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A SunCam online continuing education course

Railroads
An Introduction

by

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COURSE DESCRIPTION

This course is an *introduction* to railroads. The intent of the course IS NOT to make you an expert in railroad design, but rather, introduce you to the fundamental components that make up a railroad system. This course IS intended for those engineers that need to become sufficiently familiar with rail systems to discuss railroad requirements with a client, understand what the railroad representatives are saying, know what questions to ask on your client's behalf, and ease the pains involved if you get a project that requires a railroad construction permit. The course will begin by providing a very brief… but interesting… history of railroads in North America before presenting the technical topics on the subgrade, ballast, ties, rail, turnouts, road crossings, ladder tracks and… of course… frogs. *Again, this introductory course is about what a railroad encompasses and provides the basic information necessary for an engineer to be able to discuss the topic intelligently with a client but is NOT intended to provide the knowledge to actually design a railroad, the turnouts, or any railroad signals that may be required. Trust me… that level of knowledge requires a lot more information and experience than what a 4-hour written course can provide.*

Introduction…

Again, this course is to help you understand some of the railroad terminology used for these components, and hopefully, help you avoid embarrassing yourself in front of your client, the project team, or the railroad representatives. For instance… if you're out in the field doing a site inspection with your client and representatives from the railroad when someone asks if you've ever tripped over one of their frogs, don't start searching the grounds around you only to look back at the person and see them laughing! Once again, trust me and… just calmly respond "Not yet." For them, it's a quick test of how much… or little… you know about railroads. But we digress… for now, just keep reading because we'll discuss the frogs a little later in the course because they ARE there and you WILL see them, I promise.

For most engineers, your opportunity for rail design will likely be limited to providing track to your client's facilities for loading or unloading and possibly an on-site ladder track. These sections of track will be privately owned and maintained by your client. Any sections owned by the railroad company will likely be designed, managed, and maintained by them. Generally, their responsibility will end at the long tie of the turnout. Regardless, you will need to be familiar with the language, materials, components, designs, and how they all interact with each other for the entire railway system.

A Brief History of Railroads in North America…

There are many courses available from multiple sources that present information on railroads. However, many don't discuss the history of railroads and how the standards used today were derived. Instead, they focus more on the technical side of the rail design today. However, for the history buffs, one intriguing mystery remains today because no one really knows for certain the true historical origins of the first railroad gauge.

> *Quick question: What do you think is the standard railway gauge (distance between the rails of a railroad track) in North America? Would you guess 8 feet 6 inches, 6 feet 4 inches, 5 feet 9 inches, or 4 feet 8.5 inches? Don't know? You've probably driven across hundreds of railroad tracks and you've probably walked across many tracks in your lifetime. So, what is your guess? Well, the North American standard gauge is the same as the European standard which is 1435 mm… which equates to 56.5 inches. That would make the correct answer be 4 feet 8.5 inches. Did you get it correct? Don't be too upset if you didn't since most people guess between 6 and 8 feet… unless they happen to be a rail engineer. See the rail and wheel configuration in Figure 1 below.*

Now… the obvious question is "Why 4 feet 8.5 inches?" Well the short… and colorful… version is because North American railroads based their construction on the way they were built in England. So the prevailing gauge in North America was constructed to use locomotives and rail cars imported from England (though there were many tracks built for specific uses in North America that used other wider or narrower widths). Well, then, why did England use that gauge? Because… they were using the old existing tramways and that's what they used… and the tramways were based on the widths used for horse-pulled wagons and their wheel spacing… and the wagon spacing was based on the wheel ruts of their even older roads… and the older road wheel ruts were based on the roads built and used by Roman chariots… and the Roman chariots were based on the width of two horses! Or so goes the story for this version…. But there are other theories as well. But this course isn't about stories or theories.

Figure 1 - A rail car's wheels using the standard gauge of 4ft 8.5 inches

Now let's get back to North American history. In the early years, many materials were used for the rails including wood! And many gauges were used based on an industry's specific needs or an engineer's design philosophy. Some of these gauges were as narrow as 3 feet and others as wide as 7 feet ¼ inches depending on the product they were carrying. But as industry continued growing in North America, these different gauges prevented the locomotives and cars from switching from line to line as needed to get from Point A to Point B. A standard gauge was needed if the various industries were to continue growing.

The Pacific Railway Act was signed by President Abraham Lincoln on July 1, 1862. This act provided for Federal government support to build the first transcontinental railroad. The Pacific Railway Act of 1864 provided additional subsidies that were needed for the completion of the railway. Does this sound familiar…? It then took another 5 years to complete, and the official ceremony was finally held in Promontory, Utah on May 10, 1869. It was at last possible to travel from the Atlantic to the Pacific by rail.

But congress didn't stop there. The Railroad Right-of-Way Act of 1875 was established to provide legal rights for railroad land ownership and Rights-of-Way controlled by… congress and the railroad companies. This explains the phrase often heard about it taking an act of congress to deal with the railroads. Even today, obtaining a permit for a rail connection or a railroad crossing is not typically something that will happen in a short amount of time. So prepare your client for a lengthy process regardless of which engineering firm is selected to design and permit the project because it almost *"takes an act of congress."*

Enough history.... Now let's get back to the course.

Railway Forces

Let's look quickly at the science of railway design and the forces involved in operating a train… without getting too much into the weeds for an introductory course. These forces will give you an idea of forces encountered in moving a train from one point to another and help you grasp the forces transmitted to the track.

While reading the definitions below, you can reference Figure 2 (below) to better understand the various forces acting on a moving train.

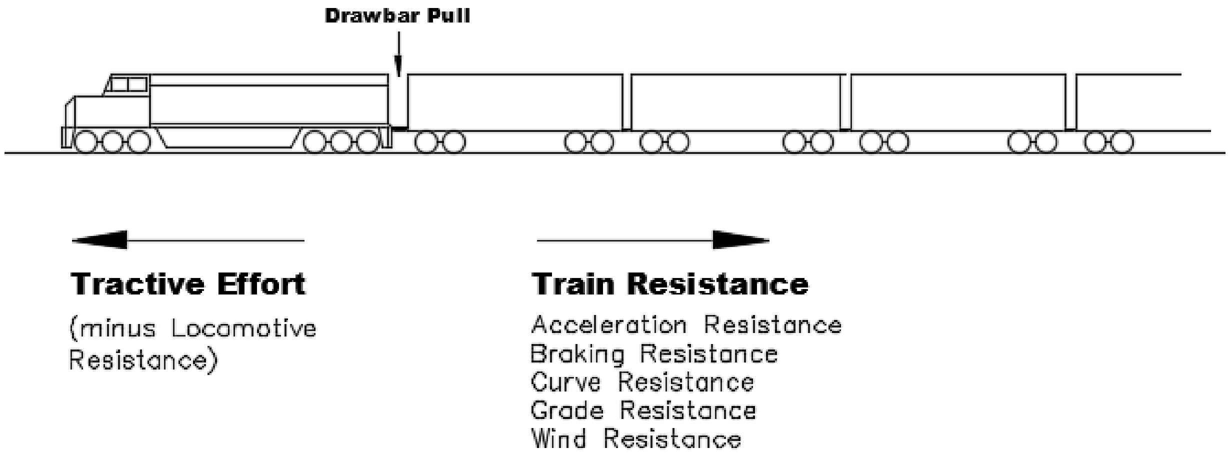

Figure 2 - Railroad forces

Tractive Effort (TE) is the force exerted by a locomotive's wheels on the rails to move the train. Tractive Effort is a combination of three forces... the net tractive effort of the locomotive, the wheel adhesion on the rails, and the high-speed limitation of the train. Note that the Net Tractive Effort equals the Tractive Effort minus the Locomotive's Resistance which cannot be ignored. If the locomotive can't develop the power needed to move the train, it goes nowhere (an embarrassing situation). Likewise, if the wheels are simply spinning in place, the train goes nowhere (receiving a chuckle or a frown). And if the high-speed limitation is exceeded, the train leaves the track (definitely not a good thing for… *anyone*!).

Drawbar Pull (DBP) is the net pull force of the locomotive at *its rear coupler*.

Acceleration Resistance (AR) is the resistance of the train to accelerate. Note that Acceleration Resistance can only be determined accurately by using a computer program that has access to current and accurate data. This requires a lot of effort to collect the required data from field measurements. However, without accurate data, the best you can hope for is an approximate estimate of the resistance.

Braking Resistance (BR) is the resistance to the train's movement by applying the brakes. Braking Resistance is another force that can only be determined by using a computer program. It is generally determined by conducting a series of braking tests on the trains at different locations and at different grades which requires not only a lot of time, but having the track available for testing and having a locomotive.

Curve Resistance (CR) is the force required to overcome the resistance induced by moving a train around a curve. Curve Resistance is very difficult to determine because of the many variables involved, but there are recognized values that may be used. For rolling cars with no rail lubrication, Curve Resistance is generally calculated as 0.8 pounds per ton per degree of curvature. For a 4 degree curve, the resistance would be calculated as 3.2 pounds per ton.

*C = 0.8 lbs/ton * Degree of Curvature*
*C = 0.8 lbs/ton * 4 (Degrees of Curvature) = 3.2 pounds per ton*

a. For locomotives and cars equipped with self-steering trucks, the Curve Resistance drops to 0.17 pounds per ton per degree of curve.

b. Another means of reducing Curve Resistance is using curves with oilers. The Curve Resistance can be reduced as much as 50% using oilers but varies with the degree of the curve. The sharper the curve, the less the reduction.

c. Additionally, for a standard car's resistance of 0.8 pounds/ton/degree of curve, the resistance of a one degree curve equates to a Grade Resistance of a 0.04% grade. This is used when reducing *Ruling Grades* (discussed later) to compensate for the curve resistance of curves on a grade and is referred to as a **Compensated Grade**.

Grade Resistance (GR) is the resistive force to move a train to a different elevation as in uphill, downhill, or level and can be positive or negative. Grade Resistance is one of the few train forces that is known and well defined. It is 20 pounds of resistance per ton of train weight per percent of grade. A **Ruling Grade** is the grade which most limits the ability of a locomotive to move a train over a specific section of railway.

1) Note that the steepest grade on a rail line MIGHT NOT be the Ruling grade. A rail grade of 1,000 feet in length is effectively reduced if the overall length of the train is 5,000 feet. The effective gradient is the elevation difference between the head of the train and the end of the train divided by the length of the train.
2) Another example is where a steep grade is longer than the train's length but is located where the train's speed is sufficient enough to prevent the train from stalling on the grade. This is referred to as its **Momentum Grade**.

Wind Resistance (WR) is the force of the wind acting on the train. Wind Resistance is the most difficult to determine since the wind direction and wind speed can vary substantially over the route and the time it takes for the train to travel the distance. Generally, the worst Wind Resistance doesn't occur with a direct head wind but actually occurs with a headwind from an angle of approximately 45 degrees to one side. This is because of the total surface area of the train that may be exposed to the headwind.

Train Resistance (TR) is the total of all of the forces that resist the train's movement. Simple enough, right?

Now that we've made it through some of the technical forces acting *on the train*, let's look at the forces acting *on the track* by the train.

Railway Alignments

Curves

Be careful when discussing or calculating railway curves. There are three types of railroad curves in use today. There are highway curves, railway curves… which ARE NOT the same as highway curves, and there are spiral curves. Many engineers have lost a lot of staff design time because they did not use the correct curve definition. So, what's the difference? Well a **Highway Curve** is defined by the Degree of Curvature using the formula R=5729.58/D where D is Degree of Curvature (degrees) and R is the Radius (ft). It is the angle formed by a ***100 ft arc*** of a specified radius. See Figure 3 below.

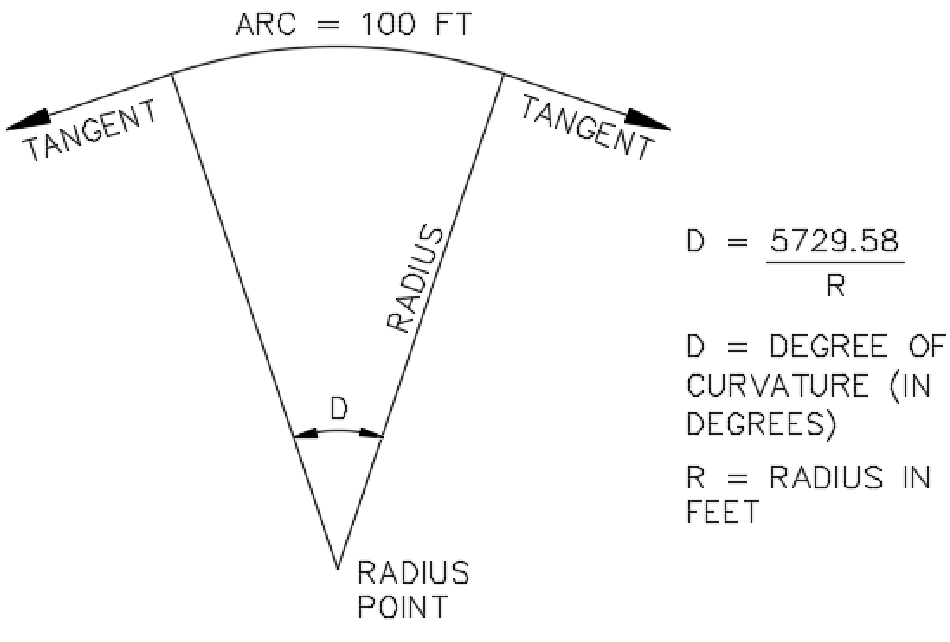

Figure 3 - Highway curve definition

Whereas, a **Railway Curve** is defined by the Degree of Curvature using the formula R=50/sin (D/2) where D is Degree of Curvature (degrees) and R is the Radius (ft). It is the angle formed by a ***100 ft chord*** of a specified radius. See Figure 4 below.

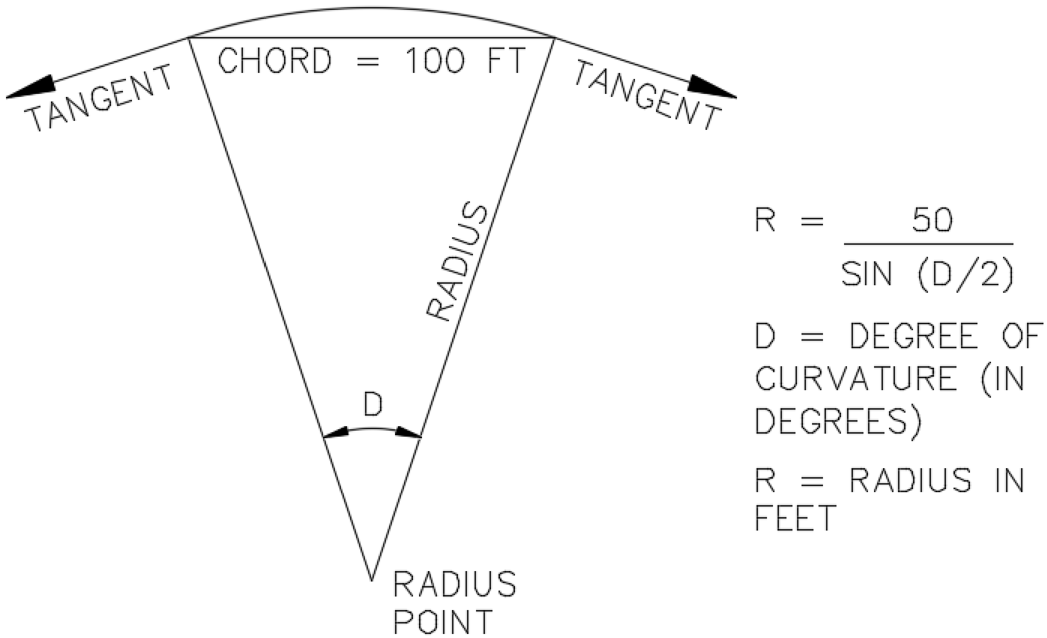

Figure 4 - Railway curve definition

A quick comparison between these two curve definitions will reveal the following:

The radius of a 10 Degree curve using a Highway Curve (100 ft arc definition) calculates the radius as being:

R = 5729.58 / D
= 5729.58 / 10
= 572.958 ft

The radius of a 10 Degree curve using a Railway Curve (100 ft chord definition) calculates the radius as being:

R = 50 / sin (D / 2)
= 50 / sin (10 / 2)
= 573.686 ft

While this doesn't appear to be a significant change, it can be a significant issue in the field. An automobile can easily handle a 1 foot jog in a travel lane but trains don't handle jogs in the alignment well at all! Even a 2-inch jog in the alignment may cause a derailment.

> ***Caution**: Once a track curve is constructed, you should try to match the definition used for that particular curve's construction or realign the track! The railroad owning the track will have a record of the curve's design calculations.*

Spiral Curves are sometimes used to deal with superelevation primarily in main tracks because of speed, but they may also be found in heavily-used branch lines and industrial lead tracks. Fortunately, there are computer programs to make the necessary calculations for engineers today. *So, if you receive a survey of a railway curve but can't get a design curve to match the existing layout, try using a spiral curve calculation.*

Vertical Curves are used to ease the transition in changes of grades to minimize stresses to the car couplers, improve the ride comfort for passengers, and prevent damage to the freight being shipped.

Reverse Curves should be separated by tangents with appropriate lengths determined by the train's speed and/or the grades needed for the existing terrain. Each railway has its own specifications for setting tangent lengths. For example, at least one railway company is currently specifying a minimum tangent of 150 feet; a tangent of 300 feet for 40-60 mph speeds; and a tangent of 500 feet for speeds above 60 mph. In rough terrain, the minimum tangent length should be at least one car length. You'll have to check with the Railroad Company owning the track to obtain its specific standards.

It should be noted that bridges with curves, or with anticipated train braking, or acceleration should be avoided if at all possible because of the forces acting on a track curve that will be transferred to the bridge members.

Grades - Rail grades play a significant role in railway design because the impacts vary depending on the type of line operations.

Heavy freight lines are very much impacted by grades and even a 0.5% grade can be detrimental to their operations.

Passenger trains, on the other hand, are minimally impacted by grades. Typically, even 2% grades are no problem for passenger trains.

Commuter lines are minimally impacted by grades, with the exception being for lines with frequent stops. This is due to the forces required when starting a train from a dead stop at a station and then having it accelerate in an uphill grade. For this reason, a 3% grade is generally the maximum grade used on commuter rail lines.

Rapid Transit and **Light Rail Transit** can normally handle 5-6% grades, with the exception of the approaches to and the departures from stations.

Grade reversals are defined as tracks with an uphill grade connected to a downhill grade. Grade Reversals are recommended to be spaced greater than the length of the train running on them… *and this is especially true for any heavy freight lines.*

Transit Rail

Commuter Rail, Heavy Rail, and Light Rail Transit have many similarities but they also have distinct differences. Some of these similarities and differences are as follows:

Characteristics of Commuter Rail

Typically consists of locomotive-hauled passenger cars that are in a push-pull (using a locomotive on each end of the train) configuration....

1) Train boarding is generally ground-accessed or low platforms but may be from elevated platforms.
2) Primarily used for daily commuters residing 10 to 50 miles from major cities.
3) Commuter rail speeds are generally less than 80 mph.
4) Typically, they use mainline freight railroad track or they may share track with freight railways.
5) Generally, track is located in open rights-of-way and on-grade, but may have sections that are elevated or may have below-grade sections (subways).

6) Commuter rail lines generally have relatively slow acceleration rates with standing passengers.
7) They use conventional couplers and passenger air-brake systems.
8) Locomotives may have conventional freight axle-loading to move the light passenger cars.

Figure 5 - Elevated Transit Rail Station

Characteristics of Heavy Rail Transit

1) The rail cars are individually powered.
2) Power is usually obtained from overhead lines or a third rail.
3) Boarding is generally from high-level platforms.
4) Heavy rail transit speeds are usually less than 60 mph.
5) These lines are separated from the general railway network.
6) Rail lines are located in isolated rights-of-way, elevated sections, or in below-grade subways. The public access is typically from station platforms.
7) Heavy rail transit is often operated with fast acceleration from stations.
8) They serve high-density routes and metropolitan areas.
9) They use non-conventional couplings and brake systems.

10) Cars with light axle loadings are used on these lines.
11) The lines may include sharp curves and steep grades when needed.
12) Most heavy rail transit lines use standard track gauge.

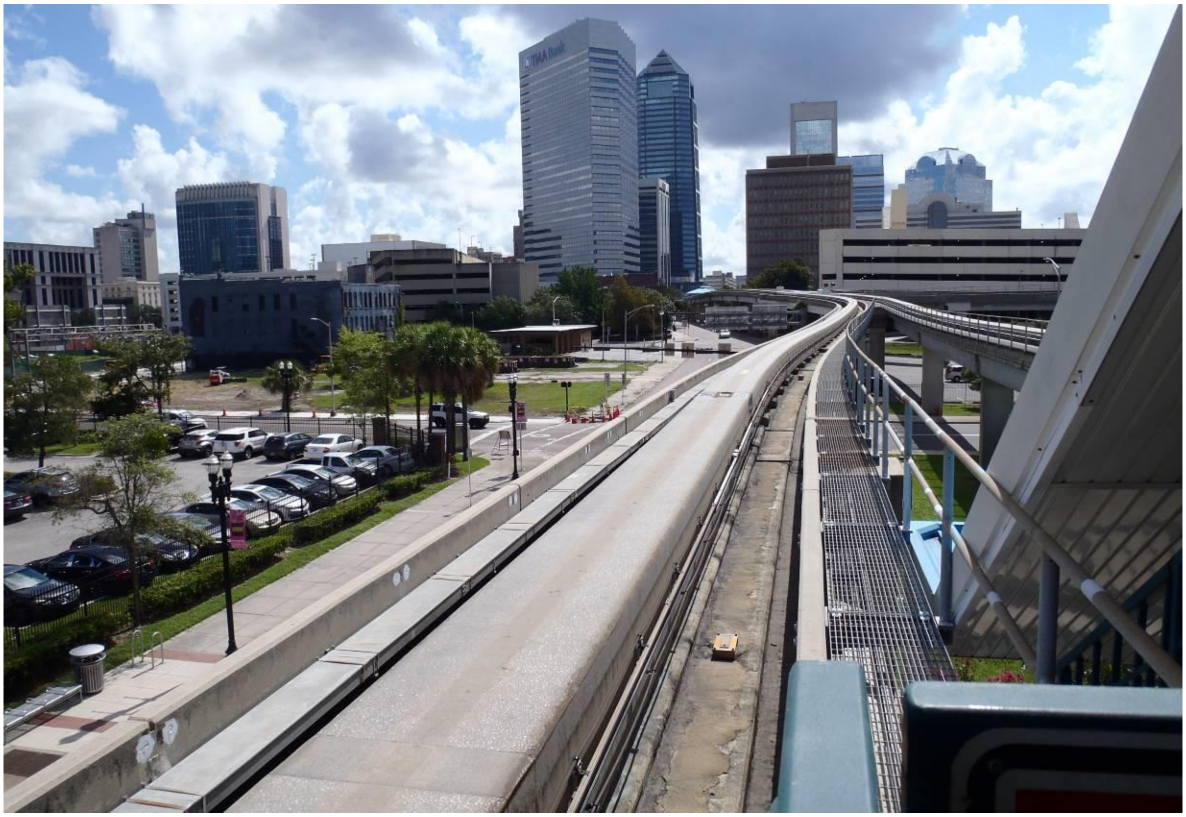
Figure 6 – Elevated commuter rail

Characteristics of Light Rail Transit

1) The cars are individually powered.
2) Power is typically obtained from overhead lines.
3) The cars have low floors.
4) Boarding is from ground level or low platforms.
5) The rail speeds are generally less than 60 mph.

6) The track may, or may not, be isolated from the general railway network. They may include the use of public street track, street median track, subways, or elevated track.
7) The routes may include public street crossings.
8) They use cars with light axle loadings.
9) The lines may include sharp curves and steep grades when needed.
10) Different cities use a variety of track gauges for their transit lines.

Figure 7 – Elevated transit rail station

References

1) American Electric Railway Engineering Association (AEREA)
2) American Railway Engineering Association (AREA)
    (a) AEREA later became ATEA
3) American Transit Engineering Association. (ATEA)
4) American Railway Engineering and Maintenance-of-Way Association (AREMA)

Track Structure

A typical railroad track consists of four primary components:

1) Rail
2) Ties
3) Ballast
4) Subgrade

Figure 8 Track Cross-section

If you consider *ONLY* the gravitational loads, an evenly loaded conventional 112-ton loaded freight car (286,000 pounds) puts 35,750 pounds on each of its eight wheels. This weight is then transferred to an area of actual contact on the rail of approximately ¼" to ½". Therefore, the rail loading works out to be approximately 143,000 to 71,500 pounds per square inch respectively depending on the actual contact area! You definitely don't want one of these running over your hand or foot… because if it does, it will only happen once!

This tremendous rail load is then distributed to the railroad ties supporting the rails. The ties then distribute the load to the ballast. And the ballast then distributes the load to the subgrade (sometimes referred to as the roadbed).

Over time, the heavy loads from the railway traffic will tend to consolidate and compress the ballast and the subgrade below it. However, this consolidation isn't consistent over the entire length of track because the underlying soil conditions change, which is why the track must be restored… or "surfaced"… over the years.

For the rail, the ballast and subgrade tend to act as one big shock absorber or spring. The amount of rail flexing… occurring in the ballast and subgrade… is referred to as " rail deflection". If this big shock absorber stops working, bad things tend to happen to the railroad cars, and you really don't want to be anywhere around when that happens.

For a railroad company, the amount of rail deflection is one of the best measurable indicators of when the ballast needs to be surfaced (restored). Of the total deflection, about 40% of the deflection occurs in the ballast, another 40% in the subgrade, and with the remaining 20% occurring in the rail and ties.

Subgrade and Sub-ballast

Obviously, rail construction doesn't begin with the rail. First, it starts with the existing grade (ground)… then the ballast… then the ties… then, *surprise*, the tie plates (which attaches the rail to the ties – See Figure 9)… and then finally, the rail.

Figure 9 – An installed Tie Plate

The subgrade is the existing soil structure that supports the ballast. As mentioned previously, it is sometimes referred to as the "roadbed". Sometimes, it is also incorrectly referred to as the "railbed" or "trackbed". These terms…

"railbed" or "trackbed" are generally referring to the layers of ballast used directly under the rail or track. So, remember "roads are on the ground" and "rails are on ballast". Got it?

The ballast is any granular material placed on the subgrade. Originally, ballast was made up of cinders or various gravel and sand mixtures. This original ballast is often found today, but over the years it has worked its way down into the sub-ballast from years of vibration and weight from passing trains. Today's ballast is generally stone mined from quarries.

The sub-ballast is the lower zone of the ballast. It consists of poorer-quality of material used to separate the large-grained heavily-loaded upper ballast from the fine-graded subgrade below. It generally contains fines that have abraded from the upper ballast and then worked their way down into the sub-ballast.

Current construction procedures call for a distinct layer of sub-ballast placed on the subgrade which is then rolled and compacted prior to placing the ballast over it. This old and new ballast serve to distribute the loads from the ballast to the subgrade. Sub-ballast also separates the larger ballast stone from the fine-graded subgrade below. The sub-ballast also provides another benefit in that it tends to drain water away from the subgrade which avoids saturating the subgrade, and consequently, weakening it.

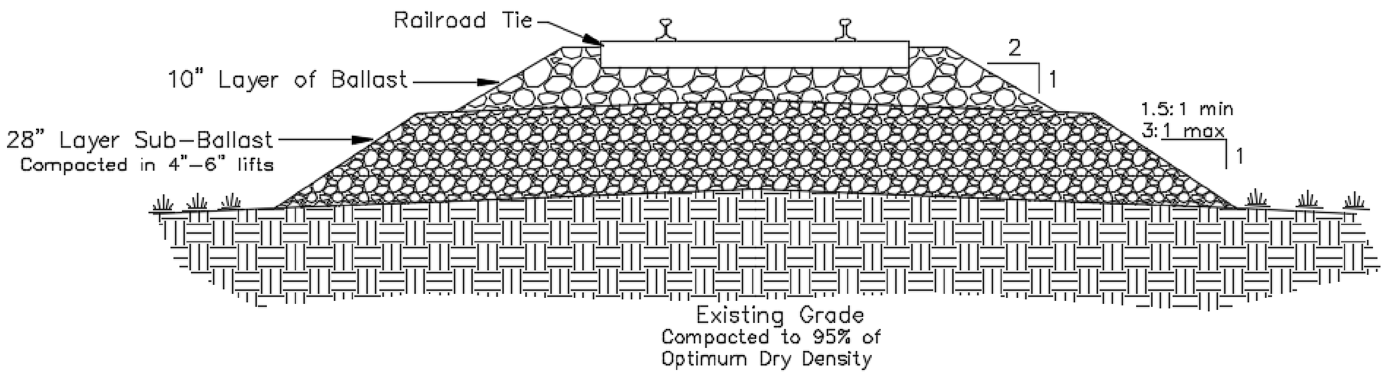

Figure 10 - Example for Heavy-Duty Track Cross-section

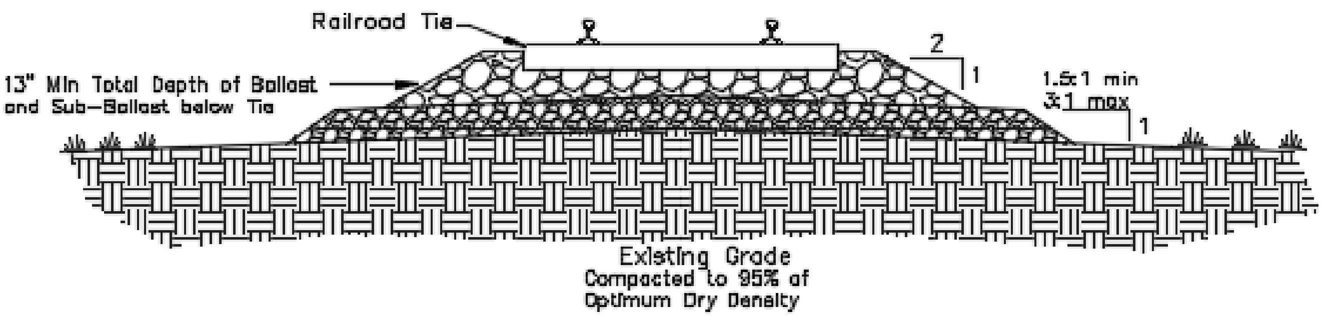

Figure 11 - Example for Light Rail Transit Track Cross-section

Note: Different railways will use different cross-sections on their lines depending on their intended use, regional soil conditions, weather, moisture, and engineering specifications.

Early track was generally constructed by cutting through the hills and placing the excavated material in the valleys or low areas. This helped reduce grade transitions and minimized the cost of hauling in expensive fill for the track construction. The ties and rails were then placed directly on the prepared roadbed allowing trains to bring in the ballast which was dumped directly on the track. The track crews would then jack and surface the track by hand. For old track, these original rail roadbeds still exist today but are now buried below multiple layers of newer ballast from years of surfacing projects. The depth of the sub-ballast in these old lines is a good indicator of the original bearing capacity of the subgrade. How is that? Simple… the greater the depth of the sub-ballast, the weaker the subgrade.

Subgrade Highlights…

1) For existing lines, the existing subgrade is something you're going to have to work with. It's probably not going to be economically feasible to remove an existing rail line, ballast, sub-ballast, and the existing subgrade just to rework the subgrade only to then rebuild it all again.
2) You're more likely to add ballast to the existing line so as to reduce the loads being placed on the existing subgrade.

3) Additionally, if possible, you might be able to design and construct an improved drainage system to lower the water table under the track, and thereby, strengthen the existing subgrade.

Rule of Thumb: Soils lose approximately 50% of their strength when they are saturated. Good drainage is a must for railroads.

Figure 12 – Railroad drainage ditch to manage stormwater

Drainage

Drainage is a critical component of track design. Railroads become very effective dams that run for miles. Consequently, maintaining stormwater flows from one side to the other requires conveyance systems through the track at proper intervals and critical locations. What was once a stormwater sheet flow across the surface, the water is now concentrated into point discharges at specific locations that are constructed through the railbed. Sometimes, these are constructed with round culverts, with box culverts, or with bridging. The sizing and locations of the discharge points are critical to avoid upstream and downstream flooding and to avoid saturating the soils under the railroad.

Figure 13 – Rail drainage system using a round culvert

Figure 14 – Rail drainage system using a box culvert

Ballast

The Ballast is the stone or other granular material placed on the subgrade. Its purpose is to distribute the load from the ties to the subgrade. It also provides the required lateral and longitudinal restraint to the ties and rails. The ballast takes the high load impacts and energy of the passing trains and distributes it to the sub-ballast and subgrade.

As discussed previously, the ballast is sometimes referred to as the “railbed” or “trackbed”. (Remember the roadbed is the subgrade.) See Figure 15 below to see how the train loads are dissipated from the rail car to the subgrade below.

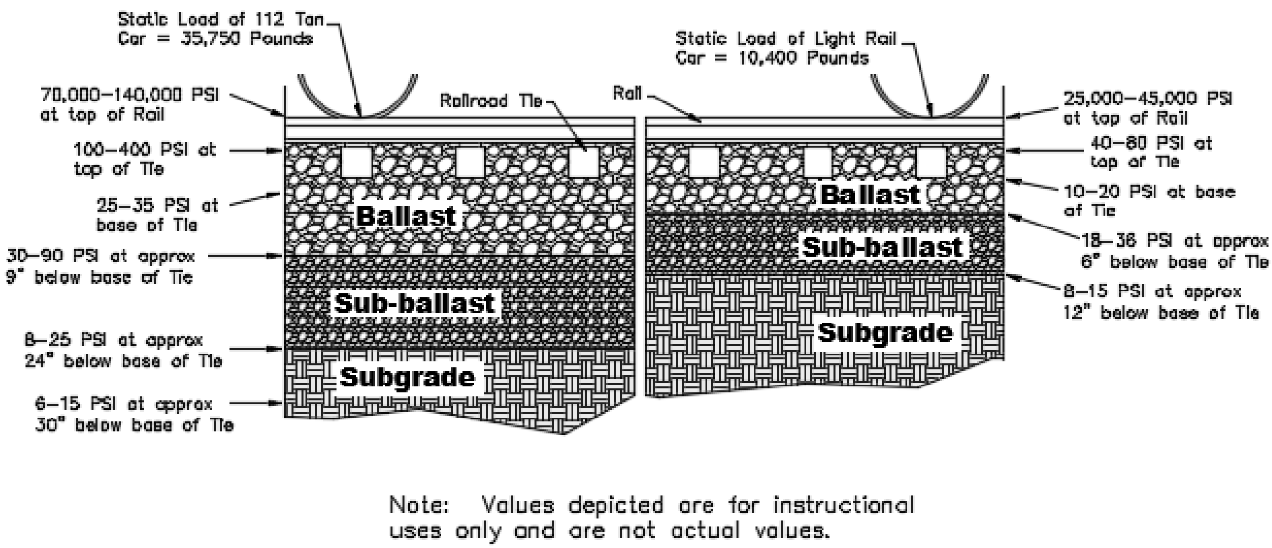

Figure 15 Distribution of loads from the rail to the subgrade

Railroad Ties

The railroad ties provide the transition from the “rigid” rail to the “elastic” ballast and subgrade. The next time you’re at a railroad crossing waiting for the train to clear the intersection, observe the elasticity of the ballast and subgrade by watching the vertical movement of the rail and ties as the train’s wheels move along the track.

The railroad ties are readily visible and easily accessible for inspection and replacement when needed. The predominant ties in use today are timber and concrete. Most North American ties are timber, while other areas around the world use concrete or some other manufactured materials. Timber ties are cheaper but concrete ties are more durable. Which is better…? That depends on the specific situation, location, and the railroad.

Timber Ties


Figure 16 - Railroad Ties – The good and the bad

The life span of timber ties ranges from 8 to 25 years. That seems like quite a spread for a simple timber tie, but like most things, you get what you pay for. The cheaper the tie the shorter the life spans.

Some factors that affect the durability and life-span of ties are:

Timber species... Obviously, some species last longer than others, but are they economically and readily available?

Seasoning… All ties must be seasoned before they can be preserved. The goal of seasoning is to reduce the interior timber's moisture to a level that it can absorb a preservative. For example, when oak is first cut, it has a moisture content between 75-80%. The goal is to get it below 50% which may take 12-16 months. But care must be taken to avoid over-seasoning, under-seasoning, or too rapid-seasoning which are all bad for a tie's life span.

Seasoning yards are typically in the open air without buildings or walls to restrict air circulation. The ties are stacked in a manner to promote the air circulation around each tie. This requires a lot of land and covered yards to properly season the timber. Then comes the monitoring, boultonizing, pre-heating, and inspections for defects (shakes, splits, checks, and wanes – See Figure 17). And, finally, comes the timber preservation through the use of creosote, pentachlorophenol, copper arsenate, copper azole, or some other preservative.

Figure 17 - A tie using a gang nail plate to control splitting during the curing process

Installation's environment or climate… The temperature and moisture of the installation's location are the biggest factors affecting the tie. Years ago a *Decay Hazard Map* was developed which indicated the worst two areas in the U.S. for using timber ties. These are the Southeast and the coastal areas of Oregon & Washington. It also reported that moderate levels of decay occur in central and eastern US. And the lowest levels of decay occur in the western US.

Traffic tonnage and frequency of traffic… These two factors are the source of many of the problems with timber ties. The higher rail car loading and the increase in the frequency of traffic are two critical factors that can significantly decrease a timber tie's life span.

Concrete Ties

The life span of concrete ties range from 30 to 60 yrs depending on how they're manufactured. Some of the benefits of concrete ties are they provide a more stable track bed… resulting in a smoother ride… which allows for longer life spans for track and cars, lower fuel consumption, and lower levels of maintenance.

Manufacturing of concrete ties requires an engineering design for the specific application and a fabrication process that incorporates the use of pre-stressed steel. From your structural training you will remember concrete is very strong in compression but is weak when in tension. To overcome this weakness in tension, it can be pre-stressed into a permanent state of compression with steel members during the curing process.

Some of the "cons" for concrete ties are the concrete ties weigh 3-4 times more than timber ties, they require special rail fasteners which cannot be changed for the life of the tie, the positions of the rail fasteners are set during the manufacturing process, and because of the higher loading on these concrete ties, a more durable ballast is required.

Rail

The rail provides the bearing surface for the rail cars' wheels and the rail foundation provides the required support of the rail and cars. Prior to the 1960s, the average freight car carried 50 tons, but by 1965, they carried 80 tons. Then by 1980 it was 100 tons, and by 1999 it was 112 tons. And that trend is likely to continue.

For new rail, improvements in the rail metallurgy and the management of rail temperature stress is continuing to improve rail lifespan, but rail loads, frequency of use, and rail curves create significant challenges. Fortunately for us, the metallurgy involved in this is beyond the scope of this course.

Prior to 1900, the standard rail length was 30 feet, but in the early 1900s, the length was increased to 33 feet. Do those lengths really matter today? Surprisingly, it does because much of that rail is still in use today! Then, during WW I, it became 39 feet and was increased again around 1980 when the options were 39 feet or 78 feet. Today, the typical options for new rail are 80 feet and 39 feet. Again, many railroads are still using and re-using rail produced almost 100 years ago. Why? Because rail companies can save significant costs by re-using these older rails.

Figure 18 – A section of rail manufactured in Tennessee in 1912
and still being used in 2018!

The next generation of rail standards was the American Railway Association using the "ARA" branding. They were followed by the American Railway Engineering Association with their brand of "RE".

Rail Markings

The various rails are specified by their weight per yard… i.e. 136RE is 136 pounds per yard using the AREA specifications… weighing 136 pounds per yard (3.0 ft) in length (0.91 m). In the past 20 years, most of what has been produced is 115RE, 132RE, 136RE, and 141RE.

It's interesting to observe the rail markings stamped on each rail because they tell you so much about that rail. Besides telling you when and where it was made, it can inform you of the weight, the rail design, the manufacturing process, and the manufacturer. For example, the marking of **136 HF OH CF&I 1941 //// E 17** indicates the following:

136 lbs/yard = (weight per yard of the rail)
HF = Head Free (rail design)
OH = Open Hearth steel (manufacturing process)
CF&I = Colorado Fuel & Iron (manufacturer)
1941 = Year of manufacture
//// = month of manufacture (4 slashes is April)
E = rail number
17 = ingot number

Another example is **11228 RE CC TENNESSEE 1939 /////** which would indicate the following:

11228 = 112 lbs / yard of section 28
RE = American Railway Engineering Association Design (AREA)
CC = Controlled Cooling manufacture process (plus CH if heat hardened)
Tennessee = Tennessee Coal and Iron Company
1939 = Year of manufacture
///// = month 5 (May)

Sometimes, the other side of the rail may have something like this... **63345 E 17**

63345 = section
E = rail number
17 = ingot number

The rail stamps are often hidden behind layers of rust such that you may need to run your hand across the side of the rail to locate the stamp. Even then, it may still be difficult to read. Wiping it with a rag sometimes helps to make it more legible. Another option is to use a piece of chalk to rub across the stamp to make the letters legible. See Figures 19, 20, and 21 showing different rail stamps photographed for this course.

Figure 19 – Rail stamp in its original condition. This one was relatively easy to find because of its good condition. Normally, the stamps are difficult to find because of being covered with rust. This 132 pound RE rail was manufactured in 1974.

Figure 20 – A 112 pound RE rail manufactured in Tennessee in December 1947 with the stamp highlighted using chalk.

Figure 21 – A rail manufactured in Colorado and currently being used in Florida

Turnouts

Turnouts are a necessary evil. What…? What does that mean? Well, they are “necessary” in that they are required to get a product to or from the customer’s property, but “evil” because they are expensive to maintain, in addition to the fact that most derailments occur at turnouts… even though they’re used at low speeds.

So, what is a turnout? Turnouts allow a train to exit a main line and switch to the customer’s track to load or unload their rail cars. Let’s look at some of the components of a turnout since much of a private sector railroad engineer’s work will involve a turnout and possibly some ladder tracks. Obviously, there are turnouts that don’t access a customer’s property, but rather, the main line simply forks to create another main line that heads in a different direction. However, the railroad’s engineer will likely design this section for the railroad… but we’re going to focus on the customer’s engineer.

A **Switch** is the mechanism used to direct a train from one track to another track or from a railroad company’s track to the customer’s tracks. It can be operated manually or electrically using a remote control. It physically moves the turnout’s track rails to align with the main tracks. Then, as the train approaches, the wheels are forced to follow the turnout track. See Figures 22 and 23.

Figure 22 – A manual switch with a turnout for a customer's facility

Figure 23 – An electric switch on a rail line

A **Frog**… at long last…**.** I told you I wouldn't forget the Frog! The Frog is the point where the turnout's outside rail crosses the main line's inside rail. Many frogs are single-piece castings but there are fabricated frogs that are bolted together. Frogs are specified by a frog number with the smaller the frog number the greater the angle of divergence. For example, a Number 6 Frog is a low-speed high-angle of divergence turnout. A Number 20 Frog is a high-speed low-angle of divergence turnout. See Figures 24 and 25.

Figure 24 – A frog located at a turnout

Figure 25 – Another frog showing the geometry of a turnout

The **Straight Track** is the through track or main track that a train will travel if it is not switched to use the turnout track.

And the **Diverging Track** is just that… the track that is diverging from the main line onto the customer's property. The railroad company will typically own the track to end of the long ties… however, the customer's engineer ***may*** design the entire turnout with the review and approval of the railroad.

Road Crossings

If you're in land development, at some point in time you're going to need to cross a railroad track for either access to your client's property or because your roadway project will cross an active railroad. Regardless of the reason, meetings with the railway engineers are rarely enjoyable and you can expect to have many meetings that will be challenging. Why is this? For a number of reasons that we will discuss briefly.

Figure 26 - A road and sidewalk crossing

First, railroads don't make money on their railroad crossings. They make money from trains carrying cargo and passengers on those tracks. When it comes to permitting a new crossing, the railway company must pay their engineers to meet, design, meet, review, meet, inspect, meet, construct, meet, inspect again, obtain asbuilt surveys, review, and approve. That's a lot of work for just a single crossing!

Second is the cost to maintain the crossing for vehicular traffic as well as rail traffic. However, the maintenance cost for a railroad crossing is significantly higher per linear foot than for the standard track maintenance per linear foot. And how long do you think that railroad crossing will be needed? A year, 10 years, 50 years, 100 years? And what do these maintenance costs total during the life of the crossing?

Third is the simple fact that no one, absolutely no one, actually likes a railroad crossing. No business man wants to have his access blocked by a train. No person wants to wait for a train to clear the intersection. No one likes the "bumps" in the road to cross a track. First Responders don't like delays caused by trains blocking the crossing during an emergency. And no one likes to live next to a track with a nightly 3am train. And… the local governing agencies don't like receiving all those calls from people complaining about the train's schedule, the horn, the frequency of trains, the train's speed or lack of speed… well, you get the picture.

Rail crossings are constructed from many materials dependent on location, climate, traffic loading, and pedestrian needs. They can be constructed of concrete, asphalt, timber, other synthetic materials, or a combination of materials. See Figures 27, 28, and 29.

Figure 27 – A rail crossing using asphalt, concrete, & timber materials

Figure 28 showing a road crossing using concrete.

Figure 29 – A pedestrian rail crossing using synthetic materials

With all that said, road crossings are an inevitable consequence of railways and will remain so. Consequently… we need to consider and remember the following for a better understanding of crossings and their requirements:

(a) Poorly located crossings create much frustration and anger for motorists because of delays.
(b) Road crossings located near rail turnouts for rail yards or terminals may cause lengthy delays for drivers.
(c) Delays cause not only inconvenience but may create life safety issues for those needing emergency care.
(d) Potential delays frequently are the root cause of auto-train accidents.
(e) Road crossings on or near curves may reduce visibility of oncoming trains.
(f) Poor visibility may require crossing arms, lights, and alarms, all of which can fail.
(g) Railroad tracks are designed to flex under loads but roadways are designed to be rigid. Where these two systems meet typically causes most of the issues for rough road crossings.
(h) Rail components all have different life cycles… rail is about 50 yrs, ties are about 30 years, and ballast life varies widely.
(i) Rail repairs will shut down the road crossing, but road repairs may not impact rail traffic since only approved rail contractors can work on the railroad crossing itself. Road contractors must stop their construction short of the rail crossing.

Remember that road crossings are actually part of the railroad track structure… not the roadway's. In most cases, the roads are crossing the railroad tracks since the tracks were likely there long before the roads were built. Except for a few isolated cases, a standard road bed can't support the loads imposed by a train. The railroad crossing must be supported by the rail ties and the ballast… as you remember from our previous discussion of the rail cross section. Right? Great!

Rail Crossing Signage, Gates, & Signals

We won't go into much detail on this topic as it is best left to the experts, and the experts are the Railway's engineers or an engineering firm that specializes in the signalization of rail crossings. The designs take into account the track geometry, grades, train speed, type of crossing needed, sensors, switches, etc. What we will look at are some of the different crossings you have probably already seen in your trips around the country but probably never paid close attention to the specific crossings themselves.

Some of the crossing types are:

(a) Rural crossings in remote areas or farms. These are 1-laned or 2-laned road crossings and may have unpaved approaches. See Figure 30.

(b) Suburban areas. These are crossings located in developing areas with a mixture of large privately owned parcels and new residential and small commercial areas. See Figure 31.

(c) Urban. These are located in downtown areas and are the ones that receive the most complaints and create the most headaches for the railroads. See Figure 32.

(d) Elevated. Typically found in areas where the terrain makes at-grade crossing impractical or warrant the additional cost for vertical separation due to the large volume of traffic or critical access points. See Figures 33 and 34.

(e) Navigable waterways are particularly challenging for railroads because of the spans required and the types of boats using the waterways for recreation or commerce. See Figure 35.

Figure 30 – A rural road crossing

Figure 31 – A suburban road crossing

Figure 32 – An urban road crossing

Figure 33 – An elevated commuter rail overpass to avoid an at-grade crossing

Figure 34 – An elevated road overpass to avoid an at-grade railroad crossing

Figure 35 – Navigable waterways are particularly challenging for railroads

The type of crossing design will be dependent on a number of factors such as amount of vehicular traffic, sight distance limitations due to vegetation, terrain, or construction, grades, type of traffic (commercial, industrial, residential, farm) and other site specific factors. Additionally, to obtain a new railroad crossing permit may require closing 1 or more existing railroad crossings on the line before the railway company will permit a new crossing. As you can imagine, finding existing crossings that can be closed is not an easy venture.

Customer Rail Facilities

For freight trains, the railway companies need rail facilities to load and unload the customers' products whether it is coal, aggregate, chemicals, merchandise, autos, tractors, etc. The size of these rail facilities will be dependent on the amount of product being handled and the number of rail cars required to transport it. The loading docks may be on-grade or off-grade (elevated loading docks) as may be required by the product being transported. Depending on the number of cars and the time to unload/load, the railway company may frown upon needing to make multiple moves which might block the main line or side track from use by other trains. Obviously, the railway doesn't want to block these tracks any longer than absolutely needed.

The number of cars required for shipping will determine the number of supporting tracks (ladder track – see Figure 36) needed to temporarily park the cars until each car can be moved to the loading docks. Ladder tracks are a series of parallel tracks generally on the customer's property to move rail cars as needed for shipping or receiving. In situations such as this, customers may need to use their own locomotive to move cars as needed to prepare for railway deliveries or shipping.


Figure 36 - A customer's ladder tracks

Glossary of Terms

Freight train – A train dedicated to transporting products or cargo rather than passengers. Cargo transported by freight cars.

Freight car – An unpowered railway vehicle designed to transport freight and cargo. A variety of freight car types are in use to handle different types of products.

Frog - A casting with "X" shaped grooves used in switches, turnouts, or crossovers. Allows a rail car to transfer from one track to another by crossing a rail and is part of a turnout.

Gauge - The gauge of a railroad is the distance between the inside vertical surfaces of the head of the rail. Standard gauge in the U.S. is 4 feet 8-1/2 inches.

Guard rail - A second rail section along a track providing rail on both sides of the wheel flange. Guard rails can be found on curves with a tight radius, switches, crossings, and are sometimes found in train yards and bridges to prevent derailments.

Heavy rail - A city-based transit rail system that runs on its own dedicated track with sections elevated or underground. A subway is considered heavy rail and denotes a passenger rail line or an inter-city rail. Do not confuse the term *heavy rail* with *heavy freight*.

Mainline - A track that is used for through trains between cities. Main line tracks are built for higher speeds and heavier loads with an increased frequency of traffic than other tracks.

Siding - A second parallel track running for a short distance along another railway line which allows a train to pass each other. A siding is typically a lower speed track used for lighter loads and less frequency. If the siding happens to be connected at both ends to the mainline, it is often referred to as a loop.

Spur - A stretch of rail that branches off the main line.

Switch - A railroad switch (or *turnout)*, is a mechanical system that transfers trains from one track to another. They are located at spurs and sidings.

Tie - Beams of wood or concrete that are placed beneath and perpendicular to track to provide support for the rails. The ties transfer the rail car loads from the rail to the ballast and subgrade. The ties also hold the rails in place and keep them spaced at the correct gauge.

Tie plate - An iron or steel plate used to spread the weight of rail over a larger area of the tie. They attach the rail to the tie using spikes, bolts, and/or clips depending on the tie material.

Turnout - A turnout (or railroad switch), is a mechanical system that allows trains to be moved from one track to another, such as at a railway junction, a siding, or a spur line.

SUMMARY

As stated in the introduction, the intent of **Railroads – An Introduction** is to introduce you to the fundamental components that make up a railroad system and how they interact with each other. The course should help you to speak intelligently with your client and with the railway engineers about the design process and the permitting required for construction. You should be sufficiently familiar with the rail components to discuss the railroad requirements, understand what the railroad representatives are saying, and ease the pains involved if you get a project that requires a railroad construction permit. It is NOT intended to provide the knowledge needed for you to actually design a railroad, the turnouts, or any railroad signals that may be required. For an actual design, you should involve an experienced railroad engineer.

The course began by providing a brief history of railroads in North America and then presented the technical topics on railroad components consisting of the subgrade, ballast, ties, rail, turnouts, road crossings, and ladder tracks. The figures and diagrams used to discuss railroad geometries and rail loading were presented to aid with visualizing the components to better understand each component and be able to briefly describe them to those who don't know. With some understanding of these topics, you should be better equipped to discuss rail issues for commercial or industrial projects that include rail services and have more productive discussions during the project development.

