CHAPTER 2

TRACK

A. GENERAL

This Chapter includes criteria and standards for the planning, design, construction, and maintenance as well as materials of Caltrain trackwork. The term track or trackwork includes special trackwork and its interface with other components of the rail system. The trackwork is generally defined as from the subgrade (or roadbed or trackbed) to the top of rail, and is commonly referred to in this document as track structure.

This Chapter is organized in several main sections, namely track structure and their materials including civil engineering, track geometry design, and special trackwork. Performance charts of Caltrain rolling stock are also included at the end of this Chapter.

The primary considerations of track design are safety, economy, ease of maintenance, ride comfort, and constructability. Factors that affect the track system such as safety, ride comfort, design speed, noise and vibration, and other factors, such as constructability, maintainability, reliability and track component standardization which have major impacts to capital and maintenance costs, must be recognized and implemented in the early phase of planning and design. It shall be the objective and responsibility of the designer to design a functional track system that meets Caltrain's current and future needs with a high degree of reliability, minimal maintenance requirements, and construction of which with minimal impact to normal revenue operations.

Because of the complexity of the track system and its close integration with signaling system, it is essential that the design and construction of trackwork, signal, and other corridor wide improvements be integrated and analyzed as a system approach so that the interaction of these elements are identified and accommodated.

The Caltrain commuter rail system consists of revenue tracks and non-revenue tracks. All Caltrain tracks are ballasted tracks. No direct fixation is allowed. The revenue tracks, carrying passengers, include main tracks, sidings, station tracks, and temporary (or shoofly) tracks. Union Pacific Railroad (UP) also operates freight service on all these tracks.

The non-revenue tracks include yard, industrial and other tracks that are constructed for the purpose of switching, storing, or maintaining rolling stock or other on-track equipment not in revenue service. Tracks that are seldom used except in emergency or other unusual situations shall be constructed as non-revenue tracks, regardless of whether passengers may be carried on the cars or not.
1.0 REGULATORY AND INDUSTRY STANDARDS

Track construction and maintenance shall conform to general requirements as described in **CHAPTER 1 – DESIGN GUIDELINES**, and all required codes and regulations, and standard industry practices and recommendations in the **APPENDIX**, specifically the following:

a. Federal Railroad Administration (FRA)  
   Title 49 Code of Federal Regulation (CFR)  
   Part 213, Track Safety Standards for Class 5 Track

b. California Public Utilities Commission (CPUC)  
   Applicable General Orders

c. American Railway Engineering and Maintenance of Way Association (AREMA)

The designer shall use this Criteria in conjunction with other Caltrain Standards, namely Caltrain Standard Drawings (SD-2000 series) and Standard Technical Specifications (Division 20, Track).

2.0 DESIGNERS QUALIFICATIONS

The designers shall have at least five (5) years of experience as the lead designer of railroad track system including main lines and yards. Possession of registration as a civil engineer, though not required, is highly desirable. Specifically the designers shall have the following qualifications:

a. Familiar with the federal (FRA) and state (CPUC) regulatory standards, as well as the industry standards and practices such as UPRR, High Speed Rail and AREMA.

b. Good understanding of track structure and its components (joints, weld, compromise joints and insulated joints), and general civil engineering principles pertaining to subgrade or trackbed and drainage requirements.

c. Knowledge of signal system and operation (commuter and freight) requirements and how they impact design speed.

d. Good understanding of the principles of track geometry, such as design of curves (simple, compound and spiral) and relationship between horizontal and vertical curves, as well as relationship between curves and superelevations. Knowledge of spiral length requirements for commuter, freight, and high speed rail systems.

e. For special trackwork the designers shall have experience in designing special trackwork track geometry (turnouts or switches, crossovers, track crossings). General knowledge in fabrication and inspection in the fabrication yard, or field construction and assemble or fabrication of the special trackwork is required. Special trackwork designers shall be familiar with the
standard industry practices generally provided by the special trackwork vendors.

f. Have experience in track construction sequencing and track construction under active conditions or tight windows. Understand specifications and related bid items for track construction.

B. TRACK STRUCTURE

The track structure consists of subgrade, subballast, ballast, ties, rail, fastening system, other track materials (OTM), special trackwork, and other elements for signals. These trackwork elements are interconnected to provide a continuous surface for running trains and an electrical conductive medium for transmitting.

Caltrain track consists of both concrete and timber ties on primarily 136 pounds continuous welded rail (CWR). Only concrete ties and 136 pounds CWR using fast clips as fastening system are used for new construction. This fastening system shall be used for standardization and for the purpose of maintaining the state of good repair system. Maintenance activities include welding to eliminate the remaining rail joints. For industry, yard and temporary tracks (shoofly), the track may be constructed of track panels of timber ties using only screw spikes.

The subballast is either an earth compacted underlayerment or a Hot Mix Asphalt Concrete (HMAC) layer. HMAC is used to minimize local settlement due to difference in track modulus. Its general applications include bridge approaches, crossovers, passenger stations, and at-grade crossings. Refer to Caltrain Standard Drawings for typical sections of track structure.

Each of the components of the track structure is briefly described below.

1.0 DRAINAGE

The three most essential elements for a sustainable stability of track structure are drainage, drainage, drainage. An effective and efficient drainage keeps the track well drained and hence in relatively moisture free environment.

The track structure requires an effective drainage system in order to keep the subgrade well drained and stable. A well drained and stable subgrade means absence of standing water therefore preventing pumping phenomena. Additionally, any standing water may shunt the signal circuits causing signal failures.

Appropriate drainage is an integral part of the trackwork design. Provisions shall be made for ditches, underdrains (at train stations) and other drain features as necessary to maintain a stable roadbed. The collected water shall eventually discharge into the municipality drainage system. The drainage system shall be protected from erosions. Ditches (longitudinal and side ditches), and any direct discharge to them shall be protected with such as riprap. Longitudinal drainage system alignment shall be as straight as possible with as little curve as possible.
When curves are not acceptable, they shall be as flat as possible, and if necessary, provide appropriate holding inlet and/or ditch slope protection.

At the bridge approaches, a positive drainage shall be provided sloping away from the abutments as well as to the sides towards the embankment. Side slopes shall be protected with such as riprap.

2.0 SUBGRADE

Subgrade, commonly referred to as the roadbed or trackbed supports the railroad loads transmitted through the rails, ties, ballast, and subballast. The subgrade shall have adequate width for walkways and a positive slope to either side of the track to keep the subgrade free of standing water.

The top of subgrade must be graded so that there is a cross slope of two (2)\% minimum towards the adjacent ditch or embankment slope, or to other longitudinal drainage system. Where existing right-of-way or other restrictions do not allow the construction of side ditches, designer shall propose other suitable gravity drainage system for consideration.

The designer shall analyze the existing subgrade and determine whether the material is considered suitable for the subgrade. If the existing subgrade is unsuitable, it shall be removed and replaced with approved backfill and shall be compacted in accordance with Caltrain Standard Specifications. Alternatively, use geogrid or filter fabric, or HMAC (hot mixed asphalt concrete). HMAC will be further discussed below.

3.0 SUBBALLAST

Subballast is a uniform layer of approved backfill placed and compacted over the entire width of the subgrade. Subballast shall always be considered when the subgrade has poor drainage, of poor material, or is subject to seasonal high or perched water table.

Similar to subgrade, subballast shall have a cross slope of two (2)\% minimum towards the side ditch or embankment slope, or other longitudinal drainage system. The sub-ballast for all tracks shall consist of a uniform minimum six (6) inches layer of base material. Where a service road is placed adjacent to the track, the subballast shall extend across the full width of the road section. Where the subgrade is soft or with relatively poor drainage, the subballast shall be increased to 12 inches over geofabric, or if necessary, shall consist of at least eight (8) inches thick Hot Mixed Asphalt Concrete (HMAC) over geotextile fabric.

For yard tracks, the requirement for subballast is similar. Subballast may not be required for yard tracks and industrial tracks with the approval of the Caltrain Deputy Director of Engineering.
4.0 HOT MIXED ASPHALT CONCRETE (HMAC) UNDERLAYMENT

HMAC, a dense graded asphalt concrete of maximum 1 to 1.5 inches aggregates common to highway applications to provide support where roadbed conditions are poor and unstable, and to facilitate drainage. The benefits of HMAC to the track structure are summarized as follows:

a. Improve load distribution to the subgrade.

b. Waterproof and confine the subgrade. Waterproofing eliminates subgrade moisture fluctuations, which effectively improves and maintains the underlying support.

c. Confine the ballast, thus providing consistent load carrying capability.

HMAC provides a positive separation of ballast from the subgrade. It eliminates pumping without substantially increasing the stiffness of the track bed. It increases the operating efficiency due to decreased maintenance costs, hence providing a long term benefit.

HMAC shall be (8) inch thick graded with positive drainage of a cross slope of two (2)% minimum toward side ditch or underdrain. The HMAC layer shall be used at all locations listed below. Details of this application are available in the Caltrain Standard Drawings.

a. All at-grade crossings (vehicular or pedestrian crossings)

b. Within limits of special trackwork

c. Within limits of station platforms

d. At bridge approaches (transition zones) where track modulus changes

The track hump commonly exists at the bridge approaches severely degrades ride quality, and increases maintenance (track surfacing) and wear and tear to both the rolling stock and the rail. The HMAC underlayment shall be graded with a positive slope away from the bridge abutments, and towards each side of the track embankment. A minimum of 50 feet long is specified in the Caltrain Standard Drawings, however, longer transition shall be provided when possible within the time constraints of construction.

It should be noted that the thickness of the ballast at the bridge approaches shall be kept under 12 inches. The risk of development of track hump increases with thicker ballast section associated with increase in ballast consolidation or breakdown.

5.0 BALLAST

Ballast is placed above the subballast, or HMAC. The ballast plays a critical role by providing support for the rail and ties, distributing railroad loads uniformly through the
subballast over the subgrade, maintaining proper track alignment, and facilitating track maintenance.

Ballast shall be crushed rock of acceptable parent material, conforming to Caltrain Standard Specifications and shall be obtained from Caltrain approved quarries. Ballast shall be Gradation Number 4A or AREMA Grade 4A.

For main tracks, including bridges, the minimum ballast depth shall be nine (9) inches, measured from the bottom of the tie. Larger ballast section (12 inches or more) is commonly used on freight main lines is not necessary because of the relatively low gross tonnage of freight operations by Union Pacific (UPRR) through Caltrain corridor.

Maximum ballast depth shall generally not exceed 18 inches. Ballast depth outside these limits must be approved by the Caltrain Deputy Director of Engineering. Thicker ballast section resulting in settlement from ballast consolidation increases the maintenance costs due to increase frequency or need for track surfacing. Track structure over embankment is particularly prone to this phenomenon because the ballast is not being contained.

For yard tracks and industrial tracks, the corresponding minimum depth of the ballast shall be six (6) inches, and 12 inches maximum. Existing ballast salvaged during construction may be used for subballast.

6.0 TIES

Only concrete ties shall be used for new construction of main tracks. Timber ties with Pandrol fastening systems shall only be used for the rehabilitation of existing timber tie tracks, construction of yard and industrial tracks, and construction of temporary main tracks. Yard tracks can be constructed on timber (at 21 inch spacing), or on concrete ties that are specifically designed for yard tracks. Longer 10 ft timber ties are installed at transition zones between areas of very different track modulus.

Concrete ties are superior over timber ties in track gage maintenance. Concrete ties are engineered to maintain track gage under harsh weather conditions and over long periods of time. Tracks on concrete ties yield higher track modulus (stiffer track) which results in stable though stiffer ride quality, however, they reduce rolling resistance which is particularly beneficial for long haul operations. Concrete ties are more economical in production compared to the traditional timber ties due to material shortage and the increasing cost of wood. With the fast clip fastening system, track construction on concrete ties also requires less labor intensive tasks.

Improved design and fabrication of concrete ties and overall deteriorating quality of timber result in concrete ties outlasting the timber ties. Furthermore, unlike timber ties that require the heavy use of the creosote treatment to prevent rotting and insect infestation, concrete ties do not require any additional chemical treatment, therefore are more environmentally friendly.
While the material handling labor is less for the lighter timber ties, overall the tracks on concrete ties are less per track mile. One of the disadvantages of concrete ties is the extent of the damage to the ties in the event of derailment.

Standard concrete ties for main tracks, including at stations shall be 8 feet 3 inches (minimum) to 8 feet 6 inches (maximum) long spaced at 24 inches. Timber ties for main tracks shall be 7 inches x 9 inches x 9 feet long at 19-1/2 inches spacing.

Standard ties for at-grade crossings are concrete suitable for moisture prone environment. They are 10 feet long to accommodate concrete crossing panels, and for enhanced load distribution from additional vehicular traffic. The corresponding concrete tie clips shall be galvanized. Maintenance of at-grade crossings involves street closure which requires the approval of the Local Agency.

Transition timber ties shall be 7 inches x 9 inches x 10 feet long and shall be used in areas of changing track modulus, between standard timber tie section and standard concrete tie section, at approaches to at-grade crossings, and at approaches to bridges. Refer to Caltrain Standard Drawings for further details.

7.0 RAIL

The standard rail for all main tracks, including the special trackwork is 136 RE. Temporary tracks during construction that will not be in service more than two (2) years may be of 132 HF rail. Other non-revenue tracks may be constructed using 119 RE rail, as available from Caltrain’s existing inventory.

8.0 RAIL FASTENING SYSTEM

Other track materials (OTM) include all materials to hold rails to the ties, and to connect between rails. Caltrain’s standard for fastening system which includes rail clips and associated tie pads and insulators. Non-standard fastening system includes screw spikes, track bolts, nuts, spring washers, tie plates, rail anchors, insulated joints, standard joint bars, and compromise bars.

Refer to Caltrain Standard Drawings and Standard Specifications for types of OTM and their applications, and for conformance to the Caltrain Specifications.

C. TRACK GEOMETRY

The primary goals of geometric criteria for Caltrain are to provide a safe, cost-effective, efficient, and comfortable ride, while maintaining adequate factors of safety with respect to overall operations, maintenance, and vehicle stability.

The geometric design criteria for trackwork have been developed using the best engineering practice and the experience of comparable operating Commuter and Class 1 railroads. The designers need to strive a balance among the following competing principles:
a. Consideration of Caltrain’s overall system safety  
b. Optimization of passenger comfort  
c. Maximization of speed  
d. Effectiveness of implementation costs  
e. Ease and efficiency of maintenance  

**TABLE 2-1** lists the general limiting factors that affect the track geometry design. It is very important for the designers to understand these elements and provide the best track geometry based on the design criteria established in this Chapter.

### TABLE 2-1  LIMITING DESIGN ELEMENTS

<table>
<thead>
<tr>
<th>DESIGN ELEMENTS</th>
<th>MAJOR LIMITING FACTORS</th>
</tr>
</thead>
</table>
| Minimum Length between Curves | • Passenger comfort  
  • Vehicle truck/ wheel forces |
| Horizontal Curves (Maximum Degree of Curve - $D_c$) | • Design speed  
  • FRA curve speed  
  • Trackwork maintenance  
  • Vehicle truck/ wheel forces |
| Compound and Reverse Curves | • Passenger comfort  
  • Vehicle suspension travel  
  • Trackwork maintenance |
| Length of Spiral Transition Curve | • Passenger comfort  
  • Trackwork maintenance  
  • Vehicle suspension travel |
| Superelevation | • Passenger comfort  
  • Vehicle stability |
| Superelevation Runoff Rate | • Passenger comfort  
  • Vehicle suspension travel |
| Vertical Tangent between Vertical Curves | • Passenger comfort  
  • Turnout locations |
| Vertical Curve/Grade (Maximum Rate of Change) | • Passenger comfort  
  • Vehicle suspension travel  
  • Slack action and train handling  
  • Horizontal and vertical tangents |
| Special Trackwork | • Passenger comfort  
  • Design speed  
  • Trackwork maintenance |
| Station Platforms | • Vehicle clearances  
  • ADA platform gap requirements |
| Mixed use of Commuter/Freight RR | • Vehicle clearance  
  • Trackwork maintenance  
  • Compatibility of operations |
1.0 GENERAL DESIGN REQUIREMENTS

Track alignment, at a minimum, shall be designed to maximum authorized speed (MAS) of 90 mph and FRA Class 5 track standards. Upon completion of the track construction, Caltrain will determine the appropriate operating speed.

The resulting track shall be with as few curves and curves as small as possible. However, small curves such as 30 minutes or less shall be discouraged because they are impractical to construct or to maintain. Furthermore, with time these small curves tend to lose their curvature hence increasing additional maintenance. When such small curves are not avoidable, then the curves need to be at least 500 feet long for ease of construction and maintenance.

Designers shall strive for speeds in 5 mph increments but other increments are permitted when practicable.

As part of the design, designers shall typically include the following information and data for Caltrain review and for during construction:

a. Track Chart (existing and proposed), in the format consistent with Caltrain published track charts.

b. Stationing continuously along the length of all main tracks, using Main Track MT-1 as reference, including mile posts.

c. Track plan (on planimetric background) showing existing and proposed, with mileposts and shall contain the following information. Left side of page is railroad north, with arrow pointing actual north.
   i. Caltrain ROW lines and other surrounding property lines or constraints, street names, landmarks, etc.
   ii. Track information: curve numbers and turnouts with their corresponding stationing, and other turnouts points.
   iii. Project related features such as (existing and proposed): Underground utilities (communications, signal, drainage, sewers); other utilities (manholes, vaults, etc.); structures (signal houses and other structures), ditches, drainage facilities.
   iv. Track drainage and other drainage (existing and proposed).

d. Track centers, every 500 feet, or when the track centers change by every 3 inches.

e. Vertical profiles (existing and proposed) including slopes (in percent) developed for each tracks in grid with elevations in two decimals for key points, such as highs, lows, change of curve, or speed.
f. Track plan and profile on the same sheet with same limits with plan on top of the page.

g. Cross sections (toward increasing stations) showing existing and proposed, including any vertical clearances.

h. Track geometry data in tabular form with the following information: design speeds (current and proposed), curve data (curve number, corresponding stationing, curve characteristics, coordinates (northing and easting), spiral length, superelevations (total, unbalance, actual).

2.0 CRITERIA LEVELS

In determining the track geometry, the following levels of criteria shall be considered for implementation.

a. Preferred Standards

This case shall be applied to main line tracks based on an evaluation of maximum passenger comfort, maximum speed, initial construction cost, and maintenance considerations. These standards shall be used where there are no significant physical restrictions or increase in construction cost.

b. Absolute Minimum Standards

This case shall be applied where physical restrictions prevent the use of the preferred standards. The absolute minimum standards are determined primarily by the rail car design and safety of operations with passenger comfort as the secondary consideration. The standards shall meet Federal and State minimum requirements and with approval from the Caltrain Deputy Director of Engineering.

c. Yard and Non-Revenue Track Standards

This case shall be applied to non-mainline and non-revenue tracks where low speed operations are in effect. These standards are determined primarily by the rail car design and safety of operations, with little or no consideration of passenger comfort.

The use of absolute minimum standards, particularly for horizontal alignment, has several potential impacts in terms of increased annual maintenance, noise, and rail car wheel wear, and shorter track component life. Their use shall be implemented with extreme caution and require approval from the Caltrain Deputy Director of Engineering. In no case shall the standards be allowed below the minimum standards mandated by Federal and State regulations.

At locations where existing alignment or other reductions preclude this, the track shall accommodate train speeds equal to or exceeds the existing speeds.
3.0 HORIZONTAL ALIGNMENT

The horizontal alignment of track consists of a series of tangents joined to circular curves and spiral transition curves as measured along the center line of track. Track superelevation in curves is used to maximize train operating speeds wherever practicable. In yards and other non-revenue tracks, spiral transition curves are rarely required.

Curvature and superelevation of track alignment are related to design speed and to the acceleration and deceleration characteristics of the rail cars and locomotives for that location. The design criteria for tangent, curve, design speed, superelevation, and spiral transition curve are described in the next few sections.

3.1 Horizontal Alignment Criteria

Horizontal alignments for Caltrain mainline tracks shall be stationed along the track centerlines of Main Track 1 from San Francisco (North) to San Jose or Gilroy (South) based on the Caltrain GIS alignment. Refer to Caltrain Track Charts for track and alignment information.

The following track center distances from the main track shall be applied along tangents.

- Main track: 15 feet minimum
- Yard track: 20 feet minimum

On curves, to provide clearance between cars and locomotives equivalent to that obtained on adjacent tangent track, track centers shall be increased as follows:

a. A minimum of one (1) inch for every 30 minutes of curvature where the amount of superelevation is the same on adjacent tracks or the superelevation of the inner track is greater than that of the outer track.

b. A minimum of one (1) inch for every 30 minutes of curvature, plus 3-1/2 inches for every inch of difference in elevation between the two tracks where the superelevation of the outer track is greater than that of the inner track.

3.2 Tangent

Horizontal tangents shall be designed based on the longest rail car length for the rail corridor and ride comfort for the passengers. A formula for tangent length in feet \((L=3V)\) where \(V\) is the design speed (MPH) for ride comfort is based on the rail car traveling at least three (3) seconds on tangent track between two curves. Tangent shall extend at least 100 feet beyond both ends of the limits of the station platforms, and of at-grade crossings.

The minimum tangent length for mainline tracks shall be established as shown in Table 2-2 below.
### TABLE 2-2 MINIMUM TANGENT LENGTH (MAIN TRACKS)

<table>
<thead>
<tr>
<th>Tangent Location On Mainline Tracks</th>
<th>Minimum Tangent Length (feet)</th>
<th>Preferred</th>
<th>Absolute Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between reverse curves</td>
<td>3V</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Between Point of Switches of turnouts (TO’s)</td>
<td>50</td>
<td>20*</td>
<td></td>
</tr>
<tr>
<td>Between PS and curve</td>
<td>100</td>
<td>15*</td>
<td></td>
</tr>
<tr>
<td>Between PS and platform</td>
<td>100</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Between PS and grade crossing</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Between PS and last long tie of T.O.</td>
<td>60</td>
<td>15*</td>
<td></td>
</tr>
<tr>
<td>Between curve and platform</td>
<td>60</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Between curve and grade crossing</td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

* Tangent length shall not be less than the length of stock rail projection

V = design speed in the area, MPH

The minimum tangent length for yard and non-revenue tracks shall be established as per Table 2-3:

### TABLE 2-3 MINIMUM TANGENT LENGTH (YARD AND NON-REVENUE TRACKS)

<table>
<thead>
<tr>
<th>Tangent Location On Yard and Non-Revenue Tracks</th>
<th>Minimum Tangent Length (feet)</th>
<th>Preferred</th>
<th>Absolute Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between reverse curves</td>
<td>60</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Between PS of T.O.’s</td>
<td>40</td>
<td>15*</td>
<td></td>
</tr>
</tbody>
</table>

* Tangent length shall not be less than the length of stock rail projection

3.3 Horizontal Curves

Horizontal curves shall be designed for the maximum speeds possible above the existing MAS without being cost prohibitive, i.e., requires additional right-of-way, impacting existing improvements like buildings, flyover supports, etc. The spiral length shall be sufficient to allow superelevation runoff for the future maximum design speed even if the existing MAS is less than the future maximum speed.

Design speeds for passenger train running through all curves shall be as shown in the following Table 2-4.
TABLE 2-4  DESIGN SPEEDS THROUGH CURVES

<table>
<thead>
<tr>
<th>Track Type &amp; Condition</th>
<th>Curve Design Speed (MPH)</th>
<th>Preferred</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Track</td>
<td>90</td>
<td>Exceed MAS</td>
<td>NA</td>
</tr>
<tr>
<td>Control Siding with #20 T.O.</td>
<td>50</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Control Siding with #14 T.O.</td>
<td>35</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Temporary Main Track</td>
<td>Existing MAS</td>
<td>(MAS – 15 MPH)</td>
<td>NA</td>
</tr>
<tr>
<td>Yard Lead</td>
<td>25</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Yard Track</td>
<td>15</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Prior to the design of the track geometry, the designer shall consult with Caltrain Deputy Director of Engineering to confirm the appropriate design speed(s) based on Caltrain’s current and future requirements. Higher future design speed shall be considered where possible.

3.3.1 Horizontal Curve

The criteria for the designer shall be to eliminate any curve, and if this is not feasible, to lessen the curvature. Implementation of curves less than 30 minutes requires the approval from Caltrain Deputy Director of Engineering. Curve data shall be provided in a table format with the following information:

- a. Design speed (MPH)
- c. Degree of curve (degrees, minutes, and seconds)
- d. Length of curve, $L_c$
- e. Amount of actual superelevation, $E_a$, (inches)
- g. Amount of unbalance, $E_u$, (inches)
- h. Length of Spiral, $L_s$

Curve alignment through grade crossings shall be avoided when possible. If tracks are superelevated through the crossing, both the track and road profiles may need to be modified to provide a smooth road profile over the crossing.

3.3.2 Circular Curve

The circular or simple curve for the track geometry shall be defined by the chord definition and specified by its degree of curve ($D_c$). The degree of curve has been adopted as a unit of sharpness and is defined as the central angle subtended by a
100 feet long chord for ease of field layout. The important relations of simple curves for the chord definition are as follows:

Radius, \( R = \frac{50}{\sin(D_c/2)} \)

Length of curve, \( L_c = 100 (\Delta/D_c) \)

Tangent distance, \( T = R \tan(\Delta/2) \)

where \( \Delta = \) central angle

The minimum length of circular curve shall be 100 feet for mainline tracks and 50 feet for yard and industry tracks.

See the following FIGURE 2-1 for illustration of the simple circular curve.

**FIGURE 2-1  SIMPLE CIRCULAR CURVE**

4.0  SUPERELEVATION

Superelevation is the height difference in inches between the high (outside) and low (inside) rail. Superelevation is used to counteract, or partially counteract the centrifugal force acting radially outward on a train when it is traveling along the curve. A state of equilibrium is reached when the centrifugal force acting on a train is
equal to the counteracting force pulling on a train by gravity along the superelevated plane of the track.

The superelevated track results in improved ride quality, and reduced wear on rail and rolling stock.

FRA currently has established the maximum unbalanced superelevation as three (3) inches, and the maximum actual superelevation as seven (7) inches for track Classes 3 through 5. The maximum actual superelevation for Caltrain tracks is five (5) inches. All curves with superelevation of five (5) inches or more shall require the approval from Caltrain Deputy Director of Engineering.

4.1 Application of Superelevation

Actual superelevation shall be accomplished by maintaining the top of the inside (or low) rail at the “top of rail profile” while raising the outside (or high) rail by an amount of the actual superelevation. The inside rail is designated as the “grade rail” (or profile rail) and the outside rail is designated as the “line rail”.

4.2 Superelevation Equation

Equilibrium superelevation shall be determined by the following equation:

\[ e = 0.0007 \ D_c V^2 \]

where:

- \( e \) = total superelevation required for equilibrium, in inches.
- \( V \) = maximum design speed through the curve, in miles per hour (MPH)
- \( D_c \) = degree of curvature, in degree

The total superelevation \( e \) is expressed as follows:

\[ e = E_a + E_u \]

where:

- \( E_a \) = actual superelevation that is applied to the curve
- \( E_u \) = unbalanced superelevation (amount of superelevation not applied to the curve)

The actual superelevation shall be rounded to the nearest 1/4 inch by the formulas above. For any curve, a 1/2 inch superelevation shall be specified.

Slower speed tracks, such as yard and non-revenue tracks, and curves within special trackwork shall not be superelevated. Curves within station and grade crossings shall be avoided. They may be superelevated only with the approval from the Caltrain Deputy Director of Engineering.

5.0 SPIRALS

Spirals (transition or easement curves) are defined as transition curves with a constantly decreasing or increasing radius proportional between either a tangent and a curve (simple spiral) or between two curves with different radii.
(compound/intermediate spiral). More specifically, the spiral is a curve whose degree-of-curve increases directly as the distance along the curve from the point of spiral.

In other words, spirals provide a gradual change of curve and ride comfort from the tangent to full curvature. Spirals are a means of introducing a superelevation at a rate corresponding to the rate of increase in curvature, which permits a gradual increase to full lateral acceleration at a comfortable, and non-destructive rate.

For example, if the spiral is to change at the rate of 10 degrees per 100 feet, at 10 feet from the beginning of the spiral, the curvature will be the same as that of an 1 degree curve; at 25 feet, as of a 2 degrees 30 minutes curve; at 60 feet, as of a 6 degrees curve. Likewise, at 60 feet, the spiral may be compounded with a 6 degree curve; at 80 feet, with an 8 degrees curve, etc.

The clothoid spiral is commonly used in most CADD design software. Since Caltrain adopted AutoCAD and its associated Civil Design Software in the design of track alignment, the clothoid spiral shall be used. The clothoid spiral is similar to the Talbot railway transition spiral which has been widely used in the railroad industry and is recognized by the AREMA.

5.1 Application of Spirals

The spiral transition curves shall be provided between circular curves and horizontal tangents. The spiral transition curve shall be the "ten-chord spiral" as defined by the AREMA Manual for Railway engineering or the "clothoid spiral" as defined by drafting software AutoCAD. See FIGURE 2-5 that follows for spiral and curve nomenclature.

Spirals are not required for curves less than 30 minutes for MAS under 20 MPH or on curve that is part of a turnout, however, a minimum of curve length of 100 feet shall be implemented. Additionally, all curves including such curves shall have a minimum 1/2 inch actual superelevation.

5.2 Length of Spirals

Spiral curve length and superelevation rate of change or runoff are directly related to passenger comfort. While passenger comfort is a major consideration, the rate of change in superelevation in a spiral also affects the rail car bodies in term of twisting, racking or diagonal warp. According to AREMA, the superelevation differential between rail car truck centers should not exceed one (1) inch. Therefore, based on an 85-foot long rail car with a truck center distance of 62 feet, the longitudinal slope of the outer rail with respect to the inner rail is limited to 1/744 or a rate of change of one (1) inch per 62 feet in length in order to avoid wheel lift.

The length of the spiral can be determined by the following three (3) criteria based on passenger comfort and operational safety.
where,  \( Dc \)  Degree of Curvature

\[
\begin{align*}
I & \quad \text{Total Intersection Angle} \\
\theta_s & \quad \text{Spiral Angle} = \left( \frac{L_s \cdot Dc}{200} \right) \\
\Delta & \quad \text{Central Angle of Circular Curve} = I - 2 \theta_s \\
R & \quad \text{Radius of Circular Curve} \\
Tc & \quad \text{Tangent Length of Circular Curve} = R \cdot \tan \left( \frac{\Delta}{2} \right) \\
Lc & \quad \text{Length of Circular Curve} = \left( \frac{\Delta}{180} \right) R \\
Ls & \quad \text{Length of Spiral} \\
TS & \quad \text{Tangent to Spiral} \\
SC & \quad \text{Spiral to Curve} \\
CS & \quad \text{Curve to Spiral} \\
ST & \quad \text{Spiral to Tangent} \\
PI & \quad \text{Point of Intersection of Main Tangents} \\
TS \; IN & \quad \text{Tangent Length of Complete Curve} \\
TS \; OUT & \quad \text{Tangent Length of Complete Curve}
\end{align*}
\]

FIGURE 2-2 CURVES WITH SPIRAL TRANSITION
Spiral Length Requirements

Based on sections AREMA Chapter 5, Section 3.1, the length of spiral shall be longest as determined from formulas:

1. \( L_s = 1.63E_u V \); or \( L_s = 1.22E_u V \) * Desirable
2. \( L_s = 1.2E_a V \) Minimum (upto 60 mph)
3. \( L_s = 62E_a \) Absolute Minimum (or Exception) upto 50 mph

* Use of Spiral length \( L_s = 1.22E_u V \) requires the approval of Caltrain Deputy Director of Engineering

where,

\( E_a \) = actual superelevation that is applied to the curve
\( E_u \) = unbalanced superelevation (amount of superelevation not applied to the curve)
\( V \) = design speed, MPH

The spiral length shall generally be rounded to the nearest 5 feet.

In determining spiral length for Caltrain’s current and future projects, cost of construction and space constraints must also be considered because of high labor and real estate costs in the San Francisco Bay Area. Longer or extremely long spirals always provide a higher level of comfort, and ease on rolling stock but they may be cost prohibitive to construct and maintain. As a result, the most economical approach using the above formulas is to determine the spiral length by balancing the actual and unbalanced superelevations based on the equilibrium superelevation. When the two formulas are balanced (formulas 1 and 2 above), the spiral length determined should satisfy the design requirements from either unbalanced or actual superelevation.

After the actual and unbalanced superelevations are balanced, the spiral lengths will be established and the longest spiral will be used.

Since the spiral lengths for the existing curves of the current Caltrain commuter corridor were determined based on the formula \( L_s=1.2E_a V \), as an exception, this formula may be used to establish the spiral length in areas with extreme site constraint with the approval of the Caltrain Deputy Director of Engineering. Examples for determining spiral lengths are in the APPENDIX.

6.0 COMPOUND CIRCULAR CURVES

Compound circular curves may be used provided that they are connected by an adequate spiral based on the difference between the required superelevations of the curves. The same speed shall be used to determine the spiral lengths and superelevations for the compound curves. The spiral lengths for compound curves shall be determined by the criteria previously described.

The minimum length of spiral between compound curves shall be 62 feet.
7.0 VERTICAL ALIGNMENT

The vertical alignment shall be defined by the profile grade represented by the top of rail (TOR) elevation of the low rail. This low rail is the grade rail.

When TOR profile is given for one track only, the TOR elevations of the other tracks are to be equal to the profile track at points radially and perpendicularly opposite. Gradients and lengths of vertical curves shall vary accordingly, (slightly), to accommodate the differences in lengths through horizontal curves. All main tracks and sidings shall be designed to the same vertical profile. In multi-track territories where there are more than two tracks, the profile of the outside tracks may be lowered based on the cross slope of the roadbed to minimize the need of increasing ballast depth.

7.1 Grades

The maximum continuous main line grade along the Caltrain commuter corridor is one (1)%. The preferred maximum design gradient for long continuous grade shall be one (1)%. Maximum design gradient, with curve compensation at 0.04 percent per degree of curve if applicable, for grades up to two (2)% may be implemented for new construction projects with the approval of the Caltrain Deputy Director of Engineering. The resulting maximum gradient $G_c$ is generally expressed as follows:

$$G_c = G - 0.04D$$

Where $G$ is the Gradient before, and $D$ is the degree of curve, in decimal.

At station platforms, a level gradient is preferred with a maximum grade of up to one (1)% is permitted. For yard tracks, where cars are stored, a level gradient is preferred, but a maximum non-rolling track gradient of 0.2% is permitted.

For mainline track, the desired length of constant profile grade between vertical curves shall be determined by the following formula (but not less than 100 feet):

$$L = 3V$$

where,

$\begin{align*}
L &= \text{minimum tangent length, feet} \\
V &= \text{design speed in the area, mph}
\end{align*}$

7.2 Vertical Curves

Vertical curves shall be designed per the requirements for high-speed main tracks and shooflies as recommended in AREMA Manual for Railway Engineering shown in the following formula:

$$L = \frac{(D V^2 K)}{A}$$

where,

$\begin{align*}
A &= \text{vertical acceleration, in ft/sec}^2 \\
D &= \text{absolute value of the difference in rates of grades expressed in decimal} \\
K &= 2.15 \text{ conversion factor to give } L, \text{ in feet}
\end{align*}$
L = length of vertical curve, in feet
V = speed of train, in miles per hour

The recommended vertical accelerations (A) for passenger and freight trains for both
sags and summits are as follows:

<table>
<thead>
<tr>
<th>Train Type</th>
<th>Recommended Vertical Acceleration (ft/sec²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Train</td>
<td>0.60 (0.02 g)</td>
</tr>
<tr>
<td>Freight Train</td>
<td>0.10</td>
</tr>
</tbody>
</table>

The longer vertical curve based on the above recommended accelerations shall be
used. Under no circumstances shall the length of vertical curve be less than 100 feet.

Station platform and special trackwork shall not be located inside vertical curves.
End of platform and point of switch shall be located at least 100 feet from beginning
and end points of vertical curve.

In summit areas, locations of all signals shall be checked for visibility.

Complex profiles, such as those with more than three grade changes exceeding
1.0% each within a distance of 3000 feet, may cause train excessive dynamic forces
and handling problems. The Caltrain Deputy Director of Engineering may require
train performance simulations to determine whether such profiles are acceptable for
passenger and/or freight operations. See the following FIGURE 2-3 for vertical curve
nomenclature.
When vertical Curve is Concave Downward:

\[ M = \frac{[(EL @ PVI \times 2) - (EL @ BVC + EL @ PVI)]}{4} \]

When vertical Curve is Concave Upward:

\[ M = \frac{[(EL @ BVC + EL @ EVC) - (EL @ PVI \times 2)]}{4} \]
D. SPECIAL TRACKWORK

Special trackwork refers to trackwork units that are used for tracks to converge, diverge, or cross each other. Special trackwork includes turnouts (or switches), crossovers, and track crossings. All special trackwork design shall be based on Caltrain Standard Drawings. In areas where with real estate constraints, special trackwork units may be designed with less than standards, with approval of the Deputy Director of Engineering.

1.0 TURNOUTS AND CROSSOVERS

Turnouts are used for tracks to diverge or converge from one track to another track. Turnouts have different types and sizes (numbers). A turnout unit consists of a switch, a frog, and straight and curve stock rails, plus a means to throw the switch and secure it.

Frog is the portion of a turnout or track crossing where wheels cross from one track to another track.

Crossovers are installed between two (2) tracks for trains to move from one track to another adjacent track. A single crossover unit consists of two turnouts. A universal crossover unit consists of two (2) continuous single crossovers installed in opposite directions.

Lateral turnout is a turnout in which the diversion due to the angle of the turnout is entirely on one side of the track from which the turnout is installed.

Equilateral turnout is a turnout in which the diversion due to the angle of the turnout is divided equally between the two tracks.

Double Slip switch (or puzzle switch) is a special trackwork unit which allows two crossing tracks to diverge from one to another. With the approval of the Caltrain Deputy Director of Engineering, this type of switch may be used at terminals and yards when the speeds will not exceed 15 MPH.

Turnout size or number is the number corresponding to the frog number of the turnout. The frog number is equal to the cotangent of the frog angle. Cotangent is the inverse of tangent.

Special trackwork requires the corresponding switch machines (to throw the switch) that are integrated with signal work.

See FIGURE 2-4 for layouts of various types of turnouts and crossovers.

2.0 APPLICATION OF TURNOUTS AND CROSSOVERS

The following standard turnouts and crossovers shall be used according to the desired maximum authorized speeds (MAS) for operations:
FIGURE 2-4  TURNOUTS AND CROSSED SOVERS
a. Lateral turnouts numbers 8 and 9 for yards

b. Lateral turnouts number 10, 14, and 20 for main line. Number 20 shall be used where there are no real estate constraints.

c. Number 9 double slip switches may be used in terminals.

d. Turnouts with Hollow Steel Ties (HST) per Standard Drawings SD-2000 series shall be used for new constructions.

The following information is required for the design of turnouts:

a. Turnout number

b. Stationing at the point of switch (PS) of the turnout

c. Stationing at the point of frog (PF) of the turnout

Detailed information on turnouts and crossovers is included in the Caltrain Standard Drawings.

2.1 Speeds Through Turnouts and Crossovers

Passenger train design speeds for turnouts and crossovers are based on three (3) inches of unbalanced superelevation for curves without spirals. Freight design speeds are for maximum of two (2) inches unbalanced superelevation.

Maximum authorized speeds (MAS) through turnouts and crossover for passenger and freight trains are as follows:

a. 10/10 MPH for turnouts number 9 for both passenger and freight

b. 25/15 (passenger/freight) MPH for turnout number 10

c. 35/25 (passenger/freight) MPH for turnout number 14

d. 50/40 (passenger/freight) MPH for turnout number 20

2.2 Standard Turnouts and Crossovers

Turnouts and crossovers shall be located to allow suitable placement of switch machines and/or switch stands to meet CPUC walkway requirements, with consideration of the placement and visibility of control signals, and with easy access for operation and maintenance.

Turnouts and crossovers shall be located on tangent tracks and shall meet the following requirements:

a. 100 feet minimum from point of switch (PS) to horizontal or vertical curves
b. Less than 100 feet from horizontal curves without superelevation with approval from the Caltrain Deputy Director of Engineering.

c. 100 feet minimum from point of switch to the edge of road crossings (including sidewalks)

d. 50 feet minimum from PS to Insulated Joint

e. 50 feet minimum from PS to opposing point of switch

f. Crossovers shall be located in parallel tracks only

g. Standard crossovers shall be of 15 feet track center

2.3 Non-Standard Turnouts and Crossovers

Design of non-standard turnouts and crossovers, such as equilateral turnouts and slip switches, shall require the approval of the Caltrain Deputy Director of Engineering. Design for conditions listed below shall require the approval of the Caltrain Deputy Director of Engineering.

a. Crossovers in non-parallel tracks

b. Crossovers with track center more than 15 feet

c. Turnouts in curves

d. Turnouts or crossovers in paved areas

3.0 DERAILS

Derails are mechanical and/or electrical safety devices intentionally used to derail or divert uncontrolled movement of train, rail vehicles, or on-track equipment away from adjacent or connecting tracks without fouling the tracks. See Caltrain Standard Drawings for layouts and details. The designer shall closely coordinate with the signal designer for design and layout requirements.

Derails shall be installed on the downgrade end of yard and secondary track that is normally used for storage of unattended vehicles, if this track is directly connected to the main track, and if its prevailing grade is descending toward the main track. With approval from the Caltrain Deputy Director of Engineering, derails may be used at other track locations where cars are moved or locomotives are stored to prevent or minimize injury to passengers and personnel, and/or damage to equipment.

Derails shall be located so that they derail equipment in a direction away from the main track. Derails shall be located beyond the clearance points of converging tracks. Double point split switch derails are installed at locations as required by Caltrain’s Operations and Engineering departments including locations where operating locomotives are stored and where cars are moved or switched by non-railroad personnel.
Derails are connected to the signal system to indicate when they are lined for train movement.

Blue Flag derails are required to protect workers on service tracks per FRA Title 49 CFR Part 218 and to protect workers during the unloading of hazardous materials per FRA Title 49 CFR Part 172.

4.0 RAILROAD CROSSINGS

Railroad crossings are where tracks cross each other. Installation of railroad crossings shall require approval from the Caltrain Deputy Director of Engineering and only where there is no other economical option. If installed, crossings shall only be located on tangent tracks at standard skew angles as recommended by AREMA. See AREMA Portfolio of Trackwork Plans for layouts and details of crossings for various skew angles.

E. TRAIN PERFORMANCE CHARTS

The Maximum Authorized Speed (MAS) of the Caltrain system is 79 MPH, which is based on FRA signal standards (49 CFR Part 236). In order to operate at speeds of 80 MPH or higher, a supplemental signal system will be required. For MAS of 79 MPH, Class 4 track standards are the minimum requirements.

The following Acceleration and Deceleration Charts were developed (FIGURES 2-5 through 2-7, respectively) by Systra Consulting for Caltrain contained in their April 4, 2004 Report: “Acceleration and Deceleration Performance of Caltrain’s FP40PH and MP36 Locomotive”. Additional report “Signal System Headway / Capacity Study” (December 31, 2005, Revised February 10, 2006) in APPENDIX.
Acceleration Tests on Level, Tangent Track
EMD F40PH-2C Locomotive with 4-10 Gallery Cars

**FIGURE 2-5  ACCELERATION CHART FOR EMD F40PH-2C LOCOMOTIVE**
Acceleration Test on Level, Tangent Track
MPI MP36PH-3C Locomotive with 4 to 10 Bombardier Cars

**FIGURE 2-6  ACCELERATION CHART FOR MPI MP36PH-3C LOCOMOTIVE**
Deceleration at 1.15 mph/Sec for MP36PH-3C Engine and F40PH-2C Engine, Each with 7 Cars

FIGURE 2-7 DECELERATION CHART FOR MP36PH-3C LOCOMOTIVE AND F40PH-2C LOCOMOTIVE

END OF CHAPTER