The purpose of the railroad track structure is to support the loads of cars and locomotives and guide their movement. In order to perform this function, the track structure must withstand the loadings applied to it by both the vehicles and the environment.

Fig. 3-1 presents an overview of the track, which consists of two steel rails that are 56½ inches apart, supported by timber, concrete, or steel crossties, resting on rock ballast and subballast, which, in turn, rests on the original subgrade or foundation of the line. This track structure must support the loads generated by a modern heavy-haul freight train, which can weigh 14,000 tons or more and each wheel of which weighs 36,000 lbs or 18 tons.

With those heavy forces at work, it's easy to see that every item in the track has to be designed and maintained to do its part through conditions of high loads, heavy traffic density, and severe weather conditions that can range from extreme cold and snow to severe heat and rain.

Fig. 3-1. Track overview
Track Alignment

Since railroad tracks must cross existing terrain that can include mountains, prairies, and rolling hills, trains are required to make numerous changes of direction, both vertical and horizontal. In the vertical direction, changes in the topography show up as grades or changes in elevation that can range from a fraction of 1 percent to over 4 percent, corresponding to a rise of 4 ft in height for every 100 ft of track traveled.

In the horizontal direction, track is divided into stretches of straight track (or tangent track as railroad engineers call it), and curved track where the track changes direction. Even though tangent track is used as much as possible because it is much easier to build and maintain, curves are a necessary part of the track layout and can be found with great frequency in hilly or mountainous terrain. In the United States, the sharpness of curved track is defined in terms of "degrees of curvature" or alternatively, in terms of the curve's radius, in feet or meters. The relationship between degrees and radius is illustrated in Fig. 3-2, which also shows typical maximum speeds for some curves.

![A 6° Curve](image)

The degree or sharpness of a railroad curve is the angle through which the track curves in 100 ft.

Radius in ft = \[
\frac{5,729}{\text{Degrees/100 ft}}
\]

<table>
<thead>
<tr>
<th>Degree of Curve</th>
<th>Radius Feet</th>
<th>Typical Max. Speed</th>
<th>Extra Curve Resistance, lb/ton</th>
<th>Equivalent Increase in Grade, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1°</td>
<td>5,729</td>
<td>100 mph</td>
<td>0.8</td>
<td>0.04</td>
</tr>
<tr>
<td>5°</td>
<td>1,146</td>
<td>50 mph</td>
<td>4.0</td>
<td>0.20</td>
</tr>
<tr>
<td>10°</td>
<td>573</td>
<td>30 mph</td>
<td>8.0</td>
<td>0.40</td>
</tr>
<tr>
<td>15°</td>
<td>383</td>
<td>25 mph</td>
<td>12.0</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Fig. 3-2. Track curvature

Railroad engineers generally prefer to keep curvature low, around 1 or 2 degrees, preferably. However, in hilly or mountainous territory, curvature is more severe, increasing to curves of 8 to 10 degrees or higher. Often railroad builders were faced with a choice of sharp curves or severe grades in order to go through mountain ranges. Since curves add significant drag to the train, where curves and grades occur together, a common practice is to compensate for curvature by reducing the grade on the curved track so that the combined resistance is the same for both tangent and curved segments of the grade.

Superelevation refers to the difference in elevation between the two rails on a curve. (The difference in elevation between the two rails on tangent track, which is usually undesirable, is referred to as cross level.) To compensate for the effect of centrifugal force, the outer rail on a curve is often raised or superelevated to tip the cars inward (Fig. 3-3). The speed at which the superelevation fully compensates for the centrifugal force is referred to as the balance speed and is a function of the degree of curvature. The maximum superelevation ordinarily used on a standard-gauge line carrying general traffic is 6 inches. However, because different trains will often operate at different speeds around a curve, under current railroad practice, track is often elevated less than that required for maximum speed. Current Federal Railroad Administration (FRA) regulations allow for operation at speeds above balance speed, usually limited to 3 inches of "cant deficiency." If heavy trains run over curves regularly at much less than the speed for which they are superelevated, however, the wheel flanges will ride the inner rail and wear it rapidly. Therefore, the maximum and minimum speeds on a given track cannot be too far apart on lines where there are many curves.

In order to allow for a smooth transition from tangent (and flat, i.e., no elevation) track to superelevated curved track, it is good practice to use a "spiral" or "easing" of gradually increasing curvature between each tangent and curved section of main-line trackage (Fig. 3-3). The spiral allows for a smooth transition in both curvature and elevation. The length of the spiral depends on the allowable speed and the amount of superelevation, and may be more than 600 ft in high-speed territory.

Track Gage

The most basic characteristic of track forming the North American rail network is its common "standard gage" of 4 ft 8 ½ in., which allows freight cars to freely roll from Canada to Mexico and from coast to coast. Fig. 3-4 shows how gage is measured.

This gage allows for a nominal clearance between the wheel flanges and the rail head on tangent track, though on curves, the wheel flange will frequently contact the side of the rail head, particularly on the outside or "high" rail of the curve. As the rail wears, the track gage increases. Excessive wear results in too wide a gage, requiring rail to be replaced or the track gage corrected.
Fig. 3.3. From tangent to curve—smoothly

Tangent Track

Spiral Curve or Easement
Increasing degree of curvature and superelevation of outer rail

P.T. (Point of Tangent)

PC. (Point of Curve)

Circular Curve

Constant
Radius of curvature and superelevation

Centrifugal Force

Gravity Resultant force through center of track

Fig. 3.4. Track-wheel relationships

Tread taper

Rail:
Head
Web
Base

(4'8½" or 1,435 mm)

5½"

Flange depth

Wheel gage

Point of measurement of gage

Tie plate (double-shoulder)

5/8" square

Rail cant

Track spike

Wood crosstie
Why Such an Odd Gage?

The current “standard” of 4 ft 8½ in. is the most commonly used gage in the world. It traces its origin back to early English tramways before the invention of the steam locomotive. Additionally, there is some basis for tracing this back to the cartwheel spacing of Roman stone gateways. George Stephenson and his son Robert, who were prominent promoters and engineers of railroad systems, adopted 4 ft 8½ in. as their standard. It is used throughout Europe, Asia, and North America with some exceptions such as the “Wide Gage” (5 ft or higher) systems in Russia, Spain, and Finland or the narrow gage (3 ft 6 in. or meter gage) used in parts of South America, Australia, and East Africa.

In the early years of United States railroading, several different gages were in use. In 1863, however, President Lincoln designated 4 ft 8½ in. as the gage for the railroad to be built to the Pacific Coast. This, then, became the standard to which all U.S. railroads conformed. Thus, the railroads south of the Potomac and Ohio Rivers that were mostly 5 ft gage until 1887 changed to standard virtually over a single weekend. By having a single common gage in North America, free transit is allowed between different railroads without the need for transferring loads or switching car trucks at “break-of-gage” points.

Loading of the Track Structure

The track structure’s function is to transform the intense load of the wheel on the head of the rail to a moderate, distributed pressure that the foundation or subgrade (i.e., the earth underneath the track) can sustain under all conditions without excessive settling or failure. This distribution capability is illustrated in Fig. 3-5.

Thus, the rail, which is the part of the track structure that contacts and supports the wheels of the railway vehicles, starts the process of load distribution by spreading each individual wheel load over a number of crossties. With wheel loads of 36,000 lbs and higher, the wheel-rail contact stresses generated can approach the strength of the rail steel. Each rail then distributes this load between 6 and 10 crossties with tie plates used between the rail and the crossties to increase the bearing surface on the ties and reduce tie surface stresses. The tie, in turn, distributes this load to the top of the “rock” ballast layer, further reducing the level of stress. Finally the ballast (and subballast) layer finishes this stress reduction process, bringing the level of stress to a level that can be withstood by the parent soil or subgrade layer of the track. Fig. 3-6 illustrates this load distribution behavior as an inverse pyramid of stress reduction, with the corresponding American Railway Engineering and Maintenance-of-Way Association (AREMA) design limits defined for each component “layer.”

This load that the track is subjected to comes from not only the locomotives and cars of the train but also from changes in the environment (such as variations in temperature, which directly affect the loading of the track structure). This includes vehicle-induced loadings in the vertical, lateral, and longitudinal planes (Fig. 3-7) as well as the thermal loading of the rails generated by changes in ambient temperature.
The vertical loads include the weight of the vehicle itself, which can weigh as high as 39,000 lbs per wheel (Table 3-1), and the additional forces generated by the dynamic interaction of the moving vehicle on the track. Dynamic impact forces as high as three times the weight of the wheel itself have been measured under very severe service conditions.

Lateral loads, which are generated by the flanging of the locomotive or railcar wheels against the rail on curves or by dynamic hunting of rail vehicles on tangent track, have been measured to be in the 15,000 lb range and even higher under severe service conditions.

Longitudinal forces are input into the track structure through two distinct mechanisms: mechanical forces through train action, and thermal forces through changes in ambient temperature. The mechanically induced longitudinal forces are directly related to train handling, and train acceleration, and braking and have been measured to be in the range of 20,000 lbs per rail and higher. Thermally induced longitudinal rail forces are present in continuous-welded rail and are caused by the change in temperature from the “neutral” temperature of the rail. These forces, which can be either tensile or compressive in nature, can reach levels of well over 100,000 lbs per rail, resulting in either buckling of the track (in hot weather) or a pull-apart of the rail (in cold weather).

---

1 Dynamic side-to-side movement of railcars at high speed

---

**Table 3.1 Static wheel loads—worldwide**

<table>
<thead>
<tr>
<th>Axle load (in tons)</th>
<th>Gross weight of cars (in lbs)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>80,000</td>
<td>Light rail transit</td>
</tr>
<tr>
<td>15</td>
<td>120,000</td>
<td>Heavy rail transit</td>
</tr>
<tr>
<td>25</td>
<td>200,000</td>
<td>Passenger cars</td>
</tr>
<tr>
<td>25</td>
<td>200,000</td>
<td>Common European freight limit</td>
</tr>
<tr>
<td>27.5</td>
<td>220,000</td>
<td>United Kingdom and Select European limit</td>
</tr>
<tr>
<td>33</td>
<td>263,000</td>
<td>North American free interchange limit; limited international use (Sweden, South Africa, Brazil)</td>
</tr>
<tr>
<td>36</td>
<td>286,000</td>
<td>Current heavy-axle-load (HAL) weight for North American Class 1 railroads</td>
</tr>
<tr>
<td>39</td>
<td>315,000</td>
<td>Very limited use (Australia, North America); undergoing research tests</td>
</tr>
</tbody>
</table>

---

**The Track Structure**

The railroad track structure has been the subject of evolution and engineering for nearly 200 years through a combination of incremental improvements and technological innovation. A good example of this is the rail itself, which has evolved both in shape and in material composition. In Fig. 3-8, the rail section has evolved from a variety of early shapes to the modern self-supporting T-rail section, which is still in use today, though with larger rail sections of up to 141 lbs per yard. Matching the changes in shape are changes in the rail manufacturing process, and in rail metallurgy and treatment, with modern continuous-casting, rolling, alloying and heat-treatment techniques providing rail sections with significantly improved strength, hardness, and resistance to failure even under modern axle loadings and severe service environments.

This evolution of the railroad track, and its key components, has been paralleled by an evolution in railroad engineering. In the 19th century, railroad engineering focused on building the railroad (with a strong emphasis on construction techniques, bridge and tunnel engineering, and route alignment engineering). Modern railroad engineering is focusing on improving the track structure's strength and the ability to carry the ever-increasing loads on the modern railway.

New technology continues to be introduced into the railroad industry (e.g., use of concrete, steel, or plastic crossties in addition to the wood crosstie), but the basic rail-
A number of issues associated with CRW is the effects of expansion and contraction on bed deck. However, more common are the effects of expansion and contraction on the railroad tie. Extreme weather conditions or changes in moisture content can lead to tie movement, which can cause wear and tear on the rail and sleeper, as well as potentially affecting the alignment and stability of the track.

One solution to this problem is the use of self-compacting concrete ties. These ties are designed to have a lower coefficient of thermal expansion than conventional ties, which helps to minimize movement and wear, thereby extending the life of the tie and reducing maintenance costs. Additionally, self-compacting concrete ties are more resistant to moisture and can withstand extreme weather conditions better than traditional ties.

The use of CRW technology has also led to improvements in the design and construction of tracks. By using computer-aided design (CAD) software and 3D modeling, engineers can create more efficient and cost-effective track designs. This has led to a reduction in the amount of material used and a decrease in construction time, which ultimately results in lower costs for the project.

In addition to the benefits of CRW, there are also environmental considerations to be taken into account. The use of recyclable materials, such as self-compacting concrete ties, contributes to a more sustainable track design. The long lifespan of CRW also means that there is less need for regular maintenance and replacement, which reduces the amount of waste generated and helps to reduce the carbon footprint of the project.

Overall, the use of CRW technology represents a significant advancement in the field of track construction. By addressing the challenges of expansion, contraction, and weather conditions, CRW technology has helped to create more durable and efficient tracks, while also promoting a more sustainable approach to track design and construction.
Fig. 3.12. Expansion and contraction of rail with temperature

Expansion of rail will cause it to bend, which will in turn cause the track alignment to change. This effect is greater at lower temperatures, as the rail expands and contracts with changes in temperature. The expansion and contraction of the rail can be accommodated by inserting expansion joints at regular intervals along the track. These joints allow the rail to move freely, preventing damage to the track structure. The expansion joints should be placed at regular intervals to ensure that the track remains straight and level. The average expansion of a rail is approximately 0.0005 per degree Celsius. Therefore, for a 100-meter-long rail, the expansion would be 0.05 meters, which is quite significant and needs to be accounted for in the design of the track.

The Track Alignment and Structure

The expansion and contraction of the rail with temperature can cause changes in the alignment of the track. These changes can be minimized by careful design and construction. The alignment of the track should be checked regularly to ensure that it remains straight and level. The track alignment should be checked at regular intervals, and any changes made to the alignment should be recorded.

Fig. 3.11. The track structure—typical main-line track

The track structure typically consists of a layer of ballast on top of the subgrade. The track is made up of wooden sleepers or steel rails, which are fixed to the subgrade with spikes or bolts. The ballast helps to distribute the load of the track and provides a smooth surface for the train wheels to run on. The sleepers or rails are joined together at regular intervals with joints that allow for expansion and contraction with temperature changes. The track is also supported by the subgrade, which is made up of layers of different materials to provide stability and support for the track.
The Track Alignment and Structure

The Track Fasteners

Ballastfasteners

The overall decline economy of the two types of track will depend mostly on how the fastenings resist the stresses and strains. The track, Plates, and ballast are all important in the stability of the track structure, as they absorb the forces applied to it. The ballast is especially important, as it prevents the plates from moving and provides a stable surface for the ties to rest on. The plates, in turn, distribute the weight of the ties and rails uniformly, ensuring even loading on the ballast. The tie, then, is simply a block of wood or concrete that supports the rail, and the rail itself is a long, narrow metal strip that runs along the track. The rail, in turn, is held in place by the ties, which are anchored to the ballast by the fastenings. The ballast, in turn, is held in place by the ties, which are anchored to the ballast by the fastenings. The ballast, in turn, is held in place by the ties, which are anchored to the ballast by the fastenings.

Crossbars

The use of crossbars in conjunction with the ballastfasteners allows for higher load-bearing capacity and better durability. The crossbars are simply horizontal metal bars that are placed under the ties to help distribute the load. This eliminates the need for large, expensive ballastfasteners and reduces the risk of settlement and other issues. The crossbars are held in place by the rails, which are anchored to the ballast by the fastenings. The rails, in turn, are held in place by the ties, which are anchored to the ballast by the fastenings.

In recent years, several new types of ballastfasteners have been introduced in an effort to improve the performance and durability of the track. Some of these include the use of composite materials, which are stronger and more resilient than traditional metal fastenings. Other innovations include the use of friction-fit fastenings, which eliminate the need for贯穿性 fastenings. These and other innovations continue to be developed in an effort to improve the performance and durability of the track.
Other important terms of track work are the crossing, crossover, double slip and

Another key design feature of the track is the "runway," which directs the train from

Tunneled, Crossings, and Track Work

Percussive, expansive and time-consuming process.

Expanding on the discussion of the principles and elements of track design, it is important to understand that the location and alignment of the track can significantly impact the performance and safety of the railway system. The layout of the track is critical in determining the grade, curvature, and alignment of the track, which in turn affects the speed and capacity of trains. Proper design and construction of the track are essential in ensuring the safe and efficient operation of the railway system.

In summary, the design, construction, and maintenance of tracks are critical components of railway infrastructure. The principles of track design are guided by the need to ensure the safe and efficient operation of trains, while also considering factors such as cost, environmental impact, and long-term sustainability. The design of the track is a complex process that requires careful consideration of various factors, including the terrain, climate, and traffic demands.

Ballast and Structure

Ballast is the layer of aggregate rock located under the crossties or even tracks. It is the bed for the railway track and plays a crucial role in distributing the loads from the trains onto the subgrade. The choice of ballast material should consider factors such as gradation, density, and durability.

The substructure comprises the foundation elements of the track, which support the track structure and transfer the loads from the track to the subgrade. The substructure should be designed to accommodate the loads and movements generated by the track and trains, while also providing stability and performance.

The track alignment and structure are critical components of railway infrastructure, and their proper design and maintenance are essential for the safe and efficient operation of trains. The principles of track design are guided by the need to ensure the performance and durability of the track, while also considering factors such as cost, environmental impact, and long-term sustainability.
**Typical Turnout Proportions**

<table>
<thead>
<tr>
<th>Frog No.</th>
<th>Turnout lead, ft</th>
<th>Sharpness of curve</th>
<th>Max. speed on diverging route</th>
<th>Typical locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>48</td>
<td>21°</td>
<td>10 mph</td>
<td>Industry tracks</td>
</tr>
<tr>
<td>8</td>
<td>67</td>
<td>12°</td>
<td>15</td>
<td>Yards</td>
</tr>
<tr>
<td>12</td>
<td>97</td>
<td>5°</td>
<td>25</td>
<td>Low-speed crossovers</td>
</tr>
<tr>
<td>16</td>
<td>131</td>
<td>3°</td>
<td>30</td>
<td>Passing tracks</td>
</tr>
<tr>
<td>20</td>
<td>152</td>
<td>13°</td>
<td>45</td>
<td>Junctions, end of double track</td>
</tr>
</tbody>
</table>

**Crossovers**

A crossover is a pair of turnouts connecting two parallel tracks.

**Crossings**

A crossing carries one track across another.

**Double Slip Switch**

Shown in position connecting B and C. The double slip, used only where space is limited, combines the functions of a crossing and turnouts to allow any one of four routings.

**Ladder**

A ladder track is a series of turnouts providing access to any of several parallel yard tracks.
The Jack Maintenance and Inspection

Jack Maintenance and Inspection

The jack maintenance and inspection section focuses on the condition of the jack and its components. This section provides a basis for maintaining and repairing the jack in a timely manner.

1. Check the condition of the jack and its components. The condition of the jack and its components can affect its performance and safety.
2. Replace any damaged or worn components. Damaged or worn components can affect the jack's performance and safety.
3. Lubricate the jack's moving parts. Proper lubrication can help ensure the jack's smooth operation.
4. Check the hydraulic system. The hydraulic system is crucial for the jack's operation. Check for leaks, fluid levels, and other issues.
5. Inspect the jack's electrical components. Electrical components can affect the jack's operation and safety.

These steps help ensure the jack's safe and efficient operation. Regular maintenance and inspection can prevent costly repairs and ensure the jack's longevity.

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These steps help ensure the jack's safe and efficient operation. Regular maintenance and inspection can prevent costly repairs and ensure the jack's longevity.
The Track Alignment and Structure

Bridges

Plate girder

Fig. 3-15. Some classifications of bridges

Through

Open deck

Ballast deck

Marine concrete

Bridge end

Girder

Floor beam

Support

Deck

Longitudinal

Transverse

Floor joist

Floor plate

Cross ties

Quarter round

10' x 12'

Bridges are often used to cross rivers, valleys, or other obstacles that would otherwise hinder travel. The design and construction of bridges involve a complex interplay of engineering principles, materials science, and structural analysis. Bridges can be classified into various types based on the arrangement of structural elements and the system of forces they transmit.

In the image, several types of bridges are illustrated, including through, open, and ballast deck bridges. Each type is characterized by its specific structural features and intended use.

Through bridges are designed to carry traffic directly over the waterway it crosses. Open deck bridges, on the other hand, are open on the sides and bottom, allowing water to flow freely beneath them. Ballast deck bridges feature a deck made of concrete or steel, which is used to distribute the weight of the bridge over a larger area, reducing stress on the supporting structures.

Understanding the principles behind these classifications is vital for the safe and efficient design of bridges, ensuring they can withstand various environmental and load conditions.
The Track Alignment and Structure

Research and Development

Chapter 3
The track alignment and structure...
renewable productivity in such major maintenance functions as neck suturing and fell re-
the main classes in stop-and-go fashion, and which are significantly increasing
their active components (lumbar fascia, for example) operate independently of
Continuous-motion neck machines, which maintain steady forward motion while
• Physically controlled maintenance planning and forecasting systems
mean, hand-held computer-based inspection of the neck, and lumbar, and so-
• Inspect, high-speed noncontact geometry measurement, neck stiffness measure-
Chaptr 3