- Track must be constructed in such a way that the trains running on it do not cause excessive environmental pollution in the form of noise and ground vibrations.
- Costs of the total service life of the track must be as low as possible.
- Maintenance should be low and as inexpensive as possible.

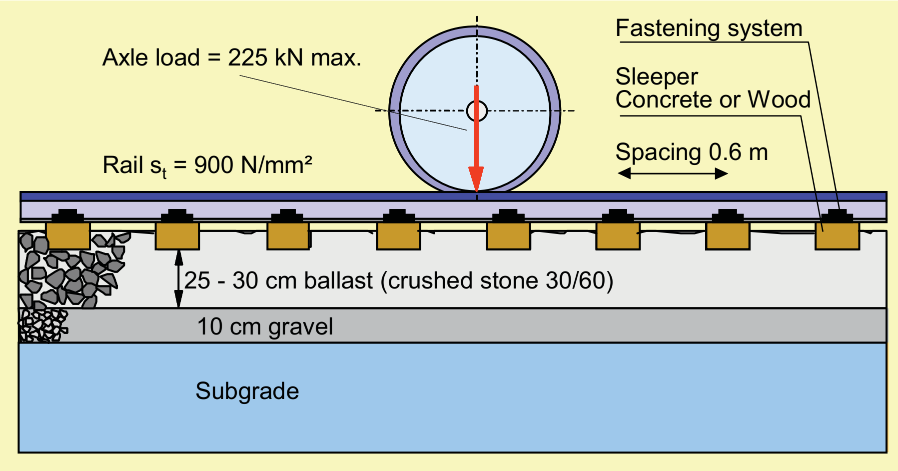

Figure 1.8: Conventional track structure

Tracks and switches are assets which will last for quite some years. The choice of a particular track system and the decision to use this system on certain lines, therefore, generally involves a decision which will hold good for 20 to 50 years. Consequently, such decisions must be taken with the future in mind, however difficult it may be to make a valid prediction. The only sure factor is that a certain degree of objectivity must be maintained vis-à-vis the present day situation, and not too much emphasis placed on random everyday events.

When choosing a track system, the above-mentioned requirements must all be given due consideration and it is clearly necessary to form some idea of the axle loads and maximum speeds to be expected in the decades to come. After this the situation regarding the various track components, such as rails, sleepers, fastenings, switches, and ballast should be examined so that the optimum track design is obtained.

1.6.2 Load-bearing function of the track

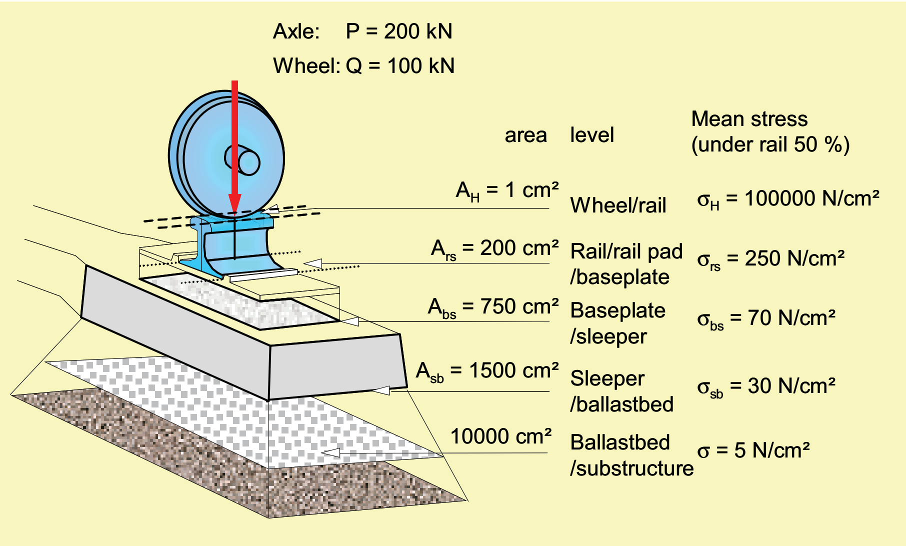

Figure 1.9: Principle of load transfer

The purpose of track is to transfer train loads to the formation. Conventional track still in use consists of a discrete system made up of rails, sleepers, and ballastbed. Figure 1.8 shows a principle sketch with the main dimensions.

Load transfer works on the principle of stress reduction, which means layer by layer, as depicted schematically in Figure 1.9. The greatest stress occurs between wheel and rail and is in the order of 30 kN/cm^2 (= 300 MPa). Even higher values may occur (see chapter 2). Between rail and sleeper the stress is two orders smaller and diminishes between sleeper and ballast bed down to about 30 N/cm^2. Finally the stress on the formation is only about 5 N/cm^2.

5 STATIC TRACK DESIGN

5.1 Introduction

The subject of this chapter is track dimensioning, the main point of which is to ensure that the track structure is suitable for the loads it has to carry and the resultant stresses and deformations. Conventional track calculation is limited to quasi-static loading of the track structure, schematized as an elastically supported beam. To the static load is added a dynamic increment. Details on rail stresses as a result of contact pressure have been given earlier. Fatigue and high frequency loads at welds or caused by wheel flats are dealt with in chapter 6 on dynamic track design.

5.2 Supporting models

5.2.1 Winkler support model

Conventional track consists basically of two parallel continuous beams, the rails, which are fixed at regular intervals onto sleepers supported from below and from the side by a medium which cannot be deformed, the ballast bed. In turn, the ballast bed rests on a formation which also cannot be deformed [292]. In elementary calculations it is usually presupposed that the Winkler hypothesis applies to track support; this hypothesis was formulated in 1867 and reads: at each point of support the compressive stress is proportional to the local compression. This relation is illustrated in Figure 5.1 and can be written as:

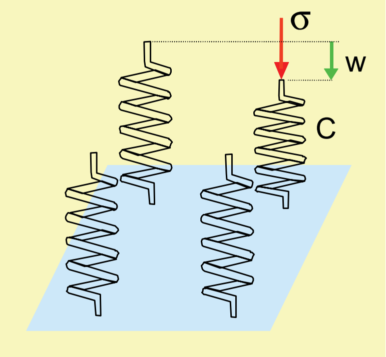

Figure 5.1: Winkler support model

$$\sigma = Cw \tag{5.1}$$

in which:
σ = local compressive stress on the support [N/m^2];
w = local subsidence of the support [m];
C = foundation modulus [N/m³].

5.2.2 Discrete rail support

Let us consider the situation of a discretely supported rail (Figure 5.2). Between the vertical force $F(x_i)$ on a support number at $x = x_i$ with effective rail support area A_{rs} and the deflection $w(x_i)$, the following relation exists according to Winkler:

$$F(x_i) = CA_{rs}w(x_i) = k_d w(x_i) \tag{5.2}$$

Hence the spring constant of the support is:

$$k_d = CA_{rs} \tag{5.3}$$

Determining the spring constant in a railway track with a homogeneous support is relatively simple using the equilibrium condition:

$$k_d = \frac{\Sigma F}{\Sigma w} = \frac{Q}{\Sigma w} \tag{5.4}$$

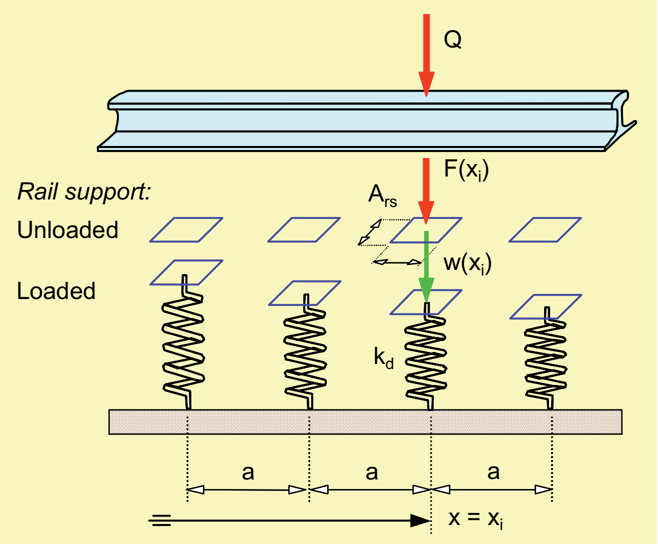

Figure 5.2: Discrete elastic support model

6 DYNAMIC TRACK DESIGN

6.1 Introduction

When dealing with track mechanics most of the problems are related in one way or another to dynamics. The dynamic interaction between vehicle and track can be described reasonably well in the vertical direction using mathematical models. Figure 6.1 gives an example of such a model made up of a discrete mass-spring system for the vehicle, a discretely supported beam to describe the track, and a Hertzian spring acting in the wheel/rail contact area.

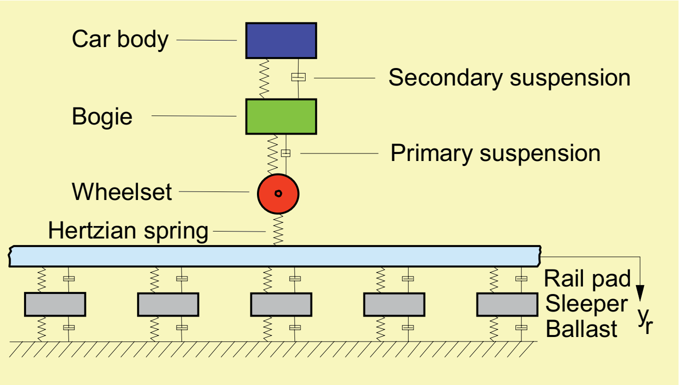

Figure 6.1: Dynamic model of vehicle-track interaction

Dynamic behaviour occurs in a fairly wide band ranging from very low frequencies of the order of 0.5-1 Hz for lateral and vertical car body accelerations to 2000 Hz as a consequence of geometrical irregularities in rails and wheel treads. The suspension system between wheelset and bogie is the first spring/damper combination to reduce vibrations originating from the wheel/rail interaction and is therefore called primary suspension. The reduction of the vibrations of lower frequency is dealt with in the second stage between bogie and car body and is called secondary suspension. This terminology can be applied to the track part of the model in the same way. The railpad and railclip represent the primary suspension of the track and the ballast layer or comparable medium represent the secondary suspension of the track.

Actual dynamic calculation is, however, extremely complex and is by no means generally accessible. Most analyses are limited to quasi-static considerations. Real dynamic problems are for the most part approached in a very pragmatic way by carrying out measurements.

In this chapter attention is given to the basic ingredients of the dynamic behaviour of railway track. Section 6.2 deals with some fundamental aspects. The 1-mass spring system, presented in Section 6.2.2, can be regarded as the most elementary system with the aid of which a number of practical problems can be considered. Extensions can be made in two directions: the construction can be enhanced to a multi degree of freedom system, and the load can be made more complex in terms of impact loads, and loads with a random character.

In Section 6.3 the track is modelled with relatively simple beam models consisting of the beam on an elastic foundation, a double beam, and a discretely supported track structure. The transfer function between track load and track displacement is discussed. Also the effect of a moving load running on the track is considered, as the track is considered to be infinitely stiff.

Track and rolling stock should in fact not be considered separately, but as one consistent system. For this reason the interaction between vehicle and track is introduced here without going into all the details required for a full treatment of this complex matter. After the introduction of the Hertzian spring, the physics of which were discussed earlier in Chapter 2, the transfer function between wheel and rail is derived in Section 6.4. This relationship plays an important role when interpreting track recording car data.

In Section 6.5 a concept is developed from which the relevant vehicle reactions can be calculated in real time using transfer functions based on track geometry measured independently of speed. A transfer function represents the contribution made by a geometry component to a vehicle reaction in the frequency domain. Geometry components include cant, level, alignment, and track gauge, and vehicle reactions include Q forces, Y forces, and horizontal and vertical vehicle body accelerations.

7 TRACK STABILITY AND LONGITUDINAL FORCES

7.1 Introduction

In conventional non-welded tracks the rails are connected by means of joints to allow for length changes caused by temperature fluctuations. Using joints prevents the development of axial forces and the consequent risk of track buckling at high temperatures. However, the penalty for this is the care for maintenance-intensive joints which generate high dynamic loads during train passage. These loads are responsible for many problems like rapid deterioration of vertical track geometry, plastic deformation of the rail head, dangerous rail cracks as well as damage to sleepers and fastenings. These problems increase progressively as speed increases. As a rule, joints have a very considerable negative effect on the service life of all track components.


Figure 7.1: Example of track buckling

Tracks with continuous welded rails (CWR) do not possess the above drawbacks. Owing to the absence of joints the quality of the track geometry is better by an order and this results in a substantial decrease in the total life cycle cost. CWR does not, however, only have advantages. As was pointed out in Chapter 5, the stresses resulting from the plane strain situation may be of the order of 100 N/mm² and should be added to the residual rail stresses and bending stresses caused by train loads which are of the same order of magnitude. Temperature stresses especially are responsible for failure of welds with small imperfections at low temperatures. On the other hand, lateral stability should be sufficiently great to resist compression forces developing at temperatures above the neutral temperature of 25°C, as buckling may otherwise occur as, for example, illustrated in Figure 7.1. The principle of this phenomenon is sketched in Figure 7.2 showing the compressive forces and the resistance forces on the track and the resulting typical buckling shape.

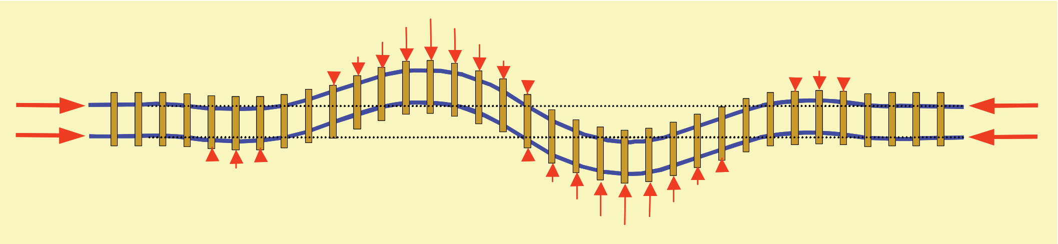
Figure 7.2: Typical buckling shape

On bridges and viaducts the deformation regime deviates from the plain track situation. The rails follow the construction which can undergo large displacements with respect to the adjacent track. Without adequate measures this would result in high rail stresses. To avoid these stresses expansion joints are applied.

This chapter is devoted to track stability and track longitudinal problems which, in the case of compression forces, are strongly interrelated. For both fields analytical and finite element modelling approaches are presented with examples. The last section discusses recently developed advanced models which describe safety considerations about track buckling or deal with more general or complicated track systems.

8 BALLASTED TRACK

8.1 Introduction

This chapter deals with the principles according to which ballasted track, also called ’classical track’ or ’conventional track’, is constructed. A detailed discussion of every type of track structure and its variants is beyond the scope of this book. Only a few examples will be given with the main intention of illustrating the principles.

The classical railway track basically consists of a flat framework made up of rails and sleepers which is supported on ballast. The ballast bed rests on a sub-ballast layer which forms the transition layer to the formation. Figure 8.1 and Figure 8.2 show the construction principle of the classical track structure. The rails and sleepers are connected by fastenings. These components and other structures such as switches and crossings are all considered as part of the track. The particulars of switches and crossings are discussed in Chapter 11.

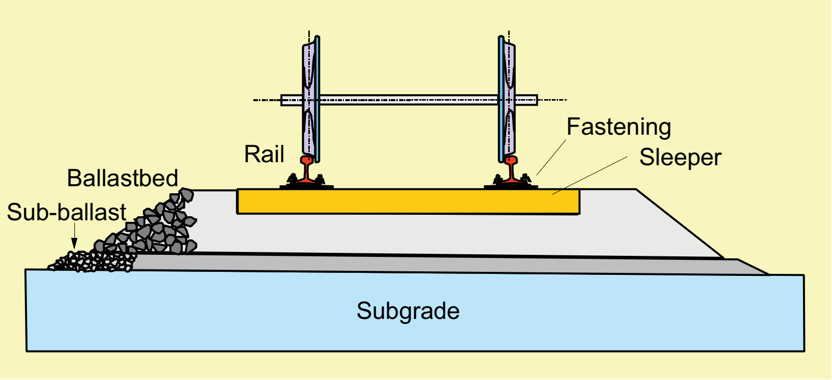

Figure 8.1: Principle of track structure: cross section

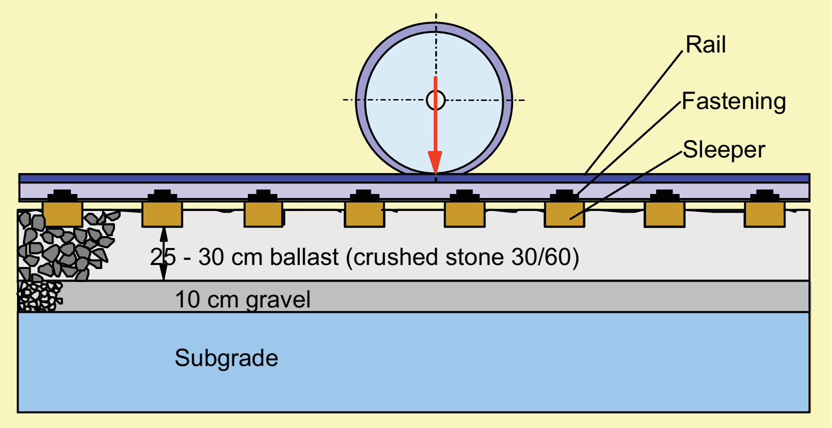

Figure 8.2: Principle of track structure: longitudinal section

Since the beginning of the railways, the principle of the ballasted track structure has not changed substantially. Important developments after the Second World War include: introduction of continuous welded rail, use of concrete sleepers, heavier rail-profiles, innovative elastic fastenings, mechanisation of maintenance, and introduction of advanced measuring equipment and maintenance management systems. As a result, the traditional ballasted superstructure can still satisfy the high demands, as demonstrated by the TGV-tracks in France.

8.8.4 Elastic fastenings

The introduction of CWR track gave rise to the need for fastenings with greater elasticity. Certainly in the case of concrete sleepers, which are susceptible to impacts, this is an absolute necessity. Since the end of the fifties the NS has used the DE clip (Deenik, Eisses). This component is fitted to both timber sleepers and concrete sleepers as shown for instance in Figure 8.15. The DE clip, which can also be used in combination with baseplates, is usually fitted in a holder. The clip holder is fixed to the sleeper by means of pins which are cast into concrete sleepers or, as in the case of timber sleepers, are pushed into pre-drilled holes.The DE clip is installed using special equipment.

As there is no threaded screw connection, in principle no maintenance or adjustment is theoretically required. But this so-called 'fit-and-forget' principle also implies a drawback. If manufacturing tolerances are not met or if excessive wear occurs, there is no means of adjusting the fastening.

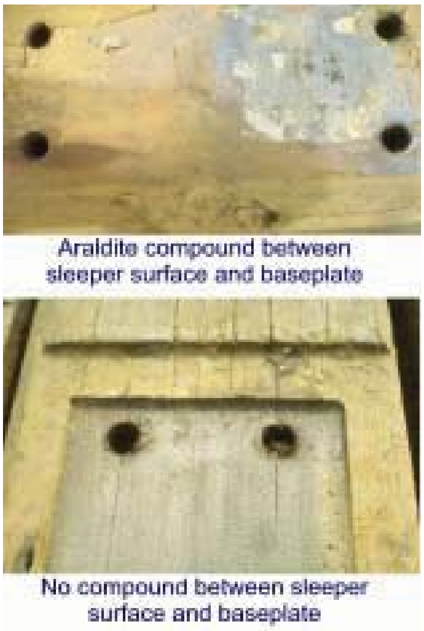

Figure 8.22: Effect of sleeper treatment with araldite

Other examples of elastic fastenings are the Pandrol standard clip, shown in Figure 8.23, the Pandrol Fastclip, shown in Figure 8.24, the Vossloh fastening, shown in Figure 8.25, and the Nabla clip, depicted in Figure 8.26.
i

Figure 8.23: Pandrol fastening system

Figure 8.24: Pandrol Fastclip

Figure 8.25: Vossloh fastening system

Figure 8.26: Nabla fastening system

9 SLAB TRACK

9.1 Introduction

Although most of the current railway tracks are still of a traditional ballasted type, recent applications tend more and more towards non-ballasted track. The major advantages of slab track are: low maintenance, high availability, low structure height, and low weight. In addition, recent life cycle studies have shown, that from the cost point of view, slab tracks might be very competitive.

Experiences in high-speed operation have revealed that ballasted tracks are more maintenance intensive. In particular, due to churning up of ballast particles at high-speed, serious damage can occur to wheels and rails, which is of course prevented in the case of slab track.

With the design of railway lines factors like life cycle cost, construction time, availability and durability play an increasingly important role. In this respect non-ballasted track concepts offer good opportunities. With the growth of traffic intensity it becomes more and more difficult to carry out maintenance and renewal work. On European networks, night time possessions often last no longer than 5 hours, or even less. Seen against this background, the current increase in the popularity of low-maintenance track designs is evident.

In the past new projects were mainly assessed on the basis of investment costs, whereas today the principle of life cycle costing is strongly emerging. As a result of these new attitude, ballasted track concepts will loose attractiveness in favour of slab track systems.

9.2 Ballasted track versus slab track

The general problem which occurs with ballasted track is the slow deterioration of the ballast material due to traffic loading. Ballast consists of packed loose granular material of which the grains wander, wear, and break up causing increasing geometrical unevenness and clogging of the ballast bed by fine particles which cause drainage problems. Therefore, regular maintenance is time after time needed to restore the track alignment.

Figure 9.1: Ballasted track ...

Figure 9.2: ... and slab track

Integrated techniques for slab track installation

In order to reduce the expensive construction costs a new installation concept was developed for Rheda 2000. By omitting the concrete trough, a complete step in the construction work sequence was eliminated. Application of the light twinblock sleepers significantly simplified their use at the construction site and at the same time enabled the mechanised installation of prefabricated track panels. Specially developed surveying techniques enhanced the cost effectiveness of the track installation process.

Figure 9.15: Track assembly, track on top of the concrete roadbed on the concrete roadbed (for the project Leipzig-Gröbers)

The installation of the Rheda 2000 system on earthworks begins with placement of a concrete roadbed by means of a slipform paver. In the case of engineering structures, the required protective and profile concrete is generally laid instead.

Application of the twinblock sleeper allows use of conventional track-installation processes. The foundation provided by the concrete base-sockets enables loaded construction vehicles to use the rails without difficulty before they are accurately positioned and secured in place. As a result, it is possible to lay the track in single-sleeper mode or in the form of assembled track panels.

The arrangement of the slab layer reinforcement within the sleeper lattice-truss makes it possible for installation of the reinforcement to take place at the exact same time the track is laid. In this process, the construction crew places the required reinforcing rods on the concrete roadbed and inserts them section at a time through the lattice-girder compartments as shown in Figure 9.15.

Figure 9.16: Alignment portals in the Leipzig-Gröbers project

Coarse and fine alignment of the track can take place with the aid of two techniques:

– By means of alignment portal (see Figure 9.16): the portal units are first put into position with their feet anchored securely into the concrete roadbed after which the formwork elements are secured. The crew checks the installation for correctness. Next, the rail head clamps are lowered into place and fixed onto the rail as the track panel will be lifted approx. 9 cm and roughly aligned to ± 0.5 mm. The surveying crew gives instructions for the necessary settings to be made by the respective portal spindles for the superelevation (cant). After the final adjustments the track panel is secured and cleared for the pouring of concrete.

10 THE RAIL

10.1 Introduction

As the rail is the most important part of the track structure a separate chapter is devoted to it. In Chapter 8 several basic functions have been discussed. In this chapter some fundamental aspects of the quality of rails are discussed, such as the rail manufacturing process, acceptance procedures, mechanical properties, flash butt and Thermit welding, control of weld geometry, required standards, rail failure types and rail defect statistics.

10.2 Modern rail manufacturing

Modern rail manufacturing technology is considered in the new standard EN 13674 of the European Community. Different to existing specifications, it is a performance based standard. Some of the manufacturing techniques are defined in order to ensure that the rail shows good service properties. The steel may be produced either by the basic oxygen process (BOF) or in an electric arc furnace, although the latter is currently not used in Europe. Ingot casting is no longer allowed. Secondary metallurgy is more or less standard practice. Vacuum degassing is mandatory in order to avoid rail breakage caused by flakes and non-metallic inclusions. The manufacturer has to apply a quality management system to ensure consistent product quality and to pass a qualifying procedure to become approved for delivery.

The rail manufacturing process consists of the following main parts as indicated in Figure 10.1:

- Blast furnace;
- Steel-making;
- Continuous casting;
- Rolling;
- Straightening;
- Measurements (ultrasonic, geometry, manual inspection);
- Final acceptance.

In the next part of this section some of these processes will be discussed in greater detail.

10.2.1 Blast furnace

Steel is in fact iron which has been refined with carefully measured amounts of other elements added to it. Iron is found as iron oxide in rocks, known as iron ore. This only occurs in sufficiently large quantities and with reasonable accessibility in a few scattered areas of the world, for the most part in Scandinavia, the Americas, Australia, North Africa, and Russia.

The ore is graded and crushed and some of the finer ore is taken to the sinter plant where it is mixed with coke and limestone and heated to form an iron-rich clinker known as sinter. This sinter is fed into the top of the blast furnace together with more iron ore, coke and limestone in controlled proportions, and the whole is fired. Great heat is generated and fanned to white hot intensity by blasts of superheated air.