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INTRODUCTION

Rail transport is the transport of passengers and goods by means of wheeled vehicles specially designed to run along railways or railroads. Rail transport is part of the logistics chain, which facilitates the international trading and economic growth in most countries.

A typical railway/railroad track consists of two parallel rails, normally made of steel, secured to cross-beams, termed sleepers (U.K.) or 'ties' (U.S.). The sleepers maintain a constant distance between the two rails; a measurement known as the 'gauge' of the track. To maintain the alignment of the track, it is either laid on a bed of ballast or else secured to a solid concrete foundation, and the whole is referred to as Permanent way.

Railway rolling stock, which is fitted with metal wheels, moves with low frictional resistance when compared to road vehicles; on the other hand locomotives and power cars normally rely solely for traction on the point of contact of the wheel with the rail whence they obtain adhesion i.e. the part of the transmitted axle load that makes the wheel "adhere" to the smooth rail. Whilst this is usually sufficient under normal dry rail conditions, adhesion can be reduced or even lost through the presence of unwanted material on the rail surface, such as grease, ice or dead leaves

DESCRIPTION

Permanent way is the generic term for the track – rails, sleepers and ballast – on which railway trains run. British practice has diverged quite sharply from that in North America and continental Europe. Although the configuration of the track today would be recognized by engineers of the 19th century, it has developed significantly over the years as technological improvements became available, and as the demands of train operation increased.

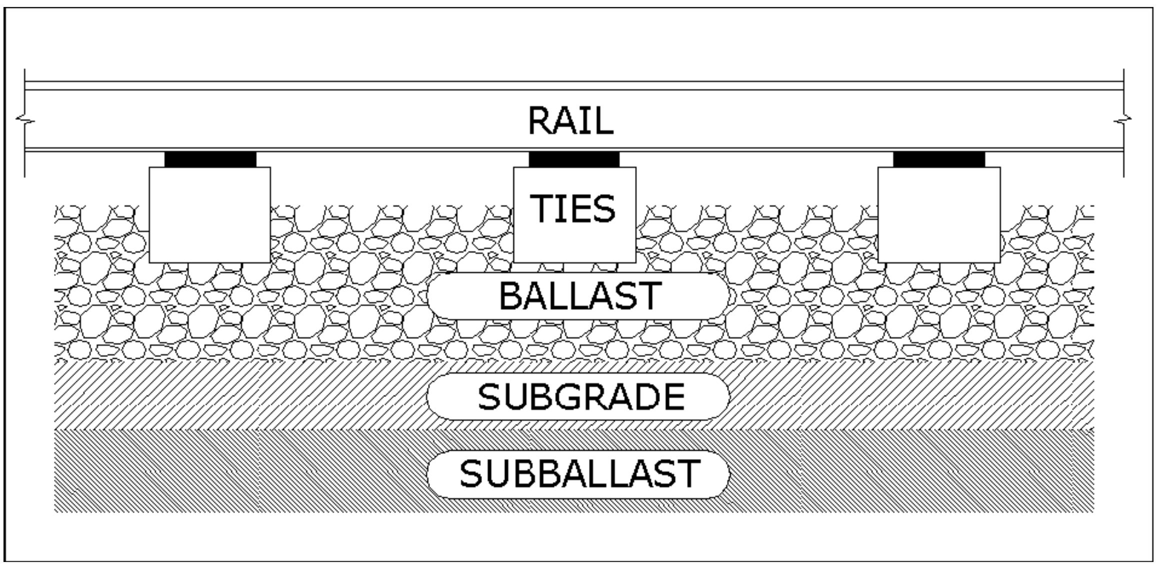
However the traditional form consists of

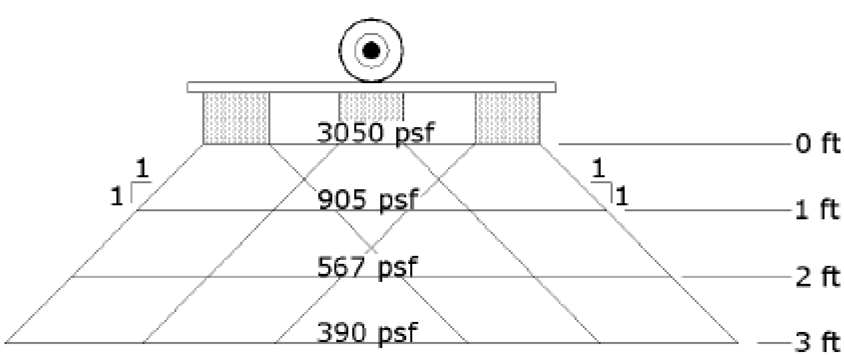
- two parallel iron or steel rails, a fixed distance apart, on which the wheels of trains run,
- transverse beams called sleepers, set at a close spacing, that maintain the specified spacing of the rails and that distribute the concentrated loading of train wheels,
- fastenings to hold the rails and sleepers together,
- a layer of mineral ballast placed under and around the sleepers, to further distribute the train loading, and to resist lateral displacement of the sleepers.

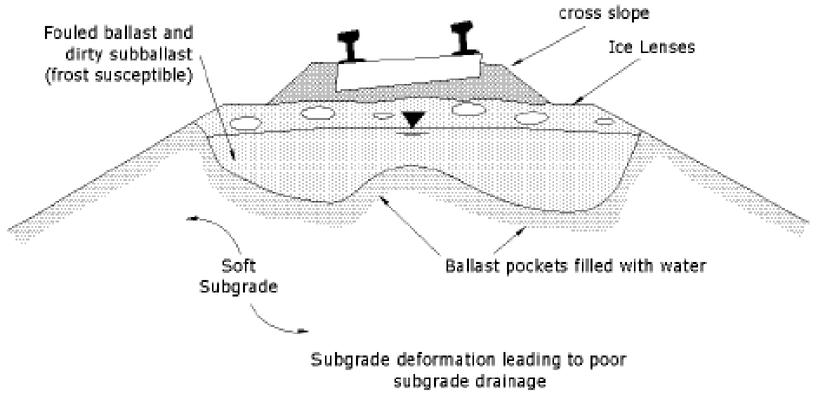
The spacing between the rails is referred to as the gauge, always measured between the inner faces of the rails. The original soil below the ballast (or a strengthened substitute) is called the formation.

Components and Functions

The track structure is made up of subgrade, sub-ballast, ballast, ties and rail as illustrated in Figure . Each of these contributes to the primary function of the track structure, which is to conduct the applied loads from train traffic across the subgrade safely. The magnitudes of typical stresses under a 50,000 lb axle load are shown in Figure 4-5. These stresses are applied repeatedly, and each repetition causes a small amount of deformation in the subgrade. In theory, the track structure should be designed and constructed to limit rail deflections to values which do not produce excessive rail wear or rates of rail failure. In reality, cumulative deformation of the subgrade causes distortion of the subgrade, leading to formation of .ballast pockets"(Figure 4-6) or outright shear failure.







Subgrade

The purpose of the subgrade is to support the track structure with limiting deflections. Every subgrade will undergo some deflection (strain) as loads (stress) are applied. The total displacement experienced by the subgrade will be transmitted to other components in the track structure. The stiffer the subgrade (i.e., the higher the modulus of elasticity), the lower the deflection values will be. It is important that adequate subgrade strength and stiffness be available on a year-round basis, particularly during spring thaw and following heavy precipitation events.

The strength, stiffness and total deflection of the subgrade can be improved by:

- Carefully selecting materials that are naturally strong (sand, gravel, boulders) with a high angle of internal friction.
- Limiting access to water to avoid buildup of pore water pressure and subsequent reduction of strength.
- Improving the soil properties, using techniques such as compaction, in situ densification, grouting and preloading.
- Maintain good drainage.
- Maintain stable subgrade geometry.

Sub-ballast

The purpose of sub-ballast is to form a transition zone between the ballast and subgrade to avoid migration of soil into the ballast, and to reduce the stresses applied to the subgrade. In theory, the gradation of the sub-ballast should form a filter zone that prevents migration of fine particles from the subgrade into the ballast. In practice, insufficient attention has been placed to sub-ballast gradation historically, and much of the sub-ballast does not adequately perform that function. This notwithstanding, the number of occurrences of subgrade contamination of ballast is relatively few.

Switch Ties

Switch ties are commonly hardwood species, usually provided in either

6" or 12" increments beginning at 9’-0" up to 23’-0" in length. Nominal cross-section dimensions are 7" x 9", although larger ties are specified by some railways. The primary use for switch ties is relegated to turnouts (thus their name). However, they are also used in bridge approaches, crossovers, at hot box detectors and as transition ties. Some railways use switch ties in heavily traveled road crossings and at insulated rail joints. Switch ties ranging in length from 9’-0" to 12’-0" can also be used as "swamp" ties. The extra length provides additional support for the track in swampy or poor-drained areas. Some railways have utilized Azobe switch ties (an extremely dense African wood) for high-speed turnouts. The benefits associated with reduced plate cutting and fastener retention may be offset by the high import costs of this timber.

Softwood Ties

Softwood timber is more rot resistant than hardwoods, but does not offer the resistance of a hardwood tie to tie plate cutting, gauge spreading and spike hole enlargement (spike killing).Softwood ties also are not as effective in transmitting the loads to the ballast section as the hardwood tie. Softwood and hardwood ties must not be mixed on the main track except when changing from one category to another. Softwood ties are typically used in open deck bridges.

Concrete ties are rapidly gaining acceptance for heavy haul mainline use, (both track and turnouts), as well as for curvature greater than 2°. They can be supplied as crossties (i.e. track ties) or as switch ties. They are made of pre-stressed concrete containing reinforcing steel wires. The concrete crosstie weighs about 600 lbs. vs. the 200 lb. timber track tie. The concrete tie utilizes a specialized pad between the base of the rail and the plate to cushion and absorb the load, as well as to better fasten the rail to the tie. Failure to use this pad will cause the impact load to be transmitted directly to the ballast section, which may cause rail and track surface defects to develop quickly. An insulator is installed between the edge of the rail base and the shoulder of the plate to isolate the tie (electrically). An insulator clip is also placed between the contact point of the elastic fastener used to secure the rail to the tie and the contact point on the base of the rail.

Steel Ties

Steel ties) are often relegated to specialized plant locations or areas not favorable to the use of either timber or concrete, such as tunnels with limited headway clearance. They have also been utilized in heavy curvature prone to gage widening. However, they have not gained wide acceptance due to problems associated with shunting of signal current flow to ground. Some lighter models have also experienced problems with fatigue cracking.

Rail Joints:
The purposes of the rail joint (made up of two joint bars or more commonly called angle bars) are to hold the two ends of the rail in place and act as a bridge or girder between the rail ends.6 The joint bars prevent lateral or vertical movement of the rail ends and permit the longitudinal movement of the rails for expanding or contracting. The joint is considered to be the weakest part of the track structure and should be eliminated wherever possible. Joint bars are matched to the appropriate rail section. Each rail section has a designated drilling pattern (spacing of holes from the end of the rail as well as dimension above the base) that must be matched by the joint bars. Although many sections utilize the same hole spacing and are even close with regard to web height, it is essential that the right bars are used so that fishing angles and radii are matched. Failure to do so will result in an inadequately supported joint and will promote rail defects such as head and web separations and bolt hole breaks. There are three basic types of rail joints

- Standard
- Compromise
- Insulated

Standard Joints

Standard joint bars connect two rails of the same weight and section. They are typically 24" in length with 4-bolt holes for the smaller rail sections or 36" in length with 6-bolt holes for the larger rail sections. Alternate holes are elliptical in punching to accommodate the oval necked track bolt. Temporary joints in CWR require the use of the 36. bars in order to permit drilling of only the two outside holes and to comply with the FRA Track Safety Standard's requirement of maintaining a minimum of two bolts in each end of any joint in CWR.

Compromise Joints
Compromise bars connect two rails of different weights or sections together. They are constructed such that the bars align the running surface and gage sides of different rails sections. There are two kinds of compromise joints:

- Directional (Right or Left hand) compromise bars are used where a difference in the width of the head between two sections requires the offsetting of the rail to align the gage side of the rail.
- Non-directional (Gage or Field Side) are used where the difference between sections is only in the heights of the head or where the difference in width of rail head is not more than 1/8" at the gage point. Gauge point is the spot on the gauge side of the rail exactly 5/8" below the top of the rail.

To determine a left or right hand compromise joint:

- Stand between the rails at the taller rail section.
- Face the lower rail section

- The joint on your right is a "right hand".
- The joint on your left is a "left hand".

GENERAL ANALYSIS

Alignment of Tracks

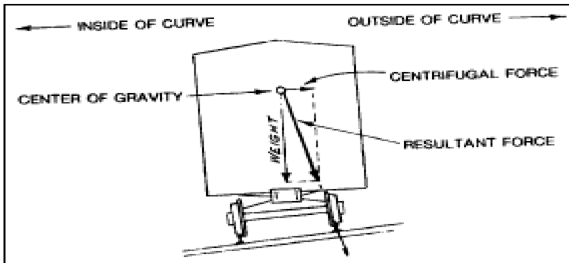
The route upon which a train travels and the track is constructed is defined as an alignment. An alignment is defined in two fashions. First, the horizontal alignment defines physically where the route or track goes (mathematically the XY plane). The second component is a vertical alignment, which defines the elevation, rise and fall (the Z component).Alignment considerations weigh more heavily on railway design versus highway design for several reasons. First, unlike most other transportation modes, the operator of a train has no control over horizontal movements (i.e. steering). The guidance mechanism for railway vehicles is defined almost exclusively by track location and thus the track alignment. The operator only has direct control over longitudinal aspects of train movement over an alignment defined by the track, such as speed and forward/reverse direction. Secondly, the relative power available for locomotion relative to the mass to be moved is significantly less than for other forms of transportation, such as air or highway vehicles. Finally, the physical dimension of the vehicular unit (the train) is extremely long and thin, sometimes approaching two miles in length. This compares, for example, with a barge tow, which may encompass 2-3 full trains, but may only be 1200 feet in length. These factors result in much more limited constraints to the designer when considering alignments of small terminal and yard facilities as well as new routes between distant locations.

The designer MUST take into account the type of train traffic (freight, passenger, light rail, length, etc.), volume of traffic (number of vehicles per day, week, year, life cycle) and speed when establishing alignments. The design criteria for a new coal route across the prairie handling 15,000 ton coal trains a mile and a half long ten times per day will be significantly different than the extension of a light rail (trolley) line in downtown San Francisco curves as D (degrees per 20 meter arc). However, there does not seem to be any widespread incorporation of this practice. When working with light rail or in metric units, current practice employs curves defined by radius.
As a vehicle traverses a curve, the vehicle transmits a centrifugal force to the rail at the point of wheel contact. This force is a function of the severity of the curve, speed of the vehicle and the mass (weight) of the vehicle. This force acts at the center of gravity of the rail vehicle. This force is resisted by the track. If the vehicle is traveling fast enough, it may derail due to rail rollover, the car rolling over or simply derailing from the combined transverse force exceeding the limit allowed by rail-flange contact.
This centrifugal force can be counteracted by the application of super elevation (or banking), which effectively raises the outside rail in the curve by rotating the track structure about the inside rail. (See Figure) The point, at which this elevation of the outer rail relative to the inner rail is such that the weight is again equally distributed on both

rails, is considered the equilibrium elevation. Track is rarely super elevated to the equilibrium elevation. The difference between the equilibrium elevation and the actual superelevation is termed under balance. Though trains rarely overturn strictly from centrifugal force from speed (they usually derail first). This same logic can be used to derive the overturning speed. Conventional wisdom dictates that the rail vehicle is generally considered stable if the resultant of forces falls within the middle third of the track. This equates to the middle 20 inches for standard gauge track assuming that the wheel load upon the rail head is approximately 60-inches apart.

As this resultant force begins to fall outside the two rails, the vehicle will begin to tip and eventually overturn. It should be noted that this overturning speed would vary depending upon where the center of gravity of the vehicle is assumed to be.

There are several factors, which are considered in establishing the elevation for a curve. The limit established by many railways is between five and six-inches for freight operation and most passenger tracks. There is also a limit imposed by the Federal Railroad Administration (FRA) in the amount of under balance employed, which is generally three inches for freight equipment and most passenger equipment.



. Effect of Centrifugal Force

Centrifugal force, which is designated "F" in the following equation, increases with the square of the speed and increases in direct proportion to the degree of curvature:

$$F = \frac{W}{g} \times \frac{V^2}{r}$$

W = weight in pounds
g = gravity (32 ft/sec/sec)
v = velocity in ft. per sec.
r = radius of curvature in feet

Underbalance limits above three to four inches (to as much as five or six inches upon FRA approval of a waiver request) for specific passenger equipment may be granted after testing is conducted. Track is rarely elevated to equilibrium elevation because not all trains will be moving at equilibrium speed through the curve.

Furthermore, to reduce both the maximum allowable super elevation along with a reduction of under balance provides a margin for maintenance. Super elevation should be applied in 1/4-inch increments in most situations. In some situations, increments may be reduced to 1/8 inch if it can be determined that construction and maintenance equipment can establish and maintain such a tolerance. Even if it is determined that no superelevation is required for a curve, it is generally accepted practice to superelevate all

curves a minimum amount (1/2 to 3/4 of an inch). Each railway will have its own standards for superelevation and under balance, which should be used unless directed
The transition from level track on tangents to curves can be accomplished in two ways. For low speed tracks with minimum superelevation, which is commonly found in yards and industry tracks, the superelevation is run-out before and after the curve, or through the beginning of the curve if space prevents the latter. A commonly used value for this run-out is 31-feet per half inch of superelevation.
On main tracks, it is preferred to establish the transition from tangent level track and curved super elevated track by the use of a spiral or easement curve. A spiral is a curve whose degree of curve varies exponentially from infinity (tangent) to the degree of the body curve. The spiral completes two functions, including the gradual introduction of superelevation as well as guiding the railway vehicle from tangent track to curved track. The curve and the first portion of tangent past the curve due to the sudden introduction and removal of centrifugal forces associated with the body curve.
There are several different types of mathematical spirals available for use, including the clothoid, the cubic parabola and the lemniscate. Of more common use on railways are the Searles, the Talbot and the AREMA 10-Chord spirals, which are empirical approximations of true spirals. Though all have been applied to railway applications to

Alignment Design

All railway alignments would be tangent and flat, thus providing for the most economical operations and the least amount of maintenance. Though this is never the set of circumstances from which the designer will work, it is that ideal that he/she must be cognizant to optimize any design.
From the macro perspective, there has been for over 150 years, the classic railway location problem where a route between two points must be constructed. One option is to construct a shorter route with steep grades. The second option is to build a longer route with greater curvature along gentle sloping topography. The challenge is for the designer to choose the better route based upon overall construction, operational and maintenance criteria. Such an example is shown below.
Suffice it to say that in today's environment, the designer must also add to the decision model environmental concerns, politics, land use issues, economics, long-term traffic levels and other economic criteria far beyond what has traditionally been considered. These added considerations are well beyond what is normally the designer's task of alignment design, but they all affect it. The designer will have to work with these issues occasionally, dependent upon the size and scope of the project.
On a more discrete level, the designer must take the basic components of alignments, tangents, grades, horizontal and vertical curves, spirals and superelevation and construct an alignment, which is cost effective to construct, easy to maintain, efficient and safe to operate. There have been a number of guidelines, which have been developed over the past 175 years, which take the foregoing into account. The application of these guidelines will suffice for approximately 75% of most design situations. For the remaining situations, the designer must take into account how the track is going to be used (train type, speed, frequency, length, etc.) and drawing upon experience and judgment, must make an educated decision. The decision must be in concurrence with that of the eventual

owner or operator of the track as to how to produce the alignment with the release of at least one of the restraining guidelines.

Though AREMA has some general guidance for alignment design, each railway usually has its own design guidelines, which complement and expand the AREMA recommendations. Sometimes, a less restrictive guideline from another entity can be employed to solve the design problem. Other times, a specific project constraint can be changed to allow for the exception. Other times, it.s more complicated, and the designer must understand how a train is going to perform to be able to make an educated decision. The following are brief discussions of some of the concepts which must be considered when evaluating how the most common guidelines were established.

A freight train is most commonly comprised of power and cars. The power may be one or several locomotives located at the front of a train. The cars are then located in a line behind the power. Occasionally, additional power is placed at the rear, or even in the center of the train and may be operated remotely from the head-end. The train can be effectively visualized for this discussion as a chain lying on a table. We will assume for the sake of simplicity that the power is all at one end of the chain.

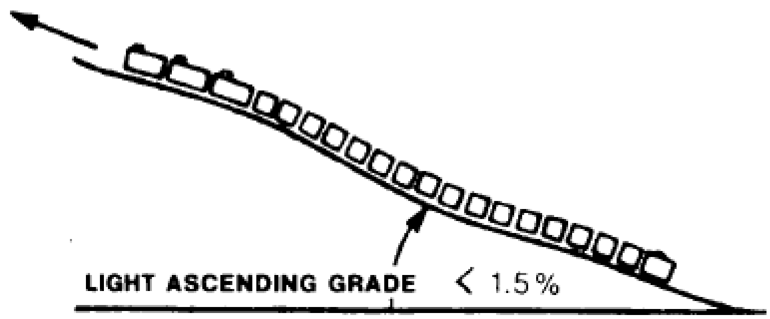
Trains, and in this example the chain, will always have longitudinal forces acting along their length as the train speeds up or down, as well as reacting to changes in grade and curvature. It is not unusual for a train to be in compression over part of its length negative longitudinal force) and in tension (positive) on another portion. These forces are often termed .buff. (Negative) and draft (Positive) forces. Trains are most often connected together with couplers (Figure 6-10). The mechanical connections of most couplers in North America have several inches (up to six or eight in some cases) of play between pulling and pushing. This is termed slack.

If one considers that a long train of 100 cars may be 6000’ long, and that each car might account for six inches of slack, it becomes mathematically possible for a locomotive and the front end of a train to move fifty feet before the rear end moves at all. As a result, the dynamic portion of the buff and draft forces can become quite large if the operation of the train, or more importantly to the designer, the geometry of the alignment contribute significantly to the longitudinal forces.

As the train moves or accelerates, the chain is pulled from one end. The force at any point in the chain is simply the force being applied to the front end of the chain minus the frictional resistance of the chain sliding on the table from the head end to the point under consideration.

As the chain is pulled in a straight line, the remainder of the chain follows an identical path. However, as the chain is pulled around a corner, the middle portion of the chain wants to deviate from the initial path of the front-end. On a train, there are three things preventing this from occurring. First, the centrifugal force, as the rail car moves about the curve, tends to push the car away from the inside of the curve. When this fails, the wheel treads are both canted inward to encourage the vehicle to maintain the course of the track. The last resort is the action of the wheel flange striking the rail and guiding the wheel back on course.

Attempting to push the chain causes a different situation. A gentle nudge on a short chain will generally allow for some movement along a line. However, as more force is applied and the chain becomes longer, the chain wants to buckle in much the same way an overloaded, un-braced column would buckle. The same theories that Euler applied to column buckling theory can be conceptually applied to a train under heavy buff forces. Again, the only resistance to the buckling force becomes the wheel/rail interface.



Drainage is the subject of storm water behavior as it relates to the properties of hydrology and hydraulics. This is a subject that is constantly being reviewed on a regular basis within the regulatory bodies of government and it is therefore always important to review local requirements to guide the engineer through the design process. Even though one method of analysis may be appropriate to use in an area one feels comfortable in, it may not be appropriate in another location. A good rule of thumb is to contact the local highway department as a starting point and continue your investigation to local authorities.

The engineer needs to be aware that one has to maintain existing drainage patterns and not increase headwaters upstream or downstream. Adjacent property owners, whether they are farmers or city dwellers, have certain rights and are protected under common law concerning storm water conveyance and elevation as it relates to property damage.

GENERAL RECCOMMENDATION

Signal System

Railway signaling techniques shall be applied at various LRT locations to enhance safety in the movement of trains and to improve the overall efficiency of train operations. These functions include the protection and control of track switches; the protection and control of bi-directional train operation where applicable; the protection for following trains operating with the normal current of traffic; and highway grade crossing warning. The need for signaling, and the type of signalization provided, shall be determined by the specific requirements of each line segment.

Automatic Block System

Automatic Block System (ABS) shall be installed at certain locations along the LRT right-of-way to permit higher operating speeds than would be possible by relying on line-of-sight operation without signals. The ABS system shall provide information to train operators concerning the condition and occupancy of the track ahead, and provide sufficient stopping distance, when required. Automatic Train Stop (ATS) shall be provided if a train passes a stop signal. A violation of a stop signal shall be reported to the Operations Control Center by means of the SCADA system.

Unless limited by operational constraints, all signals shall comply with a "double red" philosophy. Cab signals functioning in a "go-no-go" environment shall provide enforcement for all signaled moves, including those against the normal direction of traffic. There shall be no overlap where the next signal in advance is an "END ABS" sign.

All signals shall be controlled, in regard to any track switch in the block, to display a red aspect when:

- The switch points are not in position for safe train movement.
- A hand operated switch is not in the normal position.
- A switch-and-lock movement is not fully locked.
- An electric switch-locking movement is not fully normal.
- The selector lever of a dual-control switch-and-lock movement is not in the "MOTOR" position.
- A manual switch electric lock access door is not fully closed.

No signal shall display an aspect less restrictive than approach, when the next signal, in advance, displays an aspect requiring a stop. Three-aspect, non-interlocked signals shall display a proceed aspect when the next signal, in advance, displays an approach aspect.

Interlockings

Interlocking shall be provided for all power switches used on the mainline in open track. Interlocking signals shall be provided to govern train movements into and through interlocking limits. Detector, time, route, and approach locking shall be provided at all interlocking. Detector locking shall not be released until five seconds after the slow pick-up track repeater relays have closed their front contacts.

All non-interfering train movements, through interlocking, shall be permitted simultaneously.

Interlocking design shall comply with principles and accepted practices of the Association of American Railroads (AAR).

Highway Grade Crossing Warning

Warning devices for highway grade crossings shall be installed at certain locations. Each such crossing shall include automatic gates, LED flashing lights, bells, signs, approach and island track circuits, emergency batteries and associated circuitry, cabling and cases as required. Crossing gates shall be Western-Cullen-Hayes model number 3593-131 with “Gate Keeper” protective devices or approved equal.

The design of each crossing shall be specific to that site and shall provide a minimum of 20 seconds warning time, from the time that the lights first begin to flash until the time that a train traveling at track speed enters the crossing. The design of the crossing circuitry shall avoid unnecessary delays to motorists. Where necessary, the grade crossing warning system shall preempt adjacent traffic lights to avoid automobiles forming a queue across the tracks.

Center lane Divider Island shall be installed at all grade crossings to aid in the prevention of traffic gate runarounds. Crossings with permitted train speeds in excess of 30 mph shall have warning signs “High Speed Trains” with flashing yellow lights facing highway traffic. Provisions for the installation of video monitoring equipment shall be installed at each grade crossing. Highway grade crossing warning devices will be installed consistent with AAR Signal Manual and the Manual on Uniform Traffic Control Devices Standards (MUTCD).

Train to-Wayside-Communication System (TWC)

RTD's LRVs are equipped with a Train-to-Wayside Communication (TWC) system. The carborne portion of the TWC system consists of two transponders (one for each end of the LRV), and two car control units (one for each cab). The wayside portion shall consist of an inductive loop antenna and a wayside transceiver. The wayside transceiver, through the wayside loop antenna, shall constantly transmit a message asking that any carborne TWC transponder, in the immediate area, identify itself. A carborne TWC transponder receiving this message shall respond by transmitting a serial 19-bit message, identifying the LRV's car number, the train number, route number (destination), and other information. Thumb-wheel switches and push buttons in each cab are provided to train operators to enter the route number and train number of their consist and other requests such as switch call and preempt call.

A TWC system, compatible with the LRV equipped TWC system, shall be installed at all interlocking, at all passenger stations adjacent to highway crossings and provisions made for all passenger stations in street running, and at all power switches in street running, to allow train operators to enter switch call and route requests. Use of the TWC system shall be the primary method of entering route, switch requests, and SCADA train identification at those locations.

A TWC loop and hand hole shall be installed at all highblock for improved SCADA control of LRV movements. It shall include a TWC antenna and conduits to a nearby signal case for future utilization.

The TWC wayside interrogator operating frequency shall be 100 Khz. It must be capable of recording and storing data history to include all inputs and outputs for download and review for a backlog of at least 48 hours from the time of download. Data acquisition and unit programming must be easily accomplished by a signal technician with moderate laptop computer skills. Installation shall include one interrogator per loop. The wayside loop shall be a single wire loop mounted between the rails with the end to end dimension of the loop being 15 feet. The loop shall be mounted no higher than top of rail and no lower than 6 inches below top of rail. In open track areas the loop shall be housed in a pre-fabricated protective non-metallic enclosure.

Assignment of destination codes shall take into consideration future expansion plans of the LRT system. Assignments shall be developed to provide a logical progression of destination codes throughout RTD's LRT expansion plans.

Standard and Codes

The signal system shall be designed, constructed and tested in accordance with ~~to~~ the latest revision at the time of award of contract of the following codes and standards:

- U.S. Code of Federal Regulations (CFR), Title 49, Part 236
- American Railway Engineering and Maintenance Association (AREMA)
  - Signal Manual of Recommended Practice
  - American Railway Signaling Principles and Practice
  - Communication Manual of Recommended Practice
  - Typical Circuits Representing Current Practice for Railway Signaling
- Rules and Regulations of the Colorado Public Utilities Commission (PUC)
- National Electrical Code (NEC)
- National Electrical Safety Code (NESC)
- Insulated Cable Engineers Association (ICEA)
- American Society for Testing and Materials (ASTM)
- American National Standards Institute, Inc. (ANSI)
- Underwriters Laboratories, Inc. (UL)
- U.S. Department of Transportation, Federal Highway Administration, Manual on Uniform Traffic Control Devices (MUTCD)

  Institute of Electrical and Electronic Engineers (IEEE)

Safety design

Train safety shall be the prime consideration in the design of the signal system and in the selection of its components, including relays and other devices with moving parts, insulated wire, wire terminals, binding posts, housings, conduits, resistors, capacitors, transformers, inductors and other similar items. The entire signal system shall meet the requirements of this section. Circuit design shall conform to the "American Railway Signaling Principles and Practices" of the AAR Communication and Signal Section.

The following requirements shall govern the design of the portions of the system or a subsystem which affect train safety:

- Only components which have high reliability and predictable failure modes and rates and which have been proven in conditions similar to the projected service shall be utilized.
- Components shall be combined in a manner that ensures that a restrictive rather than a permissive condition will result from component failure.
- All circuits which are not confined to one housing and which affect safety shall be double-wire, double-break, except signal and switch indicator light circuits.
- The design shall be based on closed circuit principles.
- Component or system failures shall cause a more restrictive signal indication than that permitted with no failure. The built-in fault detection and alarm generation capability are preferred.
- System safety design shall be such that any single independent component or subsystem failure will result in a safe condition. Failures that are not independent (those failures which in turn always cause others) shall be considered in combination as a single failure and will not cause an unsafe condition.
- Any latent failure of the equipment, that is a failure, which by itself does not result in an unsafe condition, but which in combination with second or subsequent failures could result in an unsafe condition, must be detected and negated within a stipulated time period.
- Electronic circuit design shall insure that the following types of component failures have a restrictive rather than a permissive effect:
    - o Two terminal devices: open, short, partial open or short
    - o Multi-terminal devices: combination of opens, shorts, partial opens and/or partial shorts
- Wherever possible, built-in checks shall be included that impose a restriction and/or actuate an alarm whenever a device fails to assume its most restrictive position when conditions require that it should.
- Redundant design by itself shall not be considered an acceptable method of achieving design safety.

Headways & Block Layout

The design of the LRT signal system shall provide for minimum train headways of 130 seconds, or less. Headway is defined as the length of time taken for a given automatic block signal to upgrade to a permissive (restricting or approach) aspect after a leading train has passed that signal at normal track speed. Maximum train length will be 4 cars under normal conditions. Three-aspect signals are required to provide information about the aspect displayed by the next signal ahead so as to avoid the necessity for always approaching it while prepared to stop.

Wherever it is displayed, a stop indication shall be an absolute signal, requiring that train operators bring their trains to a full stop and call the LRT controller for authorization to pass the signal at restricted speed (i.e., prepared to stop, within one-half the range of vision, short of anything that may so require).

Signal system design headways are calculated without regard for variations in vehicles, weather conditions or individual operators. Signal system design headways will provide for sustained five minute scheduled headways.

Safe Breaking Distance

Safe braking distances shall be calculated using a 2 second vehicle reaction time, a minimum adhesion which would allow a deceleration rate on level tangent track of 1.95 MPHPS and a 35% (distance) safety margin. The assumed deceleration rate shall be reduced on downhill grades to compensate for the effects of gravity. In addition, all safe braking distance calculations in open-track territory shall assume a LRV entry into the governed area at a maximum authorized speed plus 10 mph to a maximum of 60 mph.

Train Detection

Train detection in the ABS sections and at interlocking shall be accomplished by using one of the following types of track circuits.

> Two-rail, shunt type 60 Hz, phase selective track circuits with impedance bonds and two-element vital vane relays.
>
> • Solid state electronic, coded track circuits suitable for use in overhead propulsion territory.

Single-rail (not to exceed 60 feet in length) or double rail, shunt-type 60 or 100 Hz AC track circuits shall be used to detect train presence in embedded track.

Audio-frequency, overlay, shunt-type track circuits shall be used for train detection in the control of highway grade crossing warning equipment.

The design of the LRV propulsion and traction systems and selection of track circuit frequencies and modulation schemes shall be coordinated to preclude interference between the LRV and the signal system.

A shunt with a resistance of 0.2 ohm or less at any point between the two rails of any track circuit shall cause the track circuit to indicate train occupancy. Shunt fouling shall not be allowed, and multiple track relays or series fouling shall be used for all turnouts, with the exception of the two (or four) turnouts used in crossovers between mainline tracks. Voltage regulating transformers in the feed to the track may be used or additional track circuits may be installed, if necessary, to provide this shunting capability. Impedance bonds shall be used to enhance track circuit stability.

Signals &Switch Indicators

Color Light Signals

With the exception of those signals noted below and two-aspect interlocking signals, standard railway color light, high signals, including backgrounds and split base junction boxes shall be provided for ABS sections and interlocking in open-track sections. Signals at station platforms which do not have to be viewed from a distance may be dwarf-type railway color light signals on pedestal bases. Low, dwarf-type railway color light signals may be used for non-normal moves.

Signal Aspects

Each signal aspect shall have an indication (meaning), which is the same wherever it is displayed throughout the LRT system. The system shall have two-aspect and three-aspect signals.

Fundamental aspects of color light signals shall consist of the following:

Name	Aspect	Indication
Stop	Red Light	Stop
Approach	Yellow Light	Proceed on primary route prepared to stop at next signal
Proceed	Green Light	Proceed on primary route at permitted speed
Diverging	Flashing Yellow Light	Proceed on secondary route prepared to stop at next signal
Diverging	Flashing Green Light	Proceed on secondary route at permitted speed
Exit	Red over Yellow	Proceed out of signalized territory into yard or storage track

TABLE 8B - STREET RUNNING AREA SIGNALS

Name	Aspect	Indication
Stop	Red	Stop
Proceed	Yellow	Divergent track clear; proceed in street running rules
Proceed	Green	Proceed on primary route at permitted speed

TABLE 8C - POINT INDICATORS

Name	Aspect	Indication
Stop	Dark	Stop
Reverse	Yellow Light	Switch Lined Reverse
Normal	Green Light	Switch Lined Normal

Mainline Track Switches

Track Switches in Open-Track

a) Manual Track Switches

Manually operated switches in signaled territory shall be equipped with switch and lock movements with operating rods, lock rods and point detectors, and electric switch locks as required by Federal Railroad Administration (FRA) requirements. Removing a padlock from the electric switch lock and opening the front access door shall put neighboring signals to stop and shall start a timer to ensure clearance of trains that may have just passed the controlling signals. Expiration of the 30 second timer shall permit the switches to be unlocked and hand lined.

b) Powered Track Switches

Ballasted

Switches shall be powered by dual control (motor driven/manual) switch machines on open trackwork. Power for the dual control switch machines shall be from the signal power line or from commercial 120 VAC power source, rectified to 110 VDC. Switch machines shall be equipped with operating rods, lock rods and point detectors. Electric switch and lock movements shall be US & S Type M23-A, GRS model 5F, or approved equal.

c) Switch Heaters/Snow Melters

Switch heaters are to be provided and installed by the Signal Contractor at designated locations where the presence of ice and snow could affect rail service. Switch heaters shall be operated automatically or manually and an indicator shall be provided at the control equipment enclosure to indicate that the unit is on. Snow melters shall be powered from a 208 or 240 VAC source with heater pads wired in parallel sufficiently rated to keep the switch points and stock rails free of snow and ice.

Track Switches in Paved Track

a) Manual Track Switches

Manual track switches shall be equipped with toggle type switch movements. Facing-point switches shall be equipped with switch circuit controllers and switch indicator as determined by RTD

b) Powered Track Switches

Embedded

For in street running switches designed for embedded in street applications shall be utilized. Switches shall be powered off a rectified AC source originating from the control enclosure. Power shall be a nominal 120 VAC. Switch machines shall be equipped with operating rods and point detectors. Switches shall be Western Cullen Hayes, electro-hydraulic, or approved equal.

A successful operating record shall require a minimum of 3 years of successful operation on a comparable North American transit system or railroad, as determined and approved by RTD.

ACUTALIZATION

VITAL MICROPROCESSOR INTERLOCKING SYSTEMS

If interlocking is not controlled by vital relays, then Vital Microprocessor Interlocking Systems (VMIS) shall be employed to execute all vital safety signal system functions. The VMIS system shall be compatible with the existing microprocessor equipment currently in service on the RTD light rail system.

The VMIS shall be capable of operating in a light rail transit environment including exposure to temperatures, humidify and vibration. The VMIS shall be capable of operation at temperature of -40°C to +70°C at 90% humidity non-condensing.

The VMIS software systems shall be segregated into two independent software levels as follows:

- Executive Software shall consist of the coding that performs the input, internal and output operations that is defined within the individual interlocking application logic. The executive software shall be configured on a closed loop principle to ensure that the individual vital microprocessors operate in a fail-safe manner. The executive software shall reside in a read only memory.

- Application Software shall be segregated from the executive software and consists of the vital signal logic defining a specific interlocking configuration. The application software shall derive its safety from signal circuit design practices similar to that used for relay logic. The application software shall be capable of being modified to reflect changes in a specific interlocking configuration by RTD signal engineering staff with basic computer skills. To perform these software modifications, the VMIS system shall incorporate an application software development system and software simulator in order that the modifications can be tested and verified prior to final implementation.

For large interlocking (more than four power switches and/or movable point frogs), the VMIS system shall be segregated into zones and configured in a manner that failure in one zone will not affect the operation of an adjacent zone. Redundant microprocessors (normal and hot standby) shall be provided at selected microprocessor interlocking locations and configured such that shut down of the primary microprocessor would automatically permit seamless transfer to the standby unit.

Individual VMIS units shall include both vital serial ports to interface with adjacent VMIS unit, and non-vital serial ports for interface with the non-vital control system. Interface connections to wayside signal equipment shall be designed to function with existing RTD signal equipment operating at standard voltages for the type of equipment in service. Where necessary, the VMIS system shall include vital relays to provide interface to wayside signal appliances.

The VMIS shall be equipped with a data recorder and diagnostic system capable of being accessed on-site at the VMIS location, or remotely over telephone or dedicated data lines using a diagnostic terminal or standard laptop personal computer. Data shall be capable of being accessed remotely from the data recorder and in real time on-site directly from the VMIS equipment. The diagnostic system shall be capable of identifying a failure, the nature of the failure and failure location. In addition to the diagnostic system, individual cards including; input/output boards, central processor cards and internal power supply boards shall be equipped with indicator lights that illuminate when respective input/output devices or ports are active.

The VMIS system shall be configured to operate from local available signal system power supply sources. Individual VMIS units shall be equipped with protection against unwarranted power surges at the power supply input terminals. The VMIS units shall also be protected against high levels of electric noise transmitted from external sources including radio, vehicle propulsion systems and hi-tension commercial power lines. Lightening protection including appropriate lightening arresters and equalizers shall be provided at all input terminals interfacing with wayside signal appliances.

VMIS units shall be modular and consist of stand alone card files capable of being mounted in standard instrument racks. Included in the instrument rack shall be all signal equipment required to provide a complete stand alone system.

PROGRAMMABLE LOGIC CONTROL SYSTEM

A Programmable Logic Control (PLC) system shall be employed for control and indication of the signal system. The PLC system shall interface with the VMIS at individual field locations. The PLC system shall perform all entrance-exit functions, receive inputs from various sub-system components (including; individual local control panels and central control) and transmit the appropriate command to the VMIS system. Status indications received from the VMIS shall be processed and transmitted to the local control panel and central control. The PLC system shall be compatible with equipment currently in-service on RTD's LRT system.

The PLC system shall consist of a fault tolerant microprocessor based control system, utilizing either a single unit or fully redundant normal and standby microprocessors. The RTD shall determine which locations require redundant systems based upon the affects a failure of the microprocessor would have on overall system operations. The normal and standby units shall exchange information on operations and health of each respective unit over a serial link. Automatic switch over to the standby unit shall occur if a failure is detected in the hardware or through diagnostic routines of the on-line unit.

The system software shall be field proven, commercially available and prevalent in the industry. The software system shall be designed in a manner that will permit future expansion. The application programs shall be stored on Erasable Programmable Read Only Memory (EPROM), with temporary data (controls and indications) stored in

Random Access Memory (RAM). The software shall be capable of being modified to reflect changes in system configuration by RTD signal engineering staff with basic computer skills. To perform these software modifications, the non-vital PLC system shall incorporate a software development system and software simulator in order that the modifications can be tested and verified prior to final implementation.

The PLC units shall be capable of operation in a light rail transit environment including exposure to temperatures, humidify and vibration. The PLC shall be capable of operation at temperatures of -40°C to +70°C at 90% humidity non-condensing. The PLC unit shall be protected against high levels of electrical noise transmitted from external sources including radio, vehicle propulsion systems and hi-tension commercial power lines. In addition, appropriate lightening protection shall be provided where the PLC unit interfaces with external cable systems.

The PLC units shall consist of modular card files capable of being mounted in standard instrument racks. Individual cards including; input/output boards, central processor boards and internal power supply boards shall be equipped with indicator lights that illuminate when functions on the boards are active.

CONCLUSION

Railroads have had a profound impact on civilization. Most importantly, the efficiency and speed of rail travel allow a nation's population, industry, and agriculture to be established throughout that nation's territory, even in previously remote areas. Rail transportation has also played a significant role in urban transportation systems. In many countries, rail continues to be the main mode of passenger travel. In Europe and Japan, major cities are connected by high-speed passenger trains, such as the French TGV (Train à Grande Vitesse) and the Japanese Shinkansen trains, popularly known as bullet trains.

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