runners, ladle and furnace lining etc. in the ingot during solidification. Being weak and brittle, these act as weak spots. Inclusions cannot be completely eliminated, but should be minimized. Large inclusions or inclusions in a row (stringers) are particularly objectionable. The enormous lengthening of billets during rolling of rails, not only breaks the large inclusions into tiny bits but also disperses them.

3.6 Cutting of rails :

Rails are then cut to standard lengths by hot saws. The rails while they are still hot are allowed to cool to about 500^{0}C and are then transferred to well- insulated chambers or to closed containers where they are allowed to cool very slowly to room temperature, occupying a minimum time of the order of 15 hours. This process is called controlled cooling However now a days at Bhilai Steel Plant, slow cooling is not being done as purpose of slow cooling is achieved in vacuum degassing. So the cooling is done in 4 hrs. instead of 15 hrs. earlier.

3.7 Precambering and Straightening :

Rails have asymmetrical shape. It is a well known fact that the thinnest part of the section cools the fastest. In case of rail, the had contains the larger mass, and therefore, retains the heat to the greatest degree. Consequently the contraction in the head is lesser than at the flange with the result that in cooling, the rail would naturally sweep or pull towards the foot, causing a bow in the rail, which would make it extremely unwieldy for further processing. To overcome this condition rails are given a pre-camber in opposite direction while they are hot so that in the process of cooling rails straighten themselves. At Bhilai Steel Plant, the reverse camber is given to rails by a set of 29 position controlled carriages. The programming of the carriages produces pre-cambering of the rails. The rails are clamped firmly, lifted from roller table and placed on to the walking beam cooling bed with the help of hydraulic cylinders. All these hydraulic operations are synchronized with the help of flow control valves. Hydraulic actuators of all the 29 carriage for a particular operation are actuated with a common solenoid valve. The travel mechanisms of the carriages are independent.

The various pre camber curves are set based upon temperature, rail length and profile parameters. The residual stress in the rails in this process are very small and well within norm after straightening. Cooling of full length rails on walking beam beds prevents localized bends in rails.

To meet straightness requirement, roller straightening machine, wherein the rails are passed through series of rollers, straightens the rails at Bhilai Steel Plant. The cooled rails are passed through most advanced bi-planar straightening machine, having 9 horizontal rollers and 8 vertical roller machines which are collectively capable of straightening in vertical as well

as horizontal plane. The machine with off-line straightening model enables development of straightening parameters and straightening models. This machine is capable of minimizing residual stress during roller straightening process by computing the bending pattern and elasto-plastic stress strain correlation with the help of mathematical model. Such model helps in optimizing the deflection pattern under different rollers to achieve favorable internal stresses across the rail profile. The straightening machine also communicates online with laser straightness machine such that timely corrective action for straightness can be optimized. The biplaner straightning machine used in Bhilai steel plant is shown in fig. 3.7.



Fig. 3.7. Biplaner rail roller straightning machine

After straightening, the rail are checked and inspected in continuous operation for internal defects, dimensional accuracy and running surface straightness. Provisions regarding testing of rails and important stipulations of IRS-T-12-2009 are dealt in Chapter 5 & 6.

■ ■ ■

CHAPTER - 4

CHEMICAL COMPOSITION OF RAIL STEEL

4.1 Introduction :

Apart from the iron, which is obviously the main constituent in any steel, ordinary plain carbon steel contains carbon, manganese, phosporus, sulphur and silicon. Carbon, manganese and in some steels silicon are essential ingredients while sulphur and phosphorus are unavoidable impurities. In addition, steel may contain oxygen (if not completely oxidized), traces of nitrogen and hydrogen etc. The effects of all these elements are discussed below. However, at this stage we are not discussing the effects of special alloying materials like chromium, which are added to the special and alloy steels.

4.2 Carbon :

In steel, carbon is present as iron carbide, a compound of iron and carbon also called cementite. In normalized plain carbon steels, at room temperature, upto 0.8% carbon, which is called eutectoid composition, the carbide and ferrite (alpha iron in which elements such as silicon, manganese etc. are in solid solution) form alternate lamellae, a structure known as “pearlite”. At 0.8% carbon content, the structure of steel is fully pearlitic; at lower carbon contents, the normalized structure shows proportionately lower amounts of pearlite with free ferrite areas. Above 0.8% carbon, free cementite occurs generally in the form of a fine net work at the grain boundaries, sometimes it also precipitates in the form of needles inside grains of pearlite.

Upto a little above 0.8%, carbon increases hardness, yield point and ultimate tensile strength. This it does,by

increasing the amount of pearlite. However, the increase is accompanied by reduction in percentage elongation and percentage reduction in areas i.e. loss of ductility. Beyond this percentage, however, the cementite network forming in the grain boundaries tends to make the steel brittle.

Gamma iron (austenite) has a high solubility for carbon, the maximum solubility being 2% at 1130^{0}C whereas alpha iron which is the room temperature allotrophic form of iron, has a solubility for carbon less than 0.1%. This difference in the solubility for carbon is the basis for a variety of heat treatment given to steel to obtain a very wide range of physical properties. For example, the carbon may be taken into solid solution by heating the steel into its austenite range and then cooling precipitates the carbon as cementite. Increased rates of cooling produces finer and finer cementite (and ferrite). Hardness, yield point, and ultimate tensile strength increase with fineness of cementite, with accompanying decrease in ductility. When the rate of cooling exceeds a particular limit, all the carbon is retained in supersaturated solution in alpha iron, in which form (called martensite) the material is hardest and brittle for that carbon content. Heating martensite to successively higher temperature reduces tensile strength and hardness with increased ductility.

The effect of increasing carbon can be summarized as increase in the tensile strength and hardness and decrease of ductility and more responsive to heat treatment. As per IRS-T-12-2009, the permissible range of carbon content in rail steel is 0.60% to 0.80%.

4.3 Manganese :

Manganese is used for deoxidating the molten steel since it has greater affinity for oxygen than iron. Also this element combines with sulphur present in steel to

form the insoluble manganese sulphide. If sulphur is not present as manganese sulphide, which will happen if sufficient manganese to combine with all sulphur is not present, the sulphur precipitates as a network of iron sulphide in the grain boundaries. Since this has a low melting point, it makes the steel susceptible to cracking (hot shortness) during forging and in this sense, manganese overcomes hot shortness in steel. Manganese in excess of that required for combining with sulphur is present mainly in the form of solid solution in iron at all temperatures. Some of it combines with carbon to form a carbide similar to iron carbide and precipitates along with iron carbide as a complex carbide. Above about 0.8%, manganese influences the properties of steel as an alloying element enabling higher tensile strength with no loss of ductility and better hardenability. It gives rise to finer pearlite and finer grained structure in normalized steel. As per IRS-T-12-2009, the permissible range of managnese content in 880 and 1080 HH grade rails is 0.80% to 1.30% and in 1080 Cr. grade, it is 0.80% to 1.20%.

4.4 Silicon :

Silicon has great affinity for oxygen. It is better in this respect than manganese and is therefore, used as a deoxidizing agent in the production of steel. In the combined conditions as silicates, it is present as tiny inclusions in the steel matrix but the major portion is present as solid solution in iron at all temperature. It is present less than 0.1% in rimmed steels and 0.1% to 0.3% in killed steel, it does not affect the physical properties of steel to any useful degree. As per IRS-T-12-2009, the permissible range of silicon content in 880 & 1080 HH grade rails is 0.10% to 0.50% and in 1080 Cr grade, it is 0.50% to 1.10%.

4.5 Phosphorous :

Phosphorous is a harmful element in steel as it produces cold-shortness i.e. makes steel brittle and liable to crack when cold worked. Its content therefore is restricted to 0.05% (max.) in most of the steels. Phosphorous segregates to a considerable extent during solidification of steel, the segregation being due to the selective freezing of steel leading to the concentration of the phosphorous rich metal which has a lower freezing point, in the portions of the ingot which solidifies last, i.e. the pipe. The segregation portions, are, therefore less ductile. By removing the pipe, the high phosphorous regions may be largely but not entirely eliminated. Because of the embrittling effect, the restriction in phosphorous content is called for more in the case of high carbon steels (which have less ductility) than in low carbon steels. Also, where only static loading is encountered, more phosphorous may be tolerated than in dynamically stressed components. Phosphorous is usually restricted to 0.07% in ordinary steels, 0.05% in quality steels and 0.04% in high quality steels. It increases the tensile strength, hardness and yield point, but reduces sharply the impact strength.. The improvement in yield strength is made use of in the production of high strength structural steels containing upto 0.2% phosphorous in combination with small amounts of other alloying elements such as chromium copper, silicon, etc. As per IRS-T-12-2009, the permissible limit of Phosphorous content in 880 & 1080 HH grade rail steel is 0.030% (max.) and 0.035% (max.) in finished rail. For 1080 Cr grade, it is 0.025% (max.).

4.6 Sulphur :

Like phosphorous, sulphur is also a deleterious element since it makes steel “hot short” i.e. liable to crack when hot. Sulphur upto about 0.6% is generally allowed in steels, though in high quality steels, not more than 0.04% is permitted.

4.7 Hydrogen :

Hydrogen is introduced into the steel during the melting and refining, from the dissociation of water vapour. Hydrogen is insoluble in steel at room temperature and if allowed sufficient time to escape during cooling, it does not cause any harm to low carbon steels. In very thick section and in high carbon and alloy steels, minute internal cracks known as hydrogen flakes or shattered cracks are formed, particularly when the steels are quickly cooled. In rail steel, control of hydrogen content is very important. As per IRS-T-12-2009, the pemitted hydrogen content in liquial steel is 1.6 ppm (max).

4.8 Permitted chemical composition as per IRS-T-12-2009 :

The permitted chemical composition (in percentage) of various elements in the steel to be used for making rails is specified in IRS-T-12-2009. Details are given in table 4.1

Table - 4.1

Grade	Chemical Composition (Percentage)											Mechanical Properties			
	C	Mn	Si	S (max)	P (max)	Al (max)	Mo (max)	Cr	V (max)	10^{-4}% (ppm) max by mass O	Hydrogen Content in liquid steel (max.)	UTS (MPa) (Min)	Yield Strength ***(MPa)(Min.)	Elongation % on guage length – $5.65\sqrt{So}$ (min)	Running surface hardness (BHN)
880	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	-	-	-	-	1.6ppm	880	460	10.0	Min 260**
1080 Cr	0.60-0.80	0.80-1.20	0.50-1.10	0.025	0.025	0.004	0.20	0.80-1.20	0.20	20	1.6ppm	1080	560	9.0	320-360
1080HH	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	-	-	-	-	1.6ppm	1080	460	10.0	340-390

So= Cross sectional area of tensile test piece in mm^2

*0.035 maximum for finished rail

The chemical composition specified as above are applicable to Ladle analysis and Product Analysis. Manufacture shall ensure that chemical composition at ladle analysis should be such that product analysis also satisfies the requirement of chemical composition as above.

** Desirable Value

***Frequency to be mutually agreed by purchaser and manufacturer.

SPECIAL RAIL STEEL

Table - 4.1 Cont...

Grade	Chemical Composition (Percentage)												Mechanical Properties			
	C	Mn	Si	S (max)	P (max)	Al (max)	Mo (max)	Cr	V (max)	Nb (max)	10^{-4}% (ppm) max by mass O	Hydrogen Content in liquid steel (max.)	UTS (MPa) (Min)	Yield Strength ***(MPa)(Min.)	Elongation % on guage length – 5.65√So (min)	Running surface hardness (BHN)
NIOBIUM (NB)	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	-	-	-	0.04	-	1.6ppm	880	540	10.0	Min 260**
VANADIUM (VN)	0.60-0.80	0.80-1.30	0.10-0.50	0.025*	0.030	0.015	-	-	0.20	-	20	1.6ppm	880	630	9.0	Min 260

CORROSION RESISTANT STEEL

Grade	Chemical Composition (Percentage)												Mechanical Properties			
	C	Mn	Si	S (max)	P (max)	Al (max)	Mo (max)	Cr	Cu	Ni	10^{-4}% (ppm) max by mass O	Hydrogen Content in liquid steel (max.)	UTS (MPa) (Min)	Yield Strength ***(MPa)(Min.)	Elongation % on guage length – 5.65√So (min)	Running surface hardness (BHN)
Copper-Molybdenum	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	0.2-0.3	-	0.25-0.35	-	-	1.6ppm	880	460	10.0	260
Nickel Chromium Copper	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	0.25	0.50-0.65	0.3-0.4	0.25-0.40	-	1.6ppm	880	550	10.0	260

So= Cross sectional area of tensile test piece in mm^2
*0.035 maximum for finished rail
The chemical composition specified as above are applicable to Ladle analysis and Product Analysis. Manufacture shall ensure that chemical composition at ladle analysis should be such that product analysis also satisfies the requirement of chemical composition as above.
** Desirable Value

CHAPTER - 5

TESTING OF RAILS

5.1 Introduction :

Testing of rails is necessary for ensuring conformity and quality in the manufactured product, checking up conformity with the prescribed specifications.

Testing of rails includes dimensional checks, chemical analysis and physical tests. On Indian Railways, rails are accepted as per IRS -T-12-2009 which covers flat bottom rails. In this chapter, the chemical and physical tests shall be discussed and dimensional checks will be covered in Chapter - 6 along with other important stipulations of IRS -T-12-2009 (amended upto ACS-4).

5.2 Freedom from Defects :

The rails shall be of uniform section throughout and shall be free from all detrimental defects such as cracks of all kinds, flaws, piping or lack of metal etc. having unfavourable effect on the behaviour of the rail in service.

5.2.1 USFD Testing

The absence of harmful internal defects shall be ensured by the continuous on-line ultrasonic examination.

The limits of permissible defects for ultrasonic testing of rails shall be as follows. (Para 10.3 of IRS-T-12-2009).

Head :	1.5mm dia through hole
Web :	2.0mm dia through hole
Web & foot junction :	2.0mm dia through hole
Foot :	0.5mm deep, 12.5mm long and 1.0mm wide notch (inclined at 20^{0} with vertical axis)

Bhilai steel plant is using on-line ultrasonic rail testing system. Test equipment is calibrated using a test rail with artificial defects. Ultrasonic system in Bhilai steel plant is as per table 5.1 given below :

Table - 5.1

Zone	No. of probes	Diameter of Artificial Defects
Head	6	1.5mm
Web	4	2.0mm
Foot bottom	1	2.0mm
Foot-inclined	2	1.5mm

The inspection is carried out at a line speed of 1.5 m/sec. The rails after passing through the Rail Roller Straightener Machine (RRSM) are fed into the descaling station where a high pressure water system is used. An encoder defines the speed of the rail on entry to the online automatic ultrasonic inspection system. Photoelectric cells (PEC) define the front and rear end of the individual rail to determine the defective position. The rail then passes into the on-line automatic ultrasonic inspection system. The system is totally automatic and needs no manual involvement. The ultra sonic testing machine being used in Bhilai steel plant in shown in fig. 5.1.

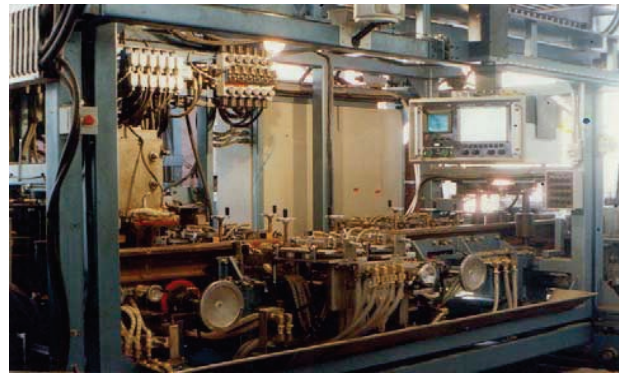


Fig. 5.1. Ultra sonic testing machine

The system provides that any flaw detected will be located against its position within the rail and along the rail length. Also, such defect events are automatically logged by type and position on a printer in the control cabin and a defect is marked on rail automatically by paint sprays on the top head of the rail at the paint gun section. Three different colour codes are being used to identify the defect zone i.e. head, web & foot. Status marking O.K. rail is done by fourth paint spray gun with white colour. The defects marked rails are segregated in a separate bed by automatic tilter. These rails are then manually tested for confirmation of the genuine defect or false signals arising due to high noise level, mechanical vibration, rough surfaces etc.

5.3 Eddy Current Testing

As per para 10.4 of IRS-T-12-2009, the manufacturer should have eddy current testing (ECT) covering bottom area of the rail as also the top surface and sides of surface head. The ECT probes should cover complete area of rail bottom and at least 80% area of top surface and sides of the head.

The surface is scanned by the Probes/Coils without physical contact as the rail passes over the probe. The test electronics power the excitation windings of probes and generates eddy currents in the surface. If there is a flaw / defect in the foot surface of the rail, the homogeneity of the flow path of eddy current is disturbed and is sensed by the receiver windings of the probes and consequently signal is displayed for flaw/defect The machine is set on predetermined threshold level above the normal noise level on rails and any abrupt signal beyond this level is marked & automatically recorded. Sometimes some spurious defect signals are also observed which arise from some other sources. Thus it is not fool proof system. Visual inspection is required and on-line eddy current system aids/helps the inspectors in concentrating more on defect signals received from eddy current

testing machine. The eddy currant testing machine being used in Bhilai steel plant is shown in fig. 5.2.

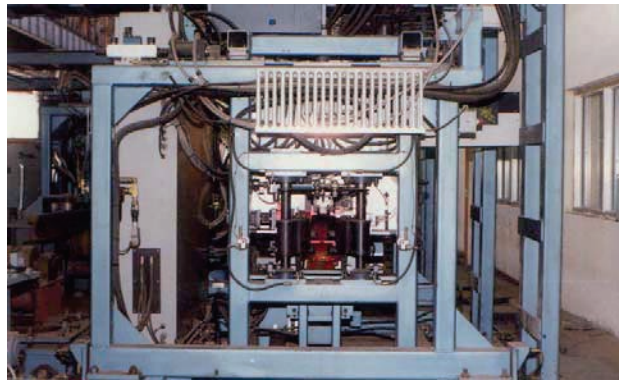


Fig. 5.2. Eddy currant testing machine

5.4 Surface Quality :

5.4.1 Hot marks

Depth of rolling guide marks anywhere on the rail should not exceed 0.5mm. A maximum of two guide marks are allowed per rail. The width of each rolling guide mark should not exceed 4.0mm.

Depth and width of guide marks must conform to table 5.2 :

Table - 5.2

Depth (mm)	Minimum width (mm)	Maximum width (mm)
0.5	1.5	4.0
0.4	1.2	4.0
0.3	0.9	4.0

5.4.2 Cold marks

Depth of longitudinal or transverse cold-formed scratches anywhere on the rail should not exceed 0.5mm.

5.4.3 Seams

Rails with seams greater than 0.2mm in depth are not acceptable and shall be ground. On the running surface of the rail, dressing shall be limited to 0.3mm deep and in other places, it shall be limited to 0.5mm deep.

5.4.4 Protrusions

All protrusions in the head or foot of the rail shall be ground to match the parent contour. Protrusions on web greater than 1.5mm high and 20mm square shall be ground. All protrusions affecting the fitment of the fishplate shall be ground.

5.4.5 During examination on the inspection banks, any shrinkage cavity, inclusion & segregation visible to the naked eye shall result in rejection of such rail or cutting out of the defective portion and re-examination.

5.4.6 Any operation carried out either in the hot or cold state with the object of hiding a defect is strictly for bidden.

5.5 Qualifying Criteria :

As per IRS-T-12-2009, the following tests shall be done for each rail section, grade and class after any change in the process of manufacture which may affect the results or annually for the first three years and if results of these three years are consecutively found satisfactory, the frequency may be relaxed to three years.

a) Residual stress measurement
b) Fracture toughness measurement
c) Fatigue test

The samples for these tests shall be collected from finished rails. These samples shall not be subjected to any further mechanical or thermal treatment. The

method for carrying out these tests is given in detail in IRS-T-12-2009.

5.5.1 Residual Stress Measurement (in rail foot)

The residual stresses in the rail foot shall be determined in accordance with procedure described in appendix - XIII of IRS-T-12-2009.

5.5.1.1 Results to be obtained

Residual tensile stress anywhere in the rail section shall not exceed 250 MPa.

5.5.2 Fracture Toughness K_{1c}

5.5.2.1 Test pieces and test methods

Tests shall be performed in accordance with APPENDIX-XI of IRS-T-12-2009.

5.5.2.2 Qualifying Criteria for Fracture Toughness

The values of K_{1c} shall comply with table given below:

Steel grade	Minimum single value K_{1c}(MPa m ½)	Minimum Mean K_{1c} (MPa m ½)
880	26	29
1080 Cr	24	26
1080 HH	30	32

Note : In some circumstances K_Q values can be used for the purpose of qualification – see B.6 of appendix XI of IRS-T-12-2009.

5.5.3 Fatigue Test

5.5.3.1 The constant amplitude fatigue test shall be carried out in accordance with ASTM E606.

5.5.3.2 Test Pieces

The test pieces shall be machined from the sample rail at a location at least 2m from the rail ends.

5.5.3.3 Number of Tests and Test Conditions

A minimum of three tests shall be performed under the following conditions:-

5.5.3.4 Each sample should endure 10 million cycles at strain of 0.00135 for 880 grade rails. For rails of grade 1080 each sample should endure 10 million cycles at strain of 0.00166. Testing shall be done in such away that peak strain shall be 0.00135 in tension and 0.00135 in compression for 880 grade rails. For rails of grade 1080 the peak strain shall be 0.00166 in tension and 0.00166 in compression.

5.6 Acceptance Tests :

For 880, 1080 Cr, 880CM, 880NC, 880VN and 880NB rails :

a) Chemical Analysis
b) Tensile test
c) Sulphur Print
d) Hardness test (for information & record)
e) Falling weight test
f) Hydrogen content
g) Inclusion Rating Level

For 1080 HH rails :

I. Before Heat treatment
   All tests stipulated above
   except tensile and hardness tests.
II. After Heat treatment

The following tests shall be carried out :

a) Tensile test
b) Hardness test
c) Macroscopic test

5.7 Chemical Analysis :

5.7.1 A complete ladle sample analysis of each cast from which the rails are to be rolled is done. The percentage of each specified element shall conform to the limits specified in Table.4.1 in Chapter 4. The location of samples for chemical analysis is as per fig. 5.3.

5.7.2 **Extent of test** (Product)

For casts < 150t, one test per cast
For casts > 150t, two tests per cast, one sample taken from first half of the cast and the other from the second half and different strand. If chemical analysis of any cast fails to conform to the provisions as given in Table 4.1 in Chapter 4, the cast shall be subjected to the retest as per provisions given below.

5.7.3 **Retest**

Two additional chemical analyses shall be made. If both analyses pass, the casts shall be considered as complying with specifications. If one or both of the analyses fail, the cast shall be rejected.

If a cast does not satisfy the conditions of the specification, the intermediate metal belonging to preceding and succeeding cast shall be rejected or subjected to a retest.

The chemical analysis for specified elements shall also be made either from drillings taken from a hole drilled in the rail, or by spectrography or any other approved method from the position shown in figure 5.3, rolled from the same cast or from the tensile test piece or piece selected by the inspecting agency and the percentage of each specified element shall be within the range specified in table 4.1 of chaper 4.

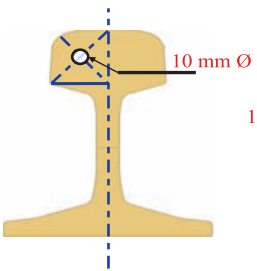


Fig. 3A for drilling

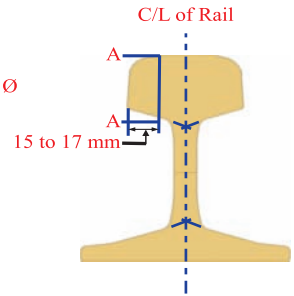
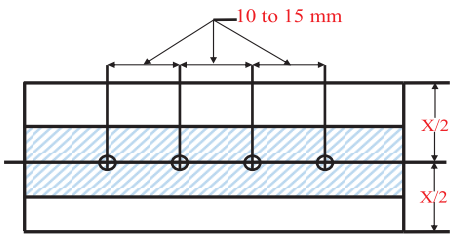


Fig. 3B for Spectrography



SECTION at A-A

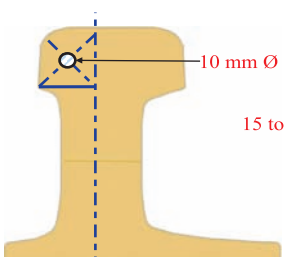


Fig. 3C for drilling

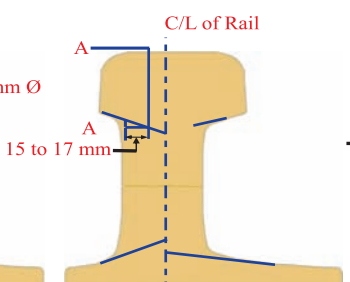
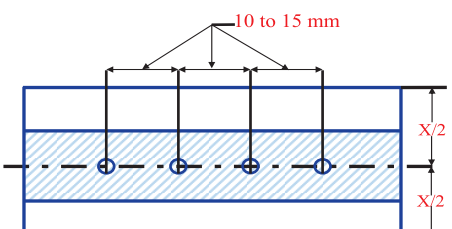


Fig. 3D for Spectrography



SECTION at A-A

Fig. 5.3 Location of sample for chemical analysis

In Bhilai Steel Plant, two lollipop samples from each heat, one at 20 M casting and other at 40 M casting from the Tundish is collected and analysed. The average of the two is reported as ladle sample analysis.

5.8 Sulphur Print Test :

In this test, a Baumann-type impression is obtained by the application of bromide paper, previously impregnated with a solution of sulphuric acid, to the clean rail sections drawn from a location within the cast at the discretion of the Inspecting Agency.

The sections intended to be used for these tests are cold sawn and are then sufficiently cleaned on one surface in order to eliminate completely all machining marks and to obtain a sharp impression.

Sulphur print tests shall be carried out at the rate of one each per cast for casts < 150 t and two per cast for casts> 150 tonnes.

5.8.1 Results to be obtained

The prints obtained must not reveal macrographic defects more marked than those of the limit prints shown in (or equivalent to those shown in) the album of macrographic print given in Appendix - VIII of IRS-T-12-2009.

5.9 Determination of Hydrogen Content :

5.9.1 Vaccum degassing of liquid steel shall be done to reduce the hydrogen content. For this purpose, RH degasser or REDA (Revolutional Degassing Activator) shall be used. All measurement of hydrogen shall be done for the liquid steel in tundish or mould.

5.9.2 The measurement of hydrogen shall be done by following method :

On line / Instantaneous Method - HYDRIS is approved as method of online instantaneous measurement. The method of measurement as prescribed by the manufacturer of HYDRIS system shall be adopted.

5.9.3 The level of hydrogen measured by the method prescribed in para 5.9.2 above shall by 1.6 ppm maximum for acceptance of a heat for production of rail.

5.10 Tensile Test :

5.10.1 For 880,1080 CR , 880 CM, 880 NC, 880 VN, And 880 NB grade Rails

5.10.1.1 Nature of Tests

The manufacturer shall determine the tensile properties of the steel in accordance with the requirements of IS: 1608. Such tests shall be made on standard test pieces taken from position shown in figure 5.4.

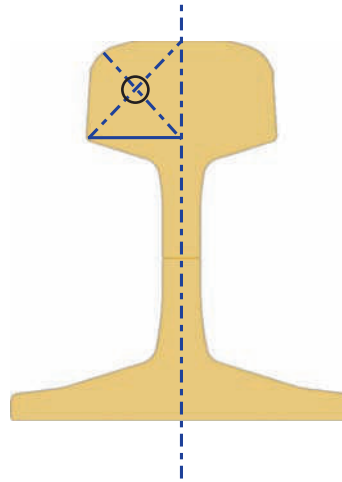


Fig. 5.4 Location of Tensile Test Piece

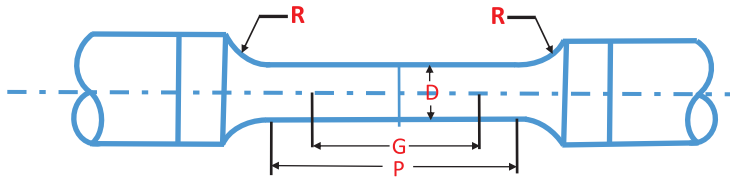


Fig. 5.5 Standard Round Tensile Test Piece

Three sizes of the standard test piece, as shown in fig. 5.5 are given in table 5.3, any of which may be adopted.

Table - 5.3

Diameter	Area of cross section	Gauge Length	Parallel Lenght	Radius at Shoulder
D mm	A mm^2	G mm	P mm	R mm
20.64	333.33	100	120	18
14.56	166.37	75	90	13
10.00	78.50	50	55	10

5.10.1.2 Extent of Tests

The extent of tests as per IRS-T-12-2009 is as follow.

For casts < 150 t, one test per cast
For casts > 150 t, two tests per cast one sample taken from the first half of the cast and the other from the second half and from different strand.

The tensile strength to be obtained shall not be lower than the minimum value given in table 4.1.

5.11 Hardness Test :

The accepted definition of the hardness is that it is a measure of the ability of a material to resist deformation, indentation or abrasion. The indentation methods are most commonly employed and the hardness is determined as the resistance offered by the material to the penetration of an indenter of specified material, shape, dimensions and underlying principles in this test is to cause an indentation under specified conditions and to measure the diameter, diagonal or depth of the indentation. In the first two cases, the area of indentation is taken as proportional to the hardness of the material, while in the third method the depth of indentation is taken as proportional to the hardness.

5.11.1 For 880,1080 CR , 880 CM, 880 NC, 880 VN, And 880 NB grade Rails

5.11.2 Nature of Test

For carrying out this test, impression shall be made on the running tread of a test piece drawn at the discretion of the manufacturer. The test shall be performed in accordance with IS : 1500.

5.11.3 Extent of Test

Test on 10% of the casts shall be done in case of 880 grade rails and 1080 grade rails for the purpose of records and for any corrective action as required. The hardness values should preferably be as under :

Grade 880 rails	Minimum 260 BHN
Grade 1080 HH	340 - 390 BHN
Grade 1080 Cr	320 - 360 BHN

Results of the test should be average of five observations on the same test piece.

5.11.4 For 1080 Grade (Head Hardened) Rails

5.11.5 Nature of Test

The hardness test on the rail head surface shall be carried out for 10% of rails, at one end of the rail (after removing the decarburised surface), at regular interval of heat treatment and the hardness should be in the range of 340-390 BHN for 1080 HH Grade Rails. In case of non-conformance of any rail, 9 consecutive rails on either side of the rails having non- conformed value shall be checked for hardness in the sequence. Rails not meeting the hardness stipulations maybe retreated only once at the option of the manufacturer and such rails may be retested as above." Hardness of rail head surface after heat treatment shall be within Brinell Hardness number 340 to 390.

5.12 Falling weight test :

The test is primarily intended to ensure that the rail is not in any way brittle and is sufficiently tough. One test per cast is carried out. The method of carrying out test is detailed in para 20 of IRS-T-12-2009.

5.13 Inclusion Rating Level :

Para 18.2 of IRS-T-12-2009 stipulates that this test shall be carried out as per IS : 4163. The inclusion rating level, when examined as per IS : 4163, shall not be worse than 2.5 A, B, C, D, or 2.0 A, B, C, D thick.

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CHAPTER - 6

IMPORTANT STIPULATIONS OF IRS-T-12-2009
(CORRECTED UPTO CORRECTION SLIP NO.- 4)

6.1 Introduction :

IRS-T-12-2009 provides standard specification for flat bottom rails. The provisions related with testing of rails for chemical and physical properties have been discussed in Chapter 5. Its other important provisions are being discussed in this chapter.

6.2 Manufacture :

The steel used for the manufacture of rails shall be made by basic oxygen or electric arc furnace process and continuously cast. The cross sectional area of the bloom shall not be less than ten times that of the rail section to be produced.

6.3 Grade, chemical composition and Mechanical properties :

IRS-T-12-2009 stipulates 7 grades of rails viz.

Grade 880	880
Grade 1080 HH	1080 HH
Grade 1080 Cr	1080 CR
Grade 880 Cu - Mo	880 CM
Grade 880 Ni Cr Cu	880 NC
Grade 880 Vanadium	880 VN
Grade 880 Niobium	880 NB

The steel for rails shall be of fully killed quality and shall conform to chemical composition and mechanical properties are given in Table 4.1 in Chapter 4.

6.4 Marking :

Brand Marks : Brand marks shall be rolled in relief on one side of the web of each rail at 3.0 to 4.0 meters interval.

The brand mark shall include:

a) Rail section

b) Grade of steel. e.g. for grade 880 - "880"

c) Identification mark of the manufacturer.

d) Month (using Roman numbers) and last two digits of year of manufacture.

e) Process of steel making :
e.g. for Basic oxygen – "O", for Electric - "E"

6.5 Hot Stamping :

Each rail shall be identified by a numerical, alphabetical or combined alphabetical and numerical code which will be distinctly hot stamped at least once every 5.0m on the web in figures and letters of suitable size from which following information can be obtained :

i) The caste number along with letter "C"
ii) Strand number
iii) For change over blooms, cast number should be the preceding cast number with prefix letter 'B'.

6.6 Cold Punching :

Following should be cold punched on one of end face of each rail :

a) Inspecting Agency ID and Group ID
b) Shift No. in which product inspected
c) Date of inspection

To avoid damage to HH rails, instead of cold punching, any other method of marking / identification on one of end face of each rail containing above information can be adopted.

6.7 Colour Code :

Rails shall be painted as per colour code given in Appendix - IV of IRS-T-12-2009. Paint of good quality should be used with the prior approval of the Inspecting Agency.

6.8 Tolerances in Dimensions :

Tolerances in sectional dimensions **(For Prime Quality rails)**
For profile as per Appendix I, II-A, III (As per IRS-T-12-2009)

Dimension	Tolerance	Remarks
Overall height of Rails	+0.8mm -0.4mm	
Width of Head	±0.5mm	This will be measured 14mm below the rails top
Width of flange	±1.0mm	For section less than 60kg/m
	+1.2mm	For section 60kg and above
	-1.0mm	
Thickness of web	+1.0mm	This will be measured at the point of minimum thickness
	-0.5mm	
Verticality/ Asymmetry	±1.2mm	Measured by gauge shown in App. V of IRS-T-12-2009
Flange	The base of the rail shall be true and flat, but a slight concavity not exceeding 0.40mm shall be permissible.	
Fishing surface	The standard template for rail fishing surface shall not stand away from the contour of web by more than 1.20mm and the clearance at the fishing surfaces shall not exceed 0.2mm at any point.	

For profile (60E1: as per EN13674-1) as per Appendix II (Revised) (Prime Quality rails) (IRS-T-12-2009)

Sr. No.	*Reference Points (see figure A1 of annexure A of IRS-T-12-2009)		Profile (tolerance in mm)	Gauge/figure number (see Annex A of IRS-T-12-2009)
1	Height of Rail[a]	*H	±0.6	A3
2	Crown Profile – Class A straightness	*C	+0.6 -0.3	A4
	-Class B straightness		±0.6	
3	Width of railhead	*WH	±0.5	A5
4	Rail Asymmetry	*As	±1.2	A6, A7
5	Height of fishing	*HF	±0.6	A8
6	Web thickness	*WT	+1.0 -0.5	A9
7	Width of Rail foot	*WF	±1.0	A10
8	Foot toe thickness	*TF	+0.75 -0.5	A11
9	Foot base concavity	-	0.3max.	-
[a]The total height variation over any rail length shall not be greater than 1.2mm for rails ≥ 165mm				

Measurement will be done as per inspection gauges at Annexure-A (IRS-T-12-2009)

Tolerances in sectional dimensions for **Industrial Use (IU)** grade rails		
For profile as per Appendix I,II-A, III (IRS-T-12-2009)		
Dimension	Tolerance	Remarks
Overall height of Rails	+2.0mm -1.0mm	
Width of Head	+2.0mm	This will be measured 14mm below the rails top
	-2.0mm	
Thickness of web	+2.0mm	This will be measured at the point of minimum thickness
	-1.0mm	
Width of flange	+1.5mm	
	-2.0mm	
Flange	The base of the rail shall be true and flat, but a slight concavity not exceeding 0.40mm shall be permissible.	
Finishing surface	The standard template for rail fishing surface shall not stand away from the contour of web by more than 1.20mm and the clearance at the fishing surfaces shall not exceed 0.2mm at any point.	

For profile as per Appendix II (Revised) (IU rails)				
Sr. No.	*Reference Points (see figure A1 of annexure A of IRS-T-12-2009))		Profile (tolerance in mm)	Gauge/figure number (see Annex A of IRS-T-12-2009)
1	Height of Rail[a]	*H	+0.6 -1.1	A3
2	Crown Profile	*C	±0.6	A4
3	Width of railhead	*WH	+0.6 -0.5	A5
4	Rail Asymmetry	*As	±1.2	A6, A7
5	Height of fishing	*HF	±0.6	A8
6	Web thickness	*WT	+1.0 -0.5	A9
7	Width of Rail foot	*WF	+1.5 -1.0	A10
8	Foot toe thickness	*TF	+0.75 -0.5	A11
9	Foot base concavity	-	0.3max	-
[a]The total height variation over any rail length shall not be greater than 1.2mm for rails ≥ 165mm				

Measurement will be done as per inspection gauges at Annexure-A (IRS-T-12-2009)

NOTE: IRS-T-12-2009 amended up to correction slip no. 4 is considered.

6.9 Length of Rails :

The standard length of rails shall be 13 metres or 25 meters or 26 metres. However, in case, rails are to be procured in longer lengths, the same shall be prescribed by the purchaser.

The manufacturer shall be entitled to supply in pairs short lengths upto 10% by weight of the quantity contracted for or ordered. Such shorter length shall not be less than 10m in length for standard length of rails of 13m and shall not be less than 23m in lengths for 25m and 24m in length of rail for 26m. The short length shall multiples of 1.0m. Tolerances in length of all rails shall be +20mm and -10mm for Prime quality rails and +30 mm & -30 mm for IU rails

6.10 End squarness :

The deviation from square in both horizontal and vertical direction shall not exceed 0.6mm on a length of 200mm.

6.11 Straightness :

The straightness of the whole rail shall be judged by naked eye but incase of doubt or dispute, the affected portion shall be checked using 1.5 metre straight edge. The maximum permissible deviations shall be 0.70 mm measured as the maximum ordinate on a chord of 1.5 metre. Wavy, kinky and twisted rails shall not be accepted.

6.12 End straightness :

The tolerances for end straightness shall be as indicated in table 6.2 and as illustrated in figure 6.1 and 6.2.

Table - 6.1

Sr. No.	Straightness	Tolerance		
		Class 'A' rails	Class 'B' rails	IU Grade rails
1.	Horizontal	Deviation of 0.5 mm measured as maximum ordinate from the chord of 2.0 meters standard straight edge.	Deviation of 0.7 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.	Deviation of 1.5 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.
2.	Vertical a) Up sweep	Deviation of 0.4 mm measured as maximum ordinate from the chord of 2.0 meters standard straight edge.	Deviation of 0.5 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.	Deviation of 1.58 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.
	b) Down Sweep	NIL	NIL	NIL

The method of measurement of end straightness are shown in figure 6.1 and 6.2 given below:-

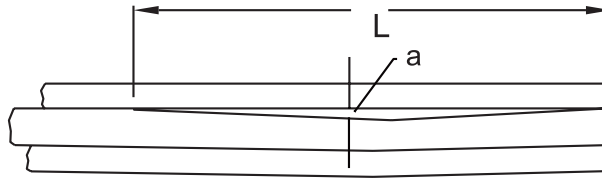


Fig. 6.1 Top view of Horizontal Tolerance at Rail Ends

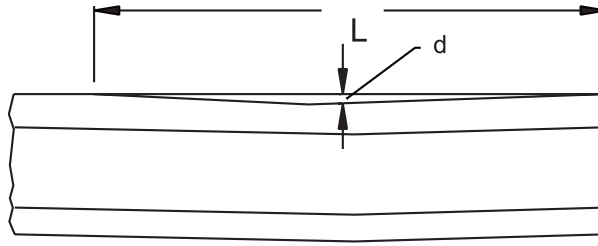


Fig. 6.2 Side view of Vertical Tolerance at Rail Ends

Note :

L = Length of straight edge specified in Table. 6.2

D = Maximum tolerance specified in Table. 6.2

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CHAPTER - 7

HANDLING OF RAILS

7.1 Introduction :

Earlier, 72 UTS rails were being used on Indian Railways. These rails were having less tensile strength and wear resistant property. At the same time these rails were more ductile. This was so because of less carbon content. The effect of carbon on strength and ductility of steel has been mentioned in chapter 4.

As these rails were having more ductility, they were less fracture prone. However, with the introduction of BOX'N' -wagon and higher axle load, 72 UTS rails were having alarming wear. To overcome this problem, the use of higher UTS i.e. 90 UTS and above rails were started. 90 UTS rails are having higher tensile strength and more wear resistant property but are brittle as the carbon content is more. This increased brittleness makes these rails more susceptible to fracture. Because of this reason proper handling of 90 UTS rails is very important.

Rails of 90 or higher UTS require extra care for handling as compared to 72 UTS rails while loading or unloading, transporting, inserting into track or any other handling related to track maintenance.

RDSO has issued guidelines for handling and stacking of rails vide CT-35 in Oct. 2014. These guidelines provide detailed precautions to be taken and methods to be followed for handling and stacking of rails.

The RDSO guidelines for handling and stacking of rails (CT-35) are at Annexure 1. All permanent way engineers must acquaint themselves with these guidelines.

CHAPTER - 8

RAIL STRESSES

8.1 Introduction :

To meet growing demand of freight traffic driven by sustained economic growth, Indian Railways has entered in an era of heavy axle load operation. Currently CC+8+2 (22.9 tonnes axle load) loading standard is widely prevalent on IR. Dedicated Freight Corridors (DFCs) are under construction which are designed for 32.5 tonnes axle load. To begin with, the train operations on DFCs shall be introduced at 25 tonnes axle load. For carrying such heavy axle loads rails need proper design to bear higher stresses in the most optimal manner for achieving overall economy.

The forces exerted by train wheels in the longitudinal, lateral and vertical directions give rise to a very complex field of stresses in the rail head. Adequate knowledge of this field is however indispensable if the maximum permissible values of forces as a function of the geometrical, mechanical and metallurgical properties of the rail or the reverse are to be determined. The complexity of the problem can be ascribed to the following peculiar circumstances:

(1) The forces are only transmitted to the rail through a very small contact area.

(2) Both the vertical and the horizontal forces are applied eccentrically to the axes of inertia.

(3) The rail profile has a form which permits a distinction to be made between three parts; the head, the web and the foot.

Because of above complexity, the rail stresses can only be determined approximately. Any theoretical calculation of rail stresses has to be validated by experimental measurement.

Use of Finite Element Method can enable more accurate theoretical evaluation of rail stresses. However, so far Indian Railways has not acquired such capabilities. We follow a simplified method similar to that described in ORE D71 report which is based on the method prescribed by Eisenmann based on the classical method originally proposed by Timoshenko and Langer.

Calculation of rail stresses is required for designing a rail section for carrying a particular axle load,.

8.2 Considerations for Rail Design :

Important properties forming the basis of rail design are illustrated below:

(i) **Sectional Properties :** The sectional properties used in calculation of rail stresses are sectional area, moment of inertia and section modulus. For a given rail, the sectional properties increase with per meter weight of the rail.

(ii) **Ultimate Tensile Strength (UTS) :** Minimum UTS specified in IRS-T-12-2009 is 880 MPa (90kg/mm^2) and 1080 MPa (110 kg/mm^2) for 880 grade steel and 1080 Cr grade steel respectively.

(iii) **Yield Strength (YS) :** Yield strength for rail steel depends upon the quality of steel and its microstructure. The Yield strength can vary largely for the same UTS. For the rail steel being manufactured by BSP(Bhilai Steel Plant) the yield strength is about 52% of the UTS. As per IRS-T-12-2009 the yield strength of 460 MPa (46.8kg/mm^2) and 560 MPa (57.1 kg/mm^2) is specified for 880 grade and 1080Cr grade steels respectively. For the rails produced by European and Japanese rail manufacturers the yield strength of rail is in the range of 60 to 65% of UTS for high strength rails.

(iv) **Endurance Limit (Fatigue Strength) :** The endurance limit is the stress limit which can be applied

to a material under cyclic loading, as in case of rail under repeated loading, without failure of the material. In the tests conducted by RDCIS (The Research and Development Centre for Iron and Steel) on the rail steel produced by BSP, the endurance limit of 90 UTS rail has been found as 333 MPa.

(v) Track Modulus : Track modulus is defined as load required per unit length of track to produce unit vertical depression of track. Following values are used for 60kg rails based on report no CT-12 of RDSO.

Table 8.1

Sleeper Density	Track Modulus in kg/cm/cm	
	Initial (for 4 t load)	Elastic (for load beyond 4 t)
1540	125	425
1660	135	540

Other properties that influence the performance of rail are fracture toughness and growth rate of fatigue cracks, which primarily depend upon chemical composition and microstructure of rail steel. This aspect is deliberated in brief in chapter 9.

8.3 Type of Rail Stresses :

Rail is subjected to following type of stresses:

(i) Bending and Torsional stresses due to wheel loads

(ii) Dynamic effect of wheel loads (as per RDSO report C-100 for BG on IR)

(iii) Thermal stresses due to variation of rail temperature over the stress free rail temperature in long welded rails

(iv) Residual stresses which are induced in the rails during the process of manufacturing

(v) Miscellaneous factors like flexed laying of rails in curves, one sided sun radiation etc.

(vi) Rail wheel contact stresses

The rail stresses due to factors (i) to (v) are termed as **bulk stresses** as they are present in the bulk of the rail cross section. The stresses due to factor (vi) are only present in the rail wheel contact zone, hence these stresses are termed as **contact stresses**.

8.3.1 Effect of Increase in Axle Load and Speed

The increase in axle load and speed results in the increase of both static as well as dynamic components of wheel load. The increase in static component is proportional to the increase in axle load but the increase in dynamic component is disproportionately high. This results in accelerated deterioration of track geometry and faster wear and tear of rail and other track components.

Results of some of the studies conducted by various research organisations indicate that:

(i) Increase in axle load from 22.9 t to 25 t may translate in damage to track that could be as much as 20% higher though the increase in load is only about 9 %.

(ii) Studies reported in ORE D/141/RP1 indicate that increase in axle load from 20t to 22 t (10% increase) is likely to result in increase in fatigue failures by 30-40%.

(iii) Studies reported in ORE D/141/RP5 indicate that cost of maintenance increases by about 37% for 10% increase in axle load.

8.3.2 Dynamic Augment

On Indian Railways the dynamic augment is considered on the basis of RDSO research report C-100(Fig.8.1). The method adopted relies only on the speed for a particular track structure and vehicle. The results of C-100 were obtained on the basis of tests carried out on track & vehicles available about 4 decades back. There is a need to adopt a more rational approach for calculating dynamic augment.

Dynamic Augment in Wheel Loads - Percentage
(To be used only for similar vehicles)

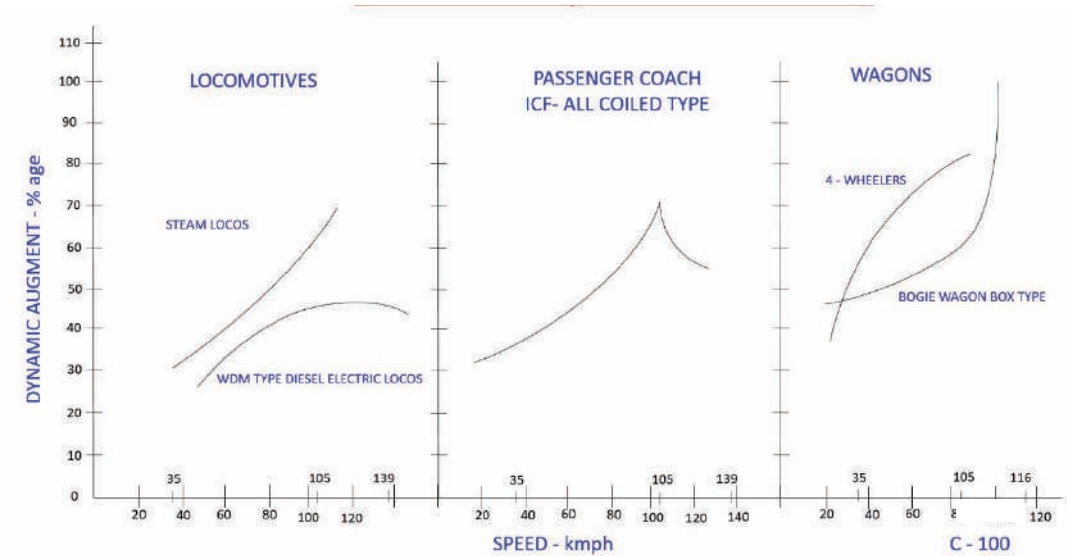


Fig 8.1 Dynamic Augment of Wheel Load as per RDSO report C-100

RDSO had conducted some trials by using WILD (Wheel Impact Load Detector) in June 2005 and reported dynamic augment as below:

Table 8.2

Rolling Stock	Speed(Kmph)	Dynamic Augment Using WILD
Box N	75	55%
Box NHS	75	50%
WDM2	110	95%
BCN	75	50%

On European Railways, a probabilistic concept of Dynamic Amplification Factor (DAF) which depends upon train speed, the track quality and a chosen factor t is used. The formula is as below :

$$DAF=1+t\Phi \text{ ..... if } V \leq 60 \text{ kmph}$$

$$DAF=1+t\Phi\left(1+\frac{V-60}{140}\right) \text{ ..... if } 60 \leq V \leq 200 \text{ kmph}$$

Table 8.3

Probability	t	Application
68.3%	1	Contact stress, subgrade
95.4%	2	Lateral load, ballast bed
99.7%	3	Rail stresses, fastenings, supports

Table 8.4

Track Condition	Φ
Very Good	0.1
Good	0.2
Bad	0.3

t = multiplication factor of standard deviation which depends upon the confidence interval. Since the rail is so important for safety and reliability of rail traffic a value of 3 is recommended for rail stresses as the chance of exceeding the maximum calculated stress is only 0.15%

Φ = factor depending upon track quality
V= train speed (Kmph)

On Indian Railways there is a need to revisit the concept of dynamic augment to make it more rational and scientific.

8.3.3 Bending Moment and Deflection

The bending stresses can be calculated by treating rail as a beam on elastic foundation (Fig 8.2). The stresses in rail due to single wheel load can be calculated by the solution of following differential equation :

$$EI \frac{(d^4w)}{(dx^4)} + Kw = 0 \quad \text{..... (i)}$$

w (x) = deflection at distance x
EI = bending stiffness of rail
K = track modulus

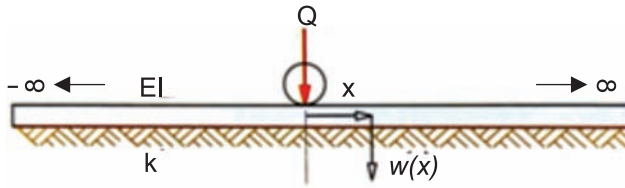


Fig. 8.2 Infinite Beam on Elastic Foundation Model

Solution of above differential equation yields:

Bending moment $M(x) = \frac{QL}{4} \mu(x)$; and..... (ii)

Deflection $w(x) = \frac{Q}{2KL}\ \eta(x)$ ..... (iii)

Where Q = effective wheel load (including dynamic augment)

L = Characteristic Length

$= \sqrt[4]{\frac{4EI}{K}}$ ..... (iv)

Shape functions

$$\mu(x) = e^{-\frac{x}{L}} \left[\cos \frac{x}{L} - \sin \frac{x}{L}\right], \quad x \geq 0 \text{ ; and}$$

$$\eta(x) = e^{-\frac{x}{L}} \left[\cos \frac{x}{L} + \sin \frac{x}{L}\right], \quad x \geq 0$$

The shape functions μ(x) and η(x) represent heavily damped harmonic waves with wavelength 2πL, they are therefore also a good tool for the approximation of finite beams with a central wheel load, provided the length of the beam is greater than 2πL.

The relative deflection and relative bending moment in a LWR due to a concentrated load, as calculated from equation (ii) and (iii), can be shown graphically as in Fig 8.3

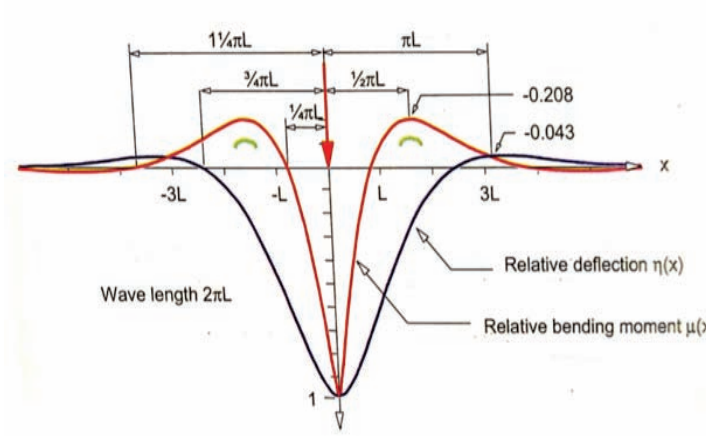


Fig. 8.3 Relative Deflection and Bending Moment in LWR track due to a concentrated Wheel Load

The bending moment and deflection calculated from equations(ii) and (iii) are modified to include the adjacent wheel effect and leading wheel effect. To include the effects of adjacent wheel and leading wheels, the concept of virtual wheel load or Talbot Load is used in stress calculations (para 8.3.4.3).

8.3.4 Rail stresses due to combined vertical and lateral wheel load

As shown is fig. 8.4 the vertical wheel load (Q) is always eccentric to the axis of rail. Rail is also subjected to horizontal lateral force (y). The maximum lateral flange force per axle can be calculated by Prud' Homme's formula as below:

Lateral Force (y) = α (10+Q/3),

Where Q is axle load and α is a factor to take into account the vehicle characteristics. On IR, α is taken as 0.85

The eccentric vertical wheel load and horizontal wheel load can be decomposed into partial loads (Fig 8.4) for the purpose of finding out the distribution of bending stresses in the rail cross section.

The bending stresses are calculated for each of the partial loads. After this the bending stresses are superimposed. The partial stresses are calculated as per the method prescribed by Eisenmann which is based on the method originally proposed by Timoshenko and Langer.

Partial Load I : The rail is loaded by a vertical force acting downwards at the axis of symmetry of the rail cross-section. The stress distribution in the rail due to such load differs from the stress distribution that could be expected on the basis of prismatic beam theory, which assumes plane sections to remain plane. Besides a maximum tensile stress at the underside of the foot and a maximum compressive stress at the top of the head of the

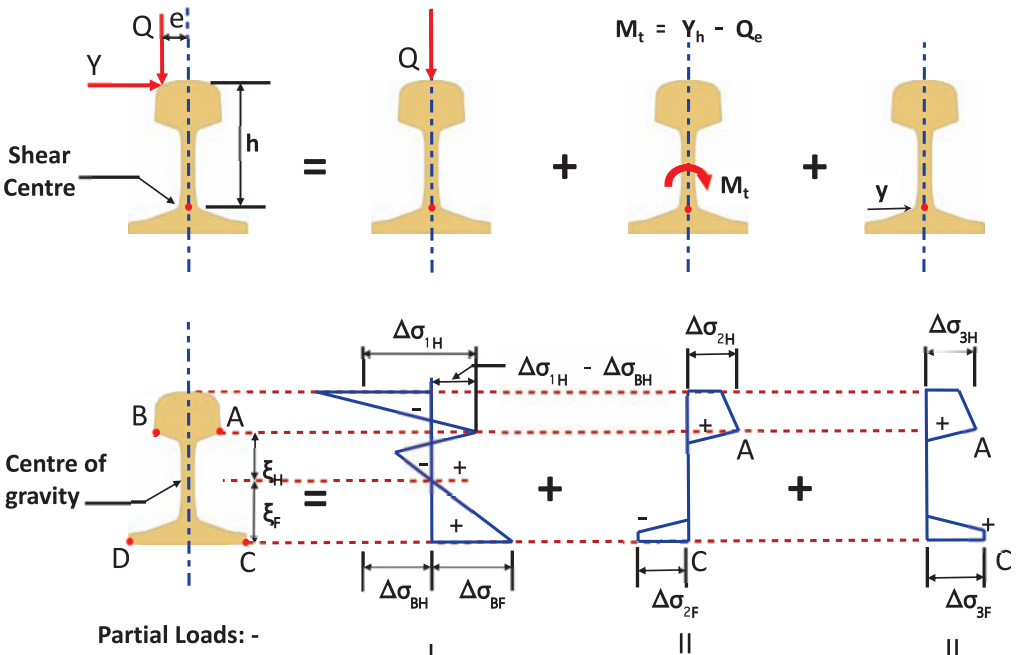


Fig 8.4 Load Decomposition for calculation of Rail Stresses

section, there also occur large tensile stresses directly below the head in consequence of the particular cross-sectional shape. This phenomenon was first investigated by S.Timoshenko and B. F. Langer in 1931, who explain it follows : The rail as a whole behaves primarily as a flexural beam. As a result of this a linear stress distribution develops over the depth of the rail section, with compression in head and tension in foot. In addition, a secondary effect occurs. Since the web elastically supports the head, the head can behave in the manner of a beam elastically supported by the web.Under the influence of the vertical wheel load the head sinks (indents) into the web. This results in extra compression at the top of the head and extra tension at the underside of the head. The overall stress configuration is obtained when the primary and the secondary flexural behaviour are superimposed upon each other. The resultant stress distribution is shown in the fig. 8.4 for **partial load I.**

Partial Load II : The torsion moment causes stresses as shown in fig.8.4 for Partial Load case II. For calculation of these stresses the rail is thought to be clamped at rail seats and the torsion moment is thought to act on the rail at the midpoint between two sleepers.

Partial Load III : The stresses caused by the horizontal load acting through the shear centre are also shown for this load case in the fig 8.4

Now to get the resultant stress distribution the partial stresses for all the three partial loads are superimposed. Superimposition of stresses is valid as long as the stresses remain in the linear zone.In view of certain assumptions when calculating $\Delta\sigma_{1H}$ to $\Delta\sigma_{3F}$, these values are about 10% too high in comparison with the measured values. The critical points where stresses would be maximum due to eccentric wheel load are marked as A, B, C and D in the fig. 8.4.

The resultant stresses are therefore :

$$\sigma_{HA,B} = -\sigma_{BH} + 0.9\,[\Delta\sigma_{1H} \pm \Delta\sigma_{2H} \pm \Delta\sigma_{3H}]$$

$$\sigma_{FC,D} = +\sigma_{BF} + 0.9\,[\quad \mp \Delta\sigma_{2F} \pm \Delta\sigma_{3F}]$$

The upper sign belongs to the first mentioned index of the stresses.

$\sigma_{HA,B}$	Resultant stress at two faces of rail head
$\sigma_{FC,D}$	Resultant stress at two faces of rail foot
σ_{BH}	Bending stress in rail head
σ_{BF}	Bending stress in rail foot
$\Delta\sigma_{1H}$	Additional tensile bending stress on the underside of rail head
$\Delta\sigma_{2H}$	Bending stress in rail head due to torsional moment due to eccentricity of vertical load and horizontal load
$\Delta\sigma_{2F}$	Bending stress in rail foot due to torsional moment due to eccentricity of vertical load and horizontal load
$\Delta\sigma_{3H}$	Bending stress in rail head due to horizontal load at shear centre
$\Delta\sigma_{3F}$	Bending stress in rail foot due to horizontal load at shear centre

For calculation of rail stresses, the sectional properties like Moment of Inertia and Section Modulus of rail are considered as 90% of the values of new rail section.

8.3.4.1. Stresses in Rail Foot Centre

On detailed theoretical analysis of bending stresses and actual measurement of stresses, it has been found that when the bending stresses under the influence of vertical wheel load (Partial load I in para 8.3.4) are combined with static normal stresses like residual stresses and thermal stresses in LWR, the resultant stresses at rail foot centre are the maximum bulk stresses anywhere in the rail cross section.The total stress at rail foot centre, therefore, determines the rail strength. The stress at rail foot centre is the sum total of (1) bending stress due

to concentric vertical wheel load , calculated by using ordinary bending theory ,(2) Residual stress at rail foot centre , and (3) thermal stresses in LWR. Lateral force on the rail or electricity of the vertical wheel load has no effect in the effective resultant stress at rail foot centre. However, knowledge of locations of maximum stresses due to bending effect of eccentric wheel load is of practical importance to understand the vulnerability of rail due to local damage at these locations. For example, during handling of rails by steel rail tongues the locations marked as A and B (fig.8.4) on the underside of rail head may get locally dented. High bending tensile stresses at such dented locations may make rail prone for fatigue fractures from such locations.

8.3.4.2. Maximum Bending stress in Rail Foot Centre

According to the Eisenmann method, the greatest expected dynamic bending tensile stress in the rail foot centre can be determined from :

$\sigma_{max} = DAF \cdot \sigma_{mean}$

The mean value of the rail bending stress follows from equation (ii):

$$\sigma_{mean} = \frac{QL}{4Z_{yf}} \quad \ldots\ldots\ldots\ldots \text{(v)}$$

(Maximum bending moment $M_{max} = QL/4$)

DAF = dynamic augment factor,
Q = effective virtual wheel load [N]; (Talbot Load)
L = characteristic length[m],
Z_{yf} = section modulus, relative to the rail foot [m^3]

Influence of parameters on bending stress :

The mean value of the rail bending stress in equation (iv) can be written as follows with the help of (iv)

$$\sigma_{mean} = \frac{Q}{A} \cdot \frac{A\sqrt[4]{I}}{4z_{yf}} \cdot 4\sqrt{\frac{4\,Ea}{k_d}} \quad \ldots\ldots\ldots\ldots\ldots \text{(vi)}$$

In which:

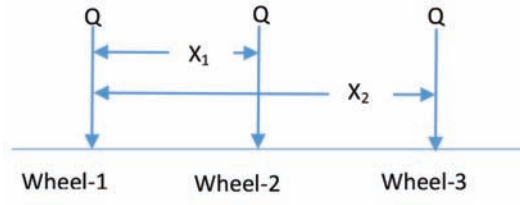
Q = effective virtual wheel load [N]
A = rail cross-sectional area [m^2];
I = moment of inertia of rail [m^4];

Z_{yf} = section modulus of rail relative to rail foot [m^3];
E = modulus of elasticity of rail steel [N/m^2]
a = sleeper spacing [m]
k_d = spring constant of discrete support [N/m] (k_d = K/a)

The first factor in equation (vi) has the dimension of a stress, the second factor is constant for geometrically identical rails, and the third factor is independent of the rail dimensions. This illustrates that if for operating reasons on a particular line the effective wheel load has to be permanently increased, the mean bending stress in the rail can be kept constant if the rail weight is increased in proportion to the wheel load.

8.3.4.3 Calculation of Rail Stresses at Rail Foot Centre:

(i) Effect of other wheel loads on net BM under a wheel.



Q= wheel load including Dynamic augment (DAF) =

$$\frac{Axle\ load}{2} x(1 + DAF)$$

BM at X distance away from a wheel

$$BM_X = \frac{QL}{4} e^{-x/L}(\cos\frac{x}{L} - \sin\frac{x}{L}) \text{ [eq. (ii)]}$$

$$= \frac{QL}{4}\mu(x) \text{ Where } \mu(x) = e^{-x/L}(\cos\frac{x}{L} - \sin\frac{x}{L}) \qquad x \geq 0$$

When we are calculating the BM under wheel-1 the presence of wheel-2 and wheel-3 at distance x_1 and x_2 respectively will affect the net load/ BM under wheel-1 provided x_1 and x_2 are within $\frac{5\pi}{4}$ distance from wheel-1 (See fig. 8.3). As evident from fig. 8.3, the BM changes sign at distance $\frac{\pi L}{4}$. From $x = \frac{\pi L}{4}$

to $x = \frac{5\pi L}{4}$ the BM is negative and it is positive from x = 0 to $x = \frac{\pi L}{4}$

BM under wheel-1

$$= \frac{QL}{4} + \frac{QL}{4} e^{-x_1/L}\left(\cos\frac{x_1}{L} - \sin\frac{x_1}{L}\right) + \frac{QL}{4} e^{-x_2/L}\left(\cos\frac{x_2}{L} - \sin\frac{x_2}{L}\right) \qquad [\mu(0) = 1]$$

$$= \frac{QL}{4} + \frac{QL}{4}\mu_{12} + \frac{QL}{4}\mu_{13}$$

(μ_{12}= effect of wheel load 2 at location of wheel 1)

(μ_{13}= effect of wheel load 3 at location of wheel 1)

$$= \frac{QL}{4}(1 + \mu_{12} + \mu_{13})$$

Net virtual wheel load under wheel-1 will be

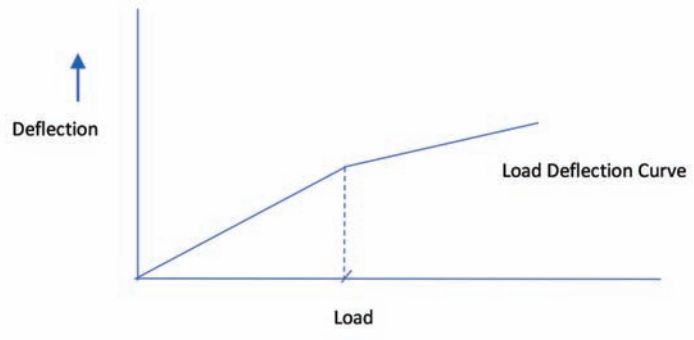
$$Q\,(1 + \mu_{12} + \mu_{13})$$

Note: 10% additional load will be considered if wheel is leading wheel. Intermediate wheels if spaced at distance more than $\frac{5\pi}{4}$ will also be considered as leading wheel.

(ii) Effect of double track modulus:

Track modulus is defined as load per unit length of rail to cause unit deflection of track.

Load deflection graph consist of 2 straight lines- one for initial loading and other for loading in elastic range.



Recommended values of track modulus (RDSO Report No. CT12)

SD	Initial (U_i) (for 4t)	Elastic (U_e) (for load beyond 4t)
1540	125kg|cm|cm	425 kg|cm|cm
1660	135kg|cm|cm	540kg|cm|cm

BM under Wheel - 1 for initial 4t load

$$= \frac{Q_i L_i}{4}(1 + \mu_{12i} + \mu_{13i}) \text{ ----------①}$$

Where Q_i = 4t

$L_i = \left(\frac{4EI}{U_i}\right)^{0.25}$ (Characteristic length corresponding to initial track modulus)

$$\mu_{12i} = e^{-x_1/L_i}\left(\cos\frac{x_1}{L_i} - \sin\frac{x_1}{L_i}\right)$$

(Effect of wheel Load - 2 at location of wheel Load - 1 due to initial load)

$$\mu_{13i} = e^{-x_2/L_i}\left(\cos\frac{x_2}{L_i} - \sin\frac{x_2}{L_i}\right)$$

(Effect of wheel Load - 3 at location of wheel Load - 1 due to initial load)

Virtual initial load = $Q_i(1 + \mu_{12i} + \mu_{13i})$----------②

$Similary\ BM\ under\ Wheel - 1\ for\ elastic\ load$

$$= \frac{Q_{eL_e}}{4}(1 + \mu_{12e} + \mu_{13e}) \text{ ----------③}$$

Where $L_e = \left(\frac{4EI}{U_e}\right)^{0.25}$ (Characteristic length corresponding to elastic track modulus)

Where $Q_e = Q - Q_i = (Q - 4)$

$$\mu_{12e} = e^{-x_1/L_e}\left(\cos\frac{x_1}{L_e} - \sin\frac{x_1}{L_e}\right)$$

$$\mu_{13e} = e^{-x_2/L_e}\left(\cos\frac{x_2}{L_e} - \sin\frac{x_2}{L_e}\right)$$

Virtual elastic load = $Q_e(1 + \mu_{12e} + \mu_{13e})$----------④

Total BM = Eq.1 + Eq.3 ----------⑤

Total Virtual Load Q_L (Talbot load) = Eq. 2 + Eq. 4 ----------⑥

Maximum Bending stresses due to vertical virtual wheel load Q_L

$$\sigma_{Max} = \frac{Total\ BM\ from\ equation\ (5)}{Section\ Modulus\ of\ rail}$$

The bending stresses calculated above are super imposed onto stresses due to thermal forces, residual stresses and stress due to unforeseen reasons. As maximum residual stress(of tensile nature) occur at rail foot centre (240 MPa, as considered by RDSO), the total stress at rail foot centre becomes the maximum bulk stress any where in the rail section. This stress is considered for rail design. The effects of eccentricity of vertical wheel load and horizontal force do not affect the stress at rail foot centre. The corners of bottom flange and corners of Rail head are other important locations where rail stresses are significant. Rail head undergoes secondary bending as it is elastically supported on web. This causes secondary tensile stresses at bottom corners of the Rail head. This is graphically shown in fig. 8.4. Rail stresses calculated for 22.9 t and 25 t axle load for 60 kg rail are tabulated in table 8.5 under para 8.4

8.3.5 Thermal Stresses

The temperature variation with respect to laying / de-stressing or stress-free temperature produces thermal stresses in long welded rails. Maximum variation in temperature occurs in temperature zone IV ($t_d = t_m + 5$ to $t_m + 10$ degree Celsius). The temperature stresses corresponding to maximum temperature variation works out as 11.32 Kg/mm^2.

8.3.6 Residual stresses

The internal residual stresses are generated in rail during cooling of rolled rail and straightening process after rolling. As per IRS-T-12-2009 the residual stress shall not exceed

250 MPa anywhere in rail section. The residual stress varies over a cross section of the rail and its principal direction is longitudinal. The distribution of residual stress on a cross section is such that the net force on this account is zero. On detailed measurements it is observed that the maximum residual stress occurs at rail foot centre and the nature of this stress is tensile. At other locations like edges of rail foot and bottom corners of the rail head the residual stresses are much less in magnitude and the nature is compressive. Thus, for the purpose of strength calculations the residual stress at rail foot centre (tensile in nature) is of importance. This stress is considered as 240 MPa for rails manufactured by BSP.

8.3.7 Stresses due to other factors

Stresses may be induced in the rail due to many other factors such as flexed laying of rails in curve, one sided sun radiation etc. As per an estimate made at RDSO in 2006, stresses in the bottom flange of rails an account of flexed laying on a 4 degree curve for 52 kg and 60 kg rails are about 57 MPa & 61 MPa respectively. However, as per current practice RDSO limits the stresses due to unforeseen causes to 10% of the calculated bending stress at rail foot centre.

8.4 Rail stresses for 22.9t and 25t axle loads :

Rail stresses(kg/mm^2)at rail foot centre worked out for 60kg rail section for 22.9t & 25t axle loads for Indian railway track laid in temperature zone IV are tabulated in table 8.5.

The values of stresses in table 8.5 indicate that maximum stress generated in the rail due to various factors is more than the yield strength of 90 UTS rail even at speed of 50 kmph for 25t axle load.

It is important to note that the maximum contribution to stress in rail at rail foot centre is due to residual stress. This is more than the combined stresses due to wheel load and thermal stress in LWR. The residual stresses can be reduced up to 100-150 MPa by adopting improved manufacturing processes.

Table - 8.5

Axle Load (t)	25				22.9			
Speed (kmph) and DA(%)	50 (43%)	60 (47%)	75 (53.5%)	100 (72%)	50 (43%)	60 (47%)	75 (53.5%)	100 (72%)
Bending stresses due to wheel load	10.51	10.79	11.23	12.51	9.68	9.93	10.34	11.51
Residual stress	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
Thermal Stresses	11.32	11.32	11.32	11.32	11.32	11.32	11.32	11.32
Stresses due to unforeseen conditions	1.05	1.08	1.12	1.25	0.97	0.99	1.03	1.15
Total Stress	47.38	47.69	48.17	49.58	46.47	46.74	47.19	48.48
Yield Strength for 90 UTS	46.8							
Yield Strength for 110 UTS	57.1							

8.5 Stresses in the Rail Head (Rail wheel contact stresses) :

The concentrated load between wheel and rail causes a shear stress distribution in the rail head as depicted in figure below.

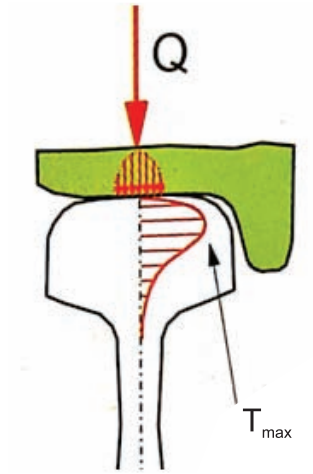


Fig. 8.5 Shear Stress Distribution in Rail Head

The maximum shear stress T_{max} occurs at some depth (4 to 8mm) from surface. This shear stress may give rise to fatigue fracture in the rail head. This problem is more serious in the case of high wheel loads or relatively small wheel diameters.
The maximum shear stress in the rail head can be approximated sufficiently by using Boussinesq half space theory. The maximum shear stress in the rail head can be estimated as

$\tau_{max} = 0.3\, q_{mean}$

Where, mean contact stress $q_{mean} = \sqrt{\dfrac{\pi EQ}{64\,(1-\nu^2)rb}}$

(from Boussinesq's half space theory)

Q = dynamic wheel load

r = wheel radius

2b = width of wheel/ rail contact area

(≈ 12mm for wheel diameter of about 1000mm)

E = modulus of elasticity of rail steel

v = Poisson's ratio

With, E= 210.000 N|mm^2, v = 0.3, b = 6mm,

$$q_{mean} = 1374\sqrt{\frac{Q}{r}}$$

Where, Q [KN], r [mm] and q_{mean} [N|mm^2]

So, T_{max} can be written as

$$T_{max} = 412\sqrt{\frac{Q}{r}}$$

Permissible shear stress : on the basis of Von Mises yield criteria, the permissible shear stress may be expressed as:

$$\bar{\tau} = \frac{\bar{\sigma}}{\sqrt{3}}$$

In which $\bar{\sigma}$ is the permissible tensile stress. On account of the fatigue nature of the load, the permissible tensile stress should, according to tests, be fixed at 50% of the ultimate tensile strength (for the purpose of calculating permissible shear stress) σ_t of rail steel, thus resulting in:

$\bar{T} = 0.3\sigma_t$

For 880 grade steel $\bar{T}$ = 0.3x 880
= 264 N|mm^2

The permissible shear stress $\bar{T}$ should be more than the maximum shear stress τ_{max} in rail head.
The value of Q being used on Indian Railways for calculation of shear stress is static wheel load. However, logically the contact stresses should be worked out for the dynamically augmented wheel load.

For Indian Railways for 25 t load, 914 mm wheel dia (minimum wheel dia as per IRSOD) and 100 kmph speed (DAF for 100 kmph speed is taken as 0.72) the maximum shear stress can be calculated as below.

$$T_{max} = 412 \sqrt{\frac{\frac{25}{2} \text{ x } 1.72 \text{ x } 9.81}{\frac{914}{2}}}$$

$$= 412 \frac{\sqrt{12.5 \text{ x } 9.81 \text{ x } 1.72}}{\sqrt{457}} = 286 \text{ N/mm}^2$$

Which is about 8 % more than the permissible stress of 264 N/mm^2 for 880 grade steel.

Thus, from above calculations it can be deduced that for 25t axle load, UIC60 kg rail with 880 grade steel is found to be inadequate from consideration of shear stress in rail head.

■ ■ ■

CHAPTER - 9

NEW DEVELOPMENTS IN RAIL STEEL

9.1 Introduction:

Most widely used rail steel has pearlite micro structure. The mechanical properties of these steels are largely governed by the distance between the cementite (Fe_3C) lamellae, their thickness and by the grin size. Different microstructures can be achieved for steels by controlling the rate of cooling.

The rail steal has to fulfil some primary requirements. Yield point and tensile strength increase as the distance between the lamellae decreases. The rail should be able to withstand wear and RCF (Rolling contact Fatigue) damage. In addition, the rail steel should be sufficiently resistant to corrosion.Rail steel should have adequate toughness so that the rail is able to sustain large size of cracks before it gets fractured. Toughness is primarily governed by the thickness of the cementite lamellae and the grain size.

9.2 Rails for higher axle loads :

Indian Railway tracks are being called upon to carry higher axle loads and higher speeds with better reliability. The dedicated freight corridors are being built to carry upto 32.5T axle loads. For such load the commonly used grades of steel with 880Mpa UTS are found to be inadequate. For heavy duty tracks, special steel grades with minimum tensile strength of 1100MPa or more have been developed. This is achieved by increasing the silica content, adding chromium and sometimes vanadium.

Pearlite microstructure is limited to about 400BH hardness. Harder rail steels need to have another type of microstructure. The banitic microstructure offers a potential to combine high strength and hardness with good toughness properties. Bainitic rail steels offer

higher resistance against RCF defects. Currently, baintic rails are not industrially produced on large scale because their manufacturing technology in more complex.

9.3 Heat Treated Rails :

Properties of rail steel like hardness wear resistance & tensile strength can be improved by Heat treatment. This process was developed in 1970s. Heat treatment is mainly applied to rails used in heavy duty tracks or the tracks with sharp curves and turnouts. Compared to alloying, heat treatment has the big advantage that toughness can sustain larger crack size before it gets fractured. Heat treatment can be applied to either the whole section or to just the rail head. Tensile strength upto 1200-1350N/mm^2 and hardness upto 350-400 BHN can be achieved by heat treatment. On IR head hardened rails have been used with advantage on some of the Ghat sections.

The rail can be heat treated either after cooling and straightening outside the rail production line (off-line method) or when it comes directly from the rolling mill (in-line method).

9.3.1 Off-line hardening

The cold finished rail is taken to the hardening plant and the head or the total cross-section is heated by induction in 2-6 minutes to the austenitising temperature of 850-950^{0}C. This is followed by accelerated cooling by compressed air, water spray or water mist down to 650-500^{0}C. This temperature is maintained until a fully pearlitic structure is attained.

In addition to the refinement of the pearlite inter-lamellar spacing, the pearlite block size becomes smaller. The microstructure and hardness shall change gradually from the head to the web.

9.3.2 In-line hardening

The rail is taken directly from the rolling mill and brought to the hardening plant at a temperature beyond 800^{0}C. The quenching may proceed continuously similar to the off line plant, or the rail is quenched in its entire length at once.

The establishment of technologies for producing clean steal and development of heat treatment technologies of rails in Japan and elsewhere since 1970s have greatly improved the ability of rails to withstand wear and RCF damage. However, use of heavier freight wagons (upto axle load of 40T) have necessitated development of rails with even better wear resistance and RCF damage resistance. Some of the developments are described below.

9.4 Premium rails :

Premium rails is a term used to refer to the rail made of high tensile strength steel. The ultimate tensile strength of these rails is around 1300 Mpa. Such high strength is achieved by reducing the spacing between the pearlite lamellae by controlling the growth rate of pearlite. Another way of improving the properties is through alloying elements such as chromium and nickel.

9.4.1 Super Pearlite Rail (SP rails)

NKK (Nippon Kaiji Kyokai) has developed a high strength pearlitic rail named the SP (Super Pearlite) rail which has superior wear and RCF damage resistance and is most suitable for heavy haul operations. Extensive research on the relation between microstructural factors and wear and RCF behaviours revealed that refining the pearlite colonies greatly improves wear and damage resistance. In the SP rail, the pearlite colonies are refined through microstructural control by means of micro alloying design andTMCP (Thermo Mechanical Controlled

Processing). Carbon content is increased to about 0.82%.

9.4.1.1 Microstructural Control

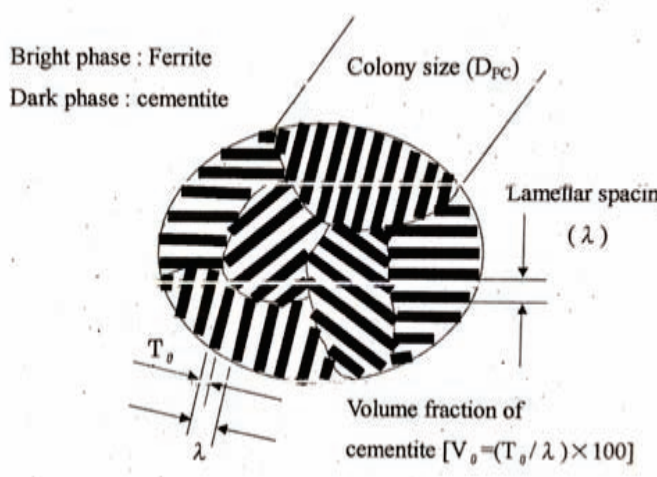


Fig 9.1Schematic drawing of Pearlitic Structure

Above figure schematically shows, the basic factors that define the microstructure of pearlitic steel are colony size (D_{PC}) lamellar spacing (λ) and volume fraction of cementite. The rail is subjected to slack quenching from the austenite state at an appropriate cooling rate. During the cooling process, the lamellar spacing (λ) is refined, and the hardness and wear resistance are improved. The lamellar spacing in the state of the art heat treated rail is as fine as about 0.1μm, which is nearly the limit that is industrially achievable.

9.4.1.2 Properties of SP Rail

Table below compares the representative tensile properties of the SP rail with those of the conventional heat – treated rail (THH370N)

	YS (MPa)	TS (MPa)	El(%)
SP	876	1312	16.0
THH370N	900	1303	13.5

YS = Yield strength, TS = Tensile strenght, El = Elongation

The strength of SP rail is almost the same as that of conventional heat treated rail. but its elongation is superior. The SP rail maintains the hardness deeper into the rail body.

SP rails exhibit better wear resistance as compared to conventional heat treated rails. The wear resistance of SP rails is improved by about 20 to 25% over that of the conventional heat treated rail. RCF damage resistance of SP rails is better by 40 % over the conventional heat treated rails. SP rails also exhibit satisfactory weldability.

9.4.2 Hyper-Eutectoid rails (HE Rails)

These rails are characterised by the application of effect of increased hardness of a rolling contact surface caused by the promotion of work- hardening of contact with train wheel. Carbon content in these rails varies from 0.9 % to 1 %. Conventionally, increasing the hardness of the steels has been considered an effective means for improving the wear resistance of rails. However, detailed investigation on different type of rails has shown that the relationship between increased harness and better wear resistance is not linear. In fact control of micro structure and the amount of carbide in the steels largely governs the wear resistance.

HE rails exhibit hardness of 370-420BHN. Tensile strength of 1350-1440 MPa and total elongation of 10% or more is achieved in these rails by controlling the micro alloys much as Mn, Cr, etc. these rails have excellent wear resistance as well as resistance to RCF damage.

9.5 Low Carbon Carbide- free Bainitic Steel :

Inspite of extensive improvements in the properties of Pearlitic rails, railway infrastructures are besieged with the problem of RCF related damage and resultant failures of rail. Rail failures pose not only safety challenges but also reduce the availability of railway track for movement of trains. The cost of repairs of failed rails is quite high. Therefore, it has been a continuous quest of rail technologists to improve rail metallurgy with aim of improving its performance with respect to RCF damage. This has led to development of Bainitic rail steel. In this type of rail steel alloying additions are made to prevent the formation of carbides, resulting in very fine interlath films of austenite which are retained between the ferrite plates. The rails made with this steel show such better toughness and better resistance to RCF induced damage in laboratory testing.

9.6 Indian Railway Scenario :

On Indian Railway 880 grade (equivalent to R 260 grade) rails of IRS 52kg and UIC 60kg section are widely used. On KK line of East Coast Rly. head hardened rails were used which gave satisfactory performance ad after completion of their life they have been replaced by 880 grade rails. Bhilai steel plant has planned to install facilities to produce heat treated rails in new rolling mill set up with universal rolling mill. In order to improve performance of rails, various micro-alloyed rails have been developed by SAIL in association with IR.

High Strength Chrome - Vanadium (Cr-V) 110 UTS Rails :

In order to cater for high axle load and to reduce wear and enhance service life of rails, high strength and wear resistant Chrome- Vanadium rail have been developed by SAIL. Chromium in combination with

Vanadium imparts strength and hardenability required for rails which have minimum UTS of 1080 MPa, YS of 560MPa and hardness of 320 BHN as per IRS T-12-2009. However, chemistry of this rail is similar to R32Cr of the European Specifications. Due to higher levels of chromium, weldability for this rail has been a challenge. It is learnt that on European network, use of this rail is now being phased out and heat treated rails are being preferred.

Corrosion Resistant Rails

Two corrosion resistant rail chemistries have been developed. Corrosion resistant Copper- Molybdenum (Cu-Mo) rail chemistry was developed in association with RDCIS, Ranchi (R&D Wing of Steel Authority of India Limited) and Bhilai Steel Plant. Another rail chemistry i.e. Nickel- Chromium- Copper (Ni-Cr-Cu) was developed in collaboration with IIT/Kanpur with SAIL as industrial partner as a part of Technology Mission of Railway Safety. These rails not only have Superior corrosion resistant properties but have excellent mechanical properties. These rails are under final stage of field trial.

Fracture Resistant Niobium Rails

In order to reduce incidents of sudden rail fracture i.e. transverse fractures without any apparent origin and to impede flaw growth, fracture resistant Niobium rails have been developed in year 2002 and laid in track in Kharagpur Division of South Eastern Railway for field trial where they have performed satisfactorily.

Wear Resistant Vanadium Rails

Vanadium rails were developed to enhance wear resistance and provide higher YS/UTS ratio for fulfilling requirement of higher yield strength. Vanadium rails were produced and rolled into UIC 60 Kg rail section and laid in Chakradharpur Division of

South Eastern Railway for conducting field trials. So far, these rails have performed satisfactorily.

Improved chemistry of rail

Further to the improved mechanical properties of V and Nb rails, micro alloyed rail to improve fracture toughness and weldability, and to reduce fatigue crack growth rate is under development by SAIL.

It is noted that the above rails are at different stages of development/ field trial. It is also noted that grades other than 1080Cr has strength superior to the existing 880 grade, but would not be adequate to cater for 25t or higher axle load operation.

■ ■ ■

Annexure 1

GUIDELINES

FOR

HANDLING AND STACKING OF RAILS

OCTOBER - 2014
(No. CT-35)

RESEARCH DESIGNS AND STANDARDS ORGANISATION

LUCKNOW – 226011

INSTRUCTIONS FOR HANDLING AND STACKING OF RAILS

1.0 Introduction :

1.1 On Indian Railways, various grade and sections of Rails are in use depending upon the traffic requirements. Use of higher UTS Rails has been necessitated to meet the requirement of traffic. Now almost all the new rails being manufactured are of 90 UTS. The 72 UTS rails (also known as MM Rails) used earlier were more ductile, hence were not susceptible to sudden fractures. Rails of higher UTS (90 and above), being brittle in nature, are susceptible to sudden fracture from locations of even minor dents. The presence of dent/deformation at the edge of the rail foot has been found as the main cause of premature fractures investigated by RDSO. The dent/deformation on the edge of the rail foot is formed mainly due to rubbing of rails during unloading and handling of rails at site. This is indicative of fact that due care is not being taken in field in handling of rails. Improper handling may cause bending, indentation or damage to surface, leading to premature failure of rails. As such, handling of rails with care and attention is important for achieving required service li fe of rails. It is essential that P. Way officials at all levels are sensitized regarding precautions to be taken during unloading and handling of rails to prevent development of defects leading to premature or sudden failures.

1.2 The instructions regarding handling of rails are available in various guidelines/ Manuals.

(a) The detailed guidelines for handling of Rails were issued by RDSO vide letter no. CT/Rail/Handling dated 13.11.2006.

(b) Para 1.1.3 of Manual for Ultrasonic Testing of Rails and Welds (Revised - 2012) states that incorrect handling of rails may cause plastic deformation, scoring and denting of rails.

(c) Para 254 and Para 255 of IRPWM contains the guidelines on stacking of rails and the precautions to be taken during handling of rails in general.

(d) Para 310 of IRPWM covers the guidelines on unloading of rails.

These guidelines shall be strictly adhered to minimize formation of dent/ deformation at the edge of the rail foot and other damages to rails.

1.3 The damage to rails including formation of dent/deformation at rail foot can be detected by inspecting rails before laying in track. Therefore, it becomes essential that Rails are thoroughly inspected at the level of SSE/P. Way for presence of damages to rails during transportation, unloading and handling, if any, before laying in the track. In case any damage including dent/deformation is noticed, such rails should not be used in track without removal of damaged portion of rails.

1.4 These comprehensive guidelines are being issued for sensitizing the field staff and other agencies involved in handling and laying of rails, so as to avoid damage to rails.

2.0 Handling and Stacking of Rails :

2.1 Stacking and Handling of rails in rail manufacturing plants, Flash Butt Welding plants and other Bulk Storage locations:

2.1.1 Stacking of Rails and welded Panels :

(i) The rails shall be stacked on level and well drained base platform. For stacking on the level ground,

unserviceable 90R or 52 kg rails should be embedded in the concrete bed of M- 20 grade concrete keeping rail head embedded in concrete and rail flange projecting above concrete surface as shown in Drawing No. RDSO/T- 6219 (Annexure-I). Intermediate distance between them should be 4.0 m. A slope of 1:400 may be given in the concrete bed across the length of rails for drainage of water as mentioned in the drawing.

(ii) Mild steel flats of 100 x25 mm size should be used between two successive layers of rails and kept at a distance not more than 4.0 m centre to centre. Number of layers in a stack should not be more than 10.

(iii) One rail panel should be reduced after every third layer to achieve proper stacking of rails.

(iv) Drawing no. RDSO/T-6219 (Annexure- I) shall be followed for stacking of free rails and welded panels.

2.1.2 Handling of Rails :

(i) Rail should be lifted preferably through magnetic chucks. In case magnetic lifting devices for rails cannot be provided, all handling of rails shall be done with synchronized electric hoists and spreader beams. This can be possible only when rails are stacked in layers properly.

(ii) Slinging Principle:

The single point slinging increases risk of excessive bending and surface damage to the rails. The overhang portion of rail beyond the outer lifting point should not be greater than one- half the distance between two adjacent lifting points. Therefore, recommended locations of lifting points for various rail lengths shall be as per Table 1:

Table - 1

Rail length (m)	No. of lifting points	Distance between two adjacent lifting points (m)	Max. rail end overhang (m)
12-13	2	6-6.5	3-3.25
26	4	6.5	3.25
39	6	6.5	3.25
130	20	6.5	3.25
260	40	6.5	3.25

2.2 Handling of Single/Three Rail Panels :

2.2.1 Loading of single rails/three rail panels :

(i) Wagon should be fit for loading and transportation of rails. Minimum three bolsters/cross beams, one at center and others at maximum inter-distance of 5.0m should be available in wagon platform to give it a uniform base for rail placement. The rails should be loaded to obtain equal overhang at each end beyond the end bolsters. Availability of both end bulk heads in BFRs shall be ensured before loading of rails.

(ii) All loaded rails should be tightened by suitably flexible but strong MS strip. While binding with MS strip, a card board or any other non-metallic material should be provided between rails and strip, so that abrasion/corrosion is avoided.

(iii) Mild steel spacers made of flat of 100x25 mm size should be provided between two layers of rails at every 4.0 m distance interval.

(iv) Shorter rails should be placed in upper layers so that each successive layer is of same or decreasing width to ensure centric and stable loading of wagons.

2.2.2 Unloading of single rails and 3 rail panels :

(i) Rails shall be unloaded fairly opposite to the position where they are to be laid. Care shall be taken to avoid unloading of materials in excess of actual requirement so as to avoid double handling.

(ii) Two or more ramps should be made in the middle of BFR using unserviceable rails, with a maximum distance of 6.5 m between them. Intermediate supports using pre-fabricated props etc. may also be given below the ramps to prevent excessive sagging. Proper greasing should be done on top surface of ramps for lubrication and easy sliding of rails downwards.

(iii) At the bottom end of ramp, gunny bag should be provided so that rails do not get damaged while unloading.

(iv) Rail should be held by 2 or 3 rail tongues in middle portion and placed on the ramp. Both ends of the rail should be tied by manila rope. After placing on ramp, rails should be slid slowly by gradually releasing manila rope to reach the rails to placement location.

2.3 Handling of Long Welded Rail Panels :

2.3.1 Loading of long rail panels in EURs :

(i) Availability of proper end unloading rakes as per standard arrangement shall be ensured for loading of long rail panels. The speed certificate and sanction of competent authority for operation of rake must be available.

(ii) The rake must be checked thoroughly before loading. All rollers should be available at their respective locations. Not even a single roller shall be missing or ineffective. It should also be checked that no roller is jammed i.e. it should be free to rotate.

(iii) Rail panels should be li fted by multiple slinging arrangements keeping intermediate distance not exceeding 6.5 m centre to centre following slinging principle mentioned at Para 2.1.2 (ii) above.

(iv) Shorter length panel should be loaded in pairs and placed on same tier keeping equal distance from center so that they can be unloaded at same location.

(v) Dynamic and localized loading in EUR rake shall be avoided.

2.3.2 Unloading of long rail panels from EURs :

(i) Unloading of rails from the End Unloading rake shall be done in traffic block.

(ii) The unloading shall be started from Top layer panels. The protective rail and flap door of bulk head shall be opened during block only for the layer to be tackled. Once all the rails of that layer are unloaded, next layer door shall be opened for unloading.

(iii) Rail panels should be tied with manila rope/slings with the help of HTS bolts through the holes provided at the end of panels. Only tested slings shall be used for unloading of welded panels.

(iv) Rope should be passed through the arrangement fixed in ramper and threader wagons attached at the end of EUR rake to prevent rails from bending while unloading.

(v) Height of rampers should be adjusted/ maintained with respect to the layer of rails being unloaded and it should be decreasing towards end of wagon. The height of ramper to be so adjusted that a smooth slope can be provided to the panels to be unloaded.

(vi) Other end of manila rope should be tied to any fixed structure capable of pulling rail load and allow the rake to move forward at very cautious speed not exceeding 15kmph so that in the event of any

unusual/unsafe situation the rake can be stopped immediately.

(vii) Rail panels at equal distances from centre line shall be unloaded. Eccentric unloading or unloading from only one side of BFR is strictly prohibited.

(viii) Just before complete unloading of first pair of rail panel, the rake should be stopped and next rail panel to be unloaded is tied with the near end of rail panel partially unloaded, with rope. Then, the rake should be moved forward to unload next rail panel. This process is to be continued for unloading of successive rail panels.

(ix) The EUR rake shall never be moved backward during unloading.

(x) The EUR rake shall not run either backward or forward with open door of bulk head in any circumstance except in block during unloading.

(xi) In case, traffic block is to be cleared before complete unloading of rake, the clamps for layers, where rail panels are left shall be re-fixed properly before movement of rake to avoid any chance of movement of panel during run.

(xii) Unloading shall not be undertaken at locations having vertical clearance less than 4500 mm from rail level to the fixed structure.

(xiii) Unloading of rail panels shall not be undertaken in platform area and on ballast-less open web girder bridges.

(xiv) Unloading of panels should be arranged in such a way that turnout and cross-overs are avoided.

2.4 Placement of single rails and welded rail panels on cess:

(i) New rails should be unloaded on one side of the track on the cess leaving the other side free for stacking released rails. Rails should be placed on cess away

from toe of ballast profile to avoid any infringement and disturbance to ballast profile.

(ii) As far as possible, rail should be kept straight otherwise a smooth curvature may be given to cross any obstruction. Care must be taken not to unload rails one over the other as this causes bending of rails.

(iii) While carrying rails, they shall be supported by rail tongs or rail slings at locations mentioned in Para 2.1.2 (ii) above.

(iv) Rails should be so spread as to rest evenly along their entire length on supports closely spaced to prevent formation of kinks. Rails should be placed with head in upward direction. Drawing no. RDSO/T-8413 (Annexure- II) shall be followed for the purpose. Free rails should be supported at least at four points, evenly along their length.

(v) Kinky rails must be jim-crowed and straightened before placing them in track.

(vi) Rails must be inspected visually for any dent/rubbing marks on the edge of rail foot. Such rails shall be placed in the track only after removal of damaged portion.

(vii) Punch marks on rails or marking by chisel should be prohibited as these cause incipient failures.

(viii) On bridges, unloaded panels are to be supported on sleepers outside the track so as not to allow them to sag downwards.

(ix) It shall be ensured that signaling bonds are not disturbed while placing the rails. In Track circuited territory, the rails shall be handled in such a way that rail does not contact both rails of track together to prevent track circuit failures.

2.5 Precautions for handling of rails in Electrified areas :

(i) In Electrified territory, no work shall be done without obtaining "permit - to work". Working under OHE shall be careful.

(ii) Touching of fallen wires should be avoided unless power is switched-off and the wire or wires are suitably earthed.

(iii) Loading and unloading shall be done under the supervision of an Engineering Official not below the rank of a SSE/P. Way who shall personally ensure that no tool or any part of body of worker comes within the "danger zone " i .e. within 2m of the OHE.

(iv) Rails should not touch each other to form a continuous metallic mast of length greater than 300m.

2.6 Handling of Rails at port :

(i) Availability of proper facilities for handling of rails at Ports as required by these guidelines should be ensured.

(ii) Magnetic lifting devices with suitable spreader beams should preferably be used. In case, it is not possible to provide magnetic lifting device for li fting of rails, electric hoists or cranes with suitable spreader beams may also be used so as to lift the rails in accordance with laid down basic principles.

(iii) Suitable enabling provisions in the contract for procurement of for rails shall be ensured for carrying out modifications in the existing facilities available at ports or to develop suitable method for unloading and handling of rails so as to avoid any damage.

3.0 Precautions for preventing damage to rails :

3.1 Protection of straightness :

Proper straightness of rails is essential for smooth riding and preventing unusual stress during operation.

Even the small variation of straightness, which is barely visible, (for example, a deflection of 0 .75 mm over 1.5m span) renders a rail unacceptable. Therefore, careful handling and stacking shall be ensured particularly on following:

(i) Heavy static loading on rails should not be done. Also, sudden impact should not be imparted to rails while unloading and handling.

(ii) While stacking in layers, localised point or line contact loading should not be allowed. It should also be checked that rails are not stacked in criss-cross manner in alternative layers at right angles to each other.

(iii) Excessive rail end overhang should not be allowed while lifting and shifting of rails. Overhangs mentioned in Table 1 shall be followed.

(iv) Rails should be kept as horizontal and straight as possible while li fting/moving.

(v) Rail ends are to be protected against damage by any impact even after having been stacked.

3.2 Protection of rail surface :

Rails are very sensitive to notches and dents/ deformations at the edge of the rail foot. Surface notches of even less than 0.25 mm in depth are liable to cause rail fracture in service. Therefore, to prevent rail surface from any damage, following shall be strictly ensured:

(i) Rails shall be protected against impact or abrasion against separators in wagons, vehicles, hatches, ships etc. and also shall be protected against brushing, notching or scoring of rail surface.

(ii) Electro- magnetic lifting devices shall be used for li fting of rails. In case of non-availability of such device, conventional slings made of flat link chains fitted with

fabric sleeves can be used for lifting rails. Round link chain slings should not be used for securing the rails.

(iii) Any rail support, handling or clamping devices and rail pinch rollers shall not apply localized or point contact to the rail and must not have sharp edges. Wherever possible, the profile of rail support, handling and clamping devices should be contoured to rail profile.

3.3 Prevention of metallurgical damages :

Rails are thermally very sensitive and are likely to develop metallurgical defects, if exposed to localized heating. The localized heating produces very hard and brittle metallurgical structures, which may lead to sudden failures. Therefore,

(i) No work of heating, flame cutting, spot welding on or adjacent to rails should be done.

(ii) Rails should not be in contact with (a) loose electric cables to produce arcs, and (b) molten metal splashes from adjacent welding operations.

3.4 Protection from contact with injurious substances :

All rail in general and 90 UTS or higher grade rails in particular due to higher carbon content, are sensitive to localized corrosion and pitting, which may cause subsequent rail fractures. Therefore, contact of rails with injurious substances causing corrosion of steel, i.e. acids, alkalis, salts, fertilizers, sulphate, chlorides, nitrates etc. should be avoided.

4.0 Safety of Personnel :

Safety of personnel involved in handling of rails is of utmost importance. Following precautions must be ensured for safety of personnel-

(i) The staff deputed for unloading of EUR rakes must never travel on BFRs. They shall travel only in tool van/ separate wagon provided in rake composition. No staff shall be allowed on ramper/threader during movement of rake from one station to another station where rake is moving for non- block activity.

(ii) Trackmen/staff shall not be allowed to stand between bulkhead doors and panels on either side of the formation while rake is on run.

(iii) The staff must use protective gloves and clothing to minimize the risk of skin abrasion, lacerations and extremes of temperature.

(iv) Handling of rails shall be done using proper tools and equipments approved by SSE (P.way) incharge. No locally made arrangements shall be used.

(v) The staff must wear distinctive coloured helmet and clothing for easy identification by crane and other machine operators to avoid accidents.

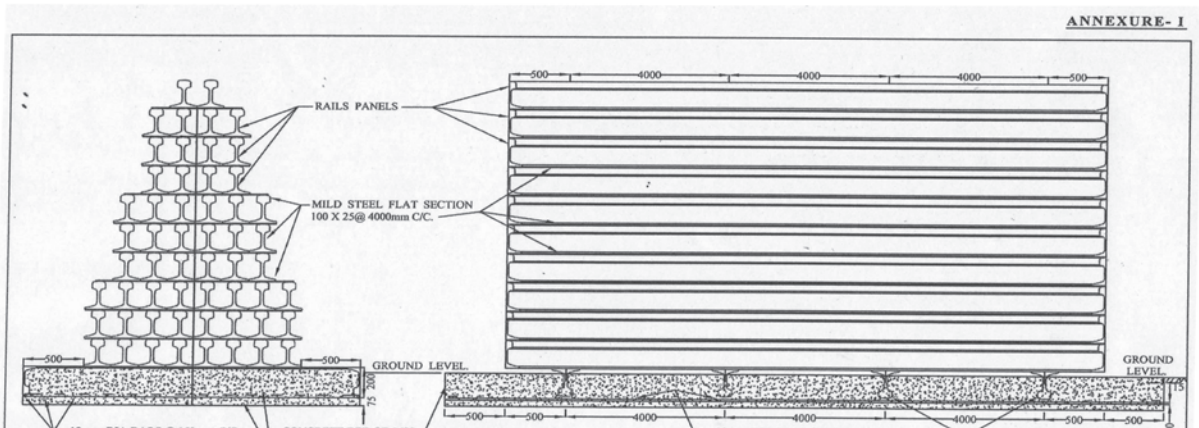
(vi) The staff shall use steel toe- capped protective footwear

(vii) The staff shall be properly trained and cautioned to avoid standing under suspended loads, sudden dropping and impact of rails.

(viii) Safe working in the vicinity of electrical conductors and cables shall be ensured.

(ix) The rails should never be carried by staff on the head or shoulder.

ANNEXURE- I



SCHEDULE OF DIMENSION

RAIL LENGTH / WELDED PANEL (METERS)	NUMBER OF EMBEDDED RAILS
12 / 13	4@ 4000 mm C/C
28	7@ 4000 mm C/C
39	10@ 4000 mm C/C
130	33@ 4000 mm C/C
200	66@ 4000 mm C/C

8. THE DRAWING SUPERSEDES THE DRG:No.RDSO/T-4962.
7. ONE RAIL/PANEL MAY BE REDUCED AFTER EVERY THIRD LAYER TO ACHIVE PROPER STACKING FROM BOTH SIDES.
6. BETWEEN TWO LAYERS OF RAILS FLAT OF SIZE 100X25mm SHOULD BE PROVIDED AT 4000mm C/C AND IT SHALL BE ENSURED THAT RAIL ENDS DO NOT OVERHANG BY MORE THEN 1500mm.
5. ONLY ONE TYPE OF FREE RAILS/WELDED PANELS SHALL BE STACKED IN ONE STACK.
4. MAX. NUMBER OF LAYERS IN WHICH FREE RAILS AS WELL AS WELDED PANELS CAN BE STACKED SHALL BE LIMITED TO 10.
3. 52Kg.per m. / 90R RAIL SHALL BE EMBEDDED IN THE CONCRETE BED OF M-20 GRADE CONCRETE (TO IS:456-1978) AS SHOWN IN THE DRG: ABOVE.
2. A SLOPE OF 1:400 MAY BE GIVEN IN CONCRETE BE ACROSS THE LENGTH OF RAIL.
1. ALL DIMENSIONS ARE IN MILLIMETRES EXCEPT WHERE OTHERWISE SHOWN.

NOTE

(I) M. S. PLATE TO IS: 226-1975.
(II) IS:450-1975 FOR CONCRETE BED.

SPECIFICATION

SCALE	ALT:	DESCRIPTION	DATE

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R. D. S. O.

ARRANGEMENT FOR STACKING FREE RAILS AND WELDED

STAND.
CANCLD.
REVSD.
ADVANCE
15.5.2002
(T)

R. D. S. O. /T- 6219

ANNEXURE - II

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ARRANGEMENT FOR PLACEMENT OF RAILS ON CESS ALONG THE TRACK

SPECIFICATION	SCALE	ALT	DESCRIPTION	DATE	R D S O / T- 8413	
NOTE						(T)

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