California High-Speed Train Project

TECHNICAL MEMORANDUM

Turnouts and Yard Tracks
TM 2.1.8

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Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:
- Technical consistency and appropriateness
- Check for integration issues and conflicts

System level reviews are required for all technical memoranda. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the System Level technical and integration review by any Subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems: _NOT REQUIRED_______________ __________
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Infrastructure: *Signed document on file*_________ 11 July 09
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ABSTRACT

This technical memorandum presents guidance for the geometric design of turnouts, crossovers, yard lead and yard tracks with turnouts and return curves to be used in the basic design in order to achieve a safe and reliable operating railway that meet applicable regulatory requirements and achieve the operational and performance requirements for equipment traveling on California High-Speed Train (CHST) rail lines.

- This technical memorandum develops and presents the specific geometric designs to be used in turnouts, crossovers and yard tracks.
- This technical memorandum is not a specification for track materials or track construction but is the guideline for the development of those specifications.
- This technical memorandum will not include analysis or discussion of the operation of turnouts.
- This technical memorandum will not discuss the spacing, nature, and length of yard tracks for specific purposes. Such items are part of the operational requirements.

The information presented in this technical memorandum will be included in the CHSTP Design Manual.

6.0 DESIGN MANUAL CRITERIA

6.1 YARD ACCESS TRACKS; YARD, STORAGE, AND OTHER LOW SPEED TRACKS

The specific track arrangement for each yard will depend upon the purpose of the yard and tracks in the yard. Therefore the basic layout will be determined by operational requirements. The requirements developed in this Technical Memorandum are therefore limited to those of a general nature except for those relating to geometric constraints due to

- Curvature related constraints due to vehicle characteristics
- Track length constraints due to train and individual vehicle length
- Profile and grade related issues

Other than the tracks connecting the yards to the revenue tracks, the design parameters for these tracks are speed-independent.

6.1.1 Track Alignment Design Parameters – Access and Main Line Connecting Tracks

Main Line Connecting Tracks: Site constraints may lead to large distances between main line access points and yards. For the purpose of minimizing time into and out of yards, and minimizing the time required to clear revenue tracks, the tracks connecting main lines to yard shall be designed to higher speed standards than the yard itself. These tracks shall therefore be designed much like a secondary main line railroad.

Since speed of trains on these tracks is likely to be highly variable, including the likelihood that trains may frequently be stopped on these tracks, superelevation shall be kept to low values to the greatest extent practical.

- Minimum Radius:
  - Desirable: 2,500 feet
  - Minimum: 900 feet
  - Exceptional: 500 feet
- Design Speed:
  - Desirable: 50 mph
  - Minimum: 35 mph
  - Exceptional: 25 mph
- Curve Radii shall be based on the allowed superelevation and unbalance for the selected speed based on the following limits for superelevation and unbalanced superelevation:
- Superelevation
  - Desirable: 2 inches or less
  - Minimum: 3 inches
  - Exceptional: 3 inches
- Unbalanced Superelevation
  - Desirable: 2 inches or less
  - Minimum: 3 inches
  - Exceptional: 3 inches

- Spiral Lengths:
  - Desirable: 75 feet per inch of superelevation or unbalance, whichever gives the greatest length
  - Minimum: 62 feet per inch of superelevation or unbalance, whichever gives the greatest length
  - Exceptional: 62 feet per inch of superelevation or unbalance, whichever gives the greatest length
- Minimum Length of Tangent between curves in the same direction:
  - Desirable: 75 feet or larger
  - Minimum: 0 feet (However, compound curves must be joined by spirals of a length equal to 62 feet per inch of change in superelevation or unbalance, whichever gives the greater length)
  - Exceptional: 0 feet (However, compound curves must be joined by spirals of a length equal to 62 feet per inch of change in superelevation or unbalance, whichever gives the greater length)
- Minimum Length of Tangent between reversing curves. The length may be reduced by one-half the combined lengths of the adjacent spirals.
  - Desirable: 75 feet or larger
  - Minimum: $L_{min} = 9{,}400{,}000 / R_1^2 + 9{,}400{,}000 / R_2^2$, but not less than 40 feet
  - Exceptional: $L_{min} = 7{,}750{,}000 / R_1^2 + 7{,}750{,}000 / R_2^2$, but not less than 25 feet
- Minimum Turnouts (see discussion in 6.2 for details):
  - Desirable: Number 20 (internal radius 3275 feet, allowed speed, 50 mph)
  - Minimum: Number 15 (internal radius 1750 feet, allowed speed 35 mph)
  - Exceptional: Number 11 (internal radius 950 feet, allowed speed 25 mph. Number 15 turnouts shall be used in track otherwise limited to 25 mph where practical.)
- Minimum Track Centers, not including allowance for catenary poles, drainage, walkways, roadways, or other facilities that will be placed between tracks in some areas:
  - Desirable: 16.50 feet
  - Minimum: 15.00 feet.
  - Exceptional: 14.00 feet
- Minimum Track Centers on small radius curves may need to be larger than the values given above. If the following calculation results in a larger value, these values shall be used. Again, these values do not including allowance for catenary poles, drainage, walkways, roadways, or other facilities that will be placed between tracks in some areas:
  - Desirable: In feet, 14.75 + 1,100 / Radius, but not less than 16.50 feet
  - Minimum: In feet, 14.75 + 1,100 / Radius, but not less than 15.00 feet
  - Exceptional: In feet, 13.75 + 1,000 / Radius, but not less than 14.00 feet
- Grades (Grade limits are independent of design speed.):
  - Desirable: 0.50% or less
  - Minimum: 2.00%.
  - Exceptional: 3.00%. grades above 2.00% shall be reduced through curves by a factor of: Grade reduction in % = 230 / Radius in feet.

- Vertical Curves (Vertical curve lengths are independent of design speed.):
  - Desirable: 200 feet minimum length with a rate of change of not more than 0.50% per 100 feet
  - Minimum: 100 feet minimum length with a rate of change of not more than 1.00% per 100 feet
  - Exceptional: 100 feet minimum length with a rate of change of not more than 2.00% per 100 feet

6.1.2 Track Alignment Design Parameters – Connecting and Switching Tracks

Connecting Tracks: The following standards apply to tracks on which cars will not be stored or left standing but are installed for the purpose of connections between yard tracks and access to yard tracks within the area designated as yards, all types, and other low speed tracks.

- Curve Radii:
  - Desirable: 950 feet or larger
  - Minimum: 620 feet
  - Exceptional: 500 feet
- Minimum Length of Tangent between curves in the same direction:
  - Desirable: 75 feet or larger
  - Minimum: 0 feet (compound curve)
  - Exceptional: 0 feet (compound curve)
- Minimum Length of Tangent between reversing curves:
  - Desirable: 75 feet or larger
  - Minimum: $L_{min} = 9{,}400{,}000 / R_1^2 + 9{,}400{,}000 / R_2^2$, but not less than 40 feet
  - Exceptional: $L_{min} = 7{,}750{,}000 / R_1^2 + 7{,}750{,}000 / R_2^2$, but not less than 25 feet
- Minimum Turnouts (see discussion in 6.2 for details):
  - Desirable: Number 11 (internal radius 950 feet)
  - Minimum: Number 9 (internal radius 620 feet). If in a track with high volume traffic, the minimum shall be a Number 11.
  - Exceptional: Number 9 (internal radius 620 feet)
- Minimum Track Centers:
  - Desirable: 15.00 feet
  - Minimum: 15.00 feet.
  - Exceptional: 14.00 feet

  Wider track centers shall be provided if catenary poles, light poles, drainage, signal masts, electrical cases, major walkways or other facilities must be placed between tracks.
- Minimum Track Centers on small radius curves may need to be larger than the values given above. If the following calculation results in a larger value, these values shall be used. Again, these values do not including allowance for catenary poles, drainage, walkways, roadways, or other facilities that will be placed between tracks in some areas:
  - Desirable: In feet, 14.75 + 1,100 / Radius, but not less than 15.00 feet
  - Minimum: In feet, 14.75 + 1,100 / Radius, but not less than 15.00 feet
  - Exceptional: In feet, 13.75 + 1,000 / Radius, but not less than 14.00 feet

- Grades:
  - Desirable: 0.50% or less
  - Minimum: 2.00%.
  - Exceptional: 3.00%. Grades above 2.00% shall be reduced through curves by a factor of: Grade reduction in % = 230 / Radius in feet.
- Vertical Curves:
  - Desirable: 100 feet minimum length with a rate of change of not more than 1.00% per 100 feet
  - Minimum: 50 feet minimum length with a rate of change of not more than 2.00% per 100 feet
  - Exceptional: 50 feet minimum length with a rate of change of not more than 2.00% per 100 feet

6.1.3 Track Alignment Design Parameters – Servicing and Storage Tracks

Tracks on which equipment will be stored or serviced: The following standards apply to those portions of tracks on which cars will be left standing, serviced, or stored. They do not apply on the approach portions of those tracks. These apply only to the usable length of track and any overrun distances or, in the case of stub end tracks the portion between usable length and the bumping post or other end of track device.

- **Usable Length of Track:** The usable length of track is defined as the length of track which is usable for its defined purpose. Thus usable length does not include space for bumping posts or other end of track devices, defined set back from the end of track device, defined set back from signals, space occupied by road crossings, turnouts to other tracks, and any other feature that render the equipment on the track inaccessible to service, if the purpose of the track is to hold equipment while being serviced, or unusable for storage if the purpose of the track is to store passenger trains or other equipment
- **Usable length of track for train servicing and storage tracks** is defined based on the maximum potential train length. Sufficient length beyond train length to hold a switch engine shall also be provided.
  - Desirable: 1450 feet
  - Minimum: 1400 feet
  - Exceptional: 1375 feet
- **Usable length of track for other purposes:** For tracks not intended to hold full length trains, the usable length shall be defined by the length of equipment that it is intended to hold plus some allowance for placement of equipment, and desirably additional length sufficient to hold a switch engine.
  - Desirable: 125 feet in addition to the length to be occupied by equipment
  - Minimum: 75 feet in addition to the length to be occupied by equipment
  - Minimum: 50 feet in addition to the length to be occupied by equipment
- Curve Radii for curves within the usable length:
  - Desirable: Tangent (No curves at all)
  - Minimum: 10,000 feet
  - Exceptional: 2,000 feet

- Grades within the usable length:
  - Desirable: between 0.20% and 0.30% down from the access point. In the case of double ended tracks, the grades shall be down toward a low point in the middle third of the usable length
  - Minimum: between 0.00% and 0.20% or between 0.30% and 0.50% down from the access point. In the case of double ended tracks, the low end access track shall not be lower than the highest point within the portion designated as usable length.
  - Exceptional: between 0.00% and 0.20% downgrade toward access tracks. Derail devices shall be applied to tracks that are downgrade toward an access point. If any point of the designated usable length is higher than the access tracks, the track is defined as being downgrade toward the access track.
- Vertical Curves:
  - Desirable: 100 feet minimum length with a rate of change of not more than 0.50% per 100 feet
  - Minimum: 50 feet minimum length with a rate of change of not more than 1.00% per 100 feet
  - Exceptional: 50 feet minimum length with a rate of change of not more than 2.00% per 100 feet
- Minimum Track Centers, between tracks on which servicing of equipment will be performed:
  - Desirable: alternating spacing of 30.00 feet and 22.00 feet
  - Minimum: alternating spacing of 28.00 feet and 20.00 feet.
  - Exceptional: alternating spacing of 28.00 feet and 20.00 feet

  These track centers provide space between tracks for roadways on the wider centers and cart paths or walkways on the narrower centers. However, they do not include allowances for catenary poles, light poles, drainage, signal masts, electrical cases, inspection platforms and pits, or other facilities that may interfere with the use of the aisles as traveled ways. Wider track centers shall be provided where these facilities are needed.
- Minimum Track Centers, between tracks on which no servicing of equipment will be performed:
  - Desirable: 15.00 feet
  - Minimum: 15.00 feet.
  - Exceptional: 14.00 feet

  Wider track centers shall be provided if catenary poles, light poles, drainage, signal masts, electrical cases, major walkways or other facilities must be placed between tracks.

6.2 TURNOUT GEOMETRY

The yard turnouts and other low and medium speed turnouts will use straight frogs having the same standard frog numbers as the current BNSF/UPRR standards so as to both reduce costs and simplify future maintenance and procurement of replacement parts.

There are certain differences between these turnouts and standard AREMA turnouts. What is not different is the definition of the point of frog. It remains the traditional ½ inch point of frog

The turnouts proposed for this project differ from standard AREMA turnouts in terms of the closure curve and switch geometry. The standard AREMA style switch point geometry is not used due to its high entry angle which could result in the possibility that the wheels could climb the switch point due to the nature of the suspension of most high-speed trainsets. Instead, the internal curve will be of a “tangent point” design so as to give a small switch point entry angle. As fabricated, the actual switch point will be cut back slightly from the true PC of the curve, but for geometric calculations this cut back may be ignored.

6.2.1 Selected Yard Turnouts

Figure 6.2.1: Low and Medium Speed Turnouts

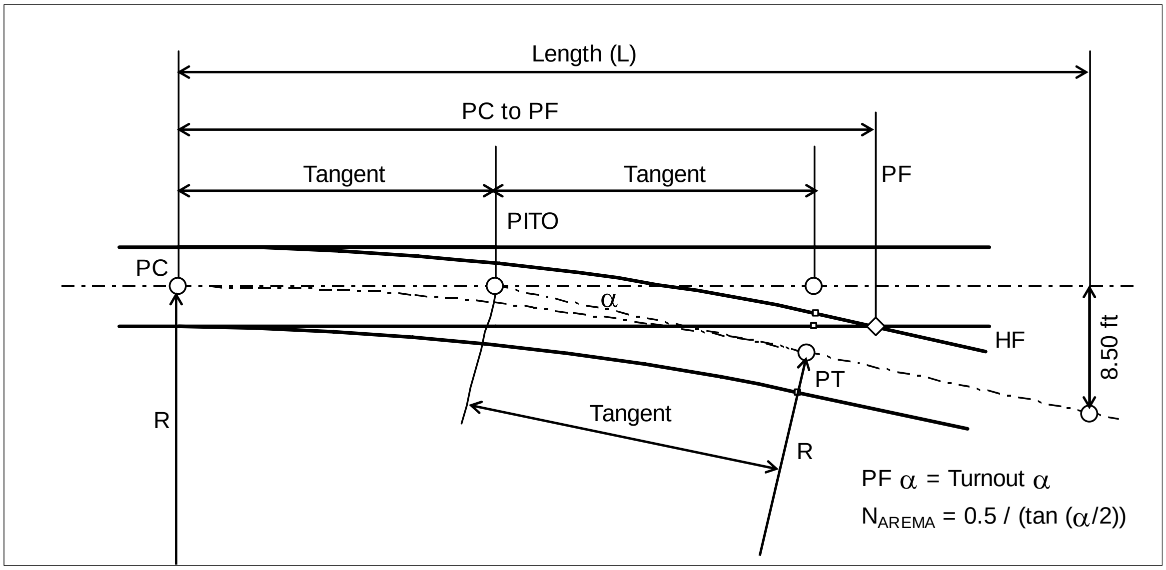


Table 6.2.1: Low and Medium Speed Turnouts

Number	9	11	15	20
Defined Angle	6d21m35s	5d12m18s	3d49m06s	2d51m51s
Radius	620 feet	950 feet	1750 feet	3275 feet
Tangent	34.44 feet	43.18 feet	58.33 feet	81.87 feet
Lead, PC to ½ inch PF	77.19 feet	95.43 feet	129.58 feet	176.87 feet
PC to 8.5 feet separation	110.71 feet	136.49 feet	185.69 feet	251.77 feet
Tangent Rail, ½ inch PF to Curve PT	8.31 feet	9.07 feet	12.92 feet	13.13 feet
Maximum Diverging Speed	20 mph	25 mph	35 mph	50 mph
Unbalance at Maximum Diverging Speed	2.58 inches	2.63 inches	2.80 inches	3.05 inches

The switch points of these turnouts will be cut back slightly from the PC location shown, but the exact shape and cutback of the switch point is beyond the scope of this Technical Memorandum.

Use of the Number 9 turnout shall be treated as an “Exceptional” condition for any situation where the traffic volume is other than very low due to the know high rate of side wear of the rails that occurs in small radius turnouts under high-speed equipment. Number 11 turnouts will be used as the standard yard turnout, and as the minimum size turnout to be installed in main tracks with speeds of 125 mph or less and in station tracks. Number 15 turnouts shall be the minimum turnouts out of main tracks for all other situation. Yard Lead or other tracks that will have traffic volume other than very low shall be no less than Number 20 turnouts if conditions permit.

6.2.2 Space between Turnouts

Run time considerations are not relevant to the spacing of low and medium speed turnouts.

It is desirable to have at least 75.00 feet of straight track in advance of a switch. Where practical, low speed turnouts shall be spaced so that the length between turnouts is at least equal to the distance from the center of one truck to the opposite end of the vehicle. Where the usage of switches that are point to point is such that trains are unlikely to use both turnouts, the switch points may be places closer, down to 45 feet apart. It is also desirable that the track off the frog end of the turnout be straight to at least the end of the switch tie set, which may be taken at this time as the point at which the tracks are 8.50 feet apart. In the development of crossovers, track ladders, and track fans, it will be seen that these desires are not always practically achievable.

6.2.3 Space beside Turnouts

Space shall be reserved adjacent to turnouts for the mounting of switch machines to move the points, along with power and control cabling for those machines. For number 9 and number 11 turnouts, a distance of 10 feet into the tangent ahead of the switch and 15 feet into the turnout any curbs or other obstructions that would be higher than the subgrade or invert supporting the track shall be located no closer than 7.75 feet from track centerline. This space shall be provided along one side of the turnout. It is desirable that the space be provided on both sides of the turnout.

For number 15 and 20 turnouts, the additional width shall be provided on both sides of the turnouts. The space requirement shall extend from 10 feet into the tangent ahead of the switch and 35 feet into the turnout for number 15 turnouts. The space requirement shall extend from 10 feet into the tangent ahead of the switch and 50 feet into the turnout for number 20 turnouts.

It is assumed that swing nose frogs will not be used with any of these turnouts where used in yard tracks and similar service, and therefore no space for the operating mechanisms moving these frogs will be needed.

6.3 CROSSOVERS

6.3.1 Single Crossovers

The most common arrangement of turnouts beyond a simple turnout to a diverging or parallel track is a simple crossover between parallel tracks. The essence of a crossover is two turnouts connected at their frog ends. Where the track centers are less than 17.0 feet there is an overlap between the turnout tie sets. This occurrence is common. The distance of concern in crossovers is the central tangent, shown as “Tangent” in Figure 6.3.1. For close track centers and small turnout numbers, this distance can be less than the truck centers plus one end overhang that is the minimum tangent distance between reversing curves.

See Table 6.3.1 for crossover data. Data not given are found in the turnout data in Table 6.2.1.

Figure 6.3.1: Crossovers

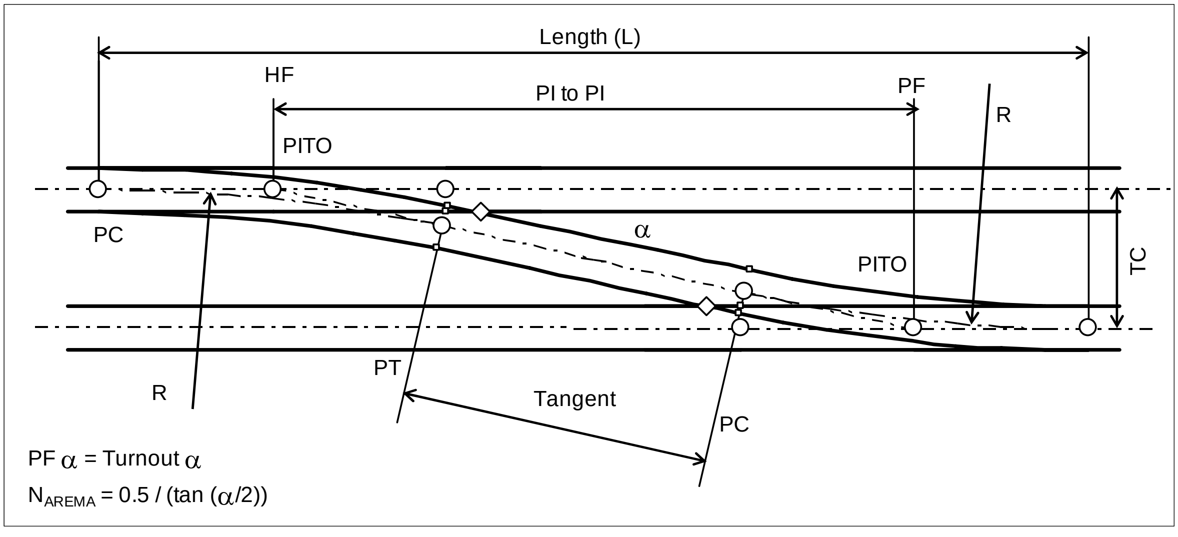


Table 6.3.1: Crossovers in Low and Medium Speed Turnouts

Number	9	11	15	20
Defined Angle	6d21m35s	5d12m18s	3d49m06s	2d51m51s
Radius	620 feet	950 feet	1750 feet	3275 feet
Length (L) end to end of crossover				
14.00 feet track centers	194.50	240.05	326.43	443.58
15.00 feet track centers	203.47	251.02	341.42	463.56
PITO to PITO distance on tangent				
14.00 feet track centers	125.61	153.69	209.77	279.83
15.00 feet track centers	134.58	164.66	224.75	299.82
Change in length per 1.000 foot change in track centers, either of the above	8.972	10.978	14.983	19.988
Tangent length on diagonal				
14.00 feet track centers	57.50	67.96	93.56	116.43
15.00 feet track centers	66.53	78.98	108.58	136.44
Change in length per 1.000 foot change in track centers	9.028	11.023	15.017	20.013

For the typical American coach that is 85.00 feet long with 59.50 feet truck centers, it can be seen that the tangent between curves is smaller than the normal end overhang plus truck centers for a number 9 crossover at both 14.00 and 15.00 feet track centers, and is slightly below this dimension for the number 11 crossover at 14.00 feet track centers. This factor is likewise true for Shinkansen coaches which are 82.00 feet long with 57.41 feet truck centers, and for the 61.35 feet long TGV articulated vehicle. However, it is known that all these vehicles do operate over crossovers having these characteristics.

Since small radii curves in turnouts result in short component life and working the equipment to near its limits of movement is undesirable, it is desirable that the turnouts in crossover be number 11 or larger. It is also desirable to keep the track centers at 15.00 feet or larger for this and other reasons.

6.3.2 Double Crossovers (Scissors Crossovers)

Where space is constrained, and crossovers allowing universal moves are desired, crossovers may be overlapped to form a double crossover. This form of crossover is also sometimes called a scissors crossover, as on some systems the term “double crossover” means two single crossovers of opposite hand placed in succession.

Double (scissors) crossovers shall be used only under exceptional conditions due to their high cost and maintenance requirements. In 14.00 feet track centers, only the number 9 double (scissors) crossover can be properly guarded. For the number 11 and larger turnouts in double crossovers in 14.00 feet track centers, the relationship between the end gap of the center diamond and the turnout frog gaps is such that guarding is compromised.

Under exception conditions, the following double crossovers may be used:

- Number 9 at 14.00 feet or larger track centers
- Number 11 at 15.00 feet or larger track centers
- Number 15 at 15.00 feet or larger track centers

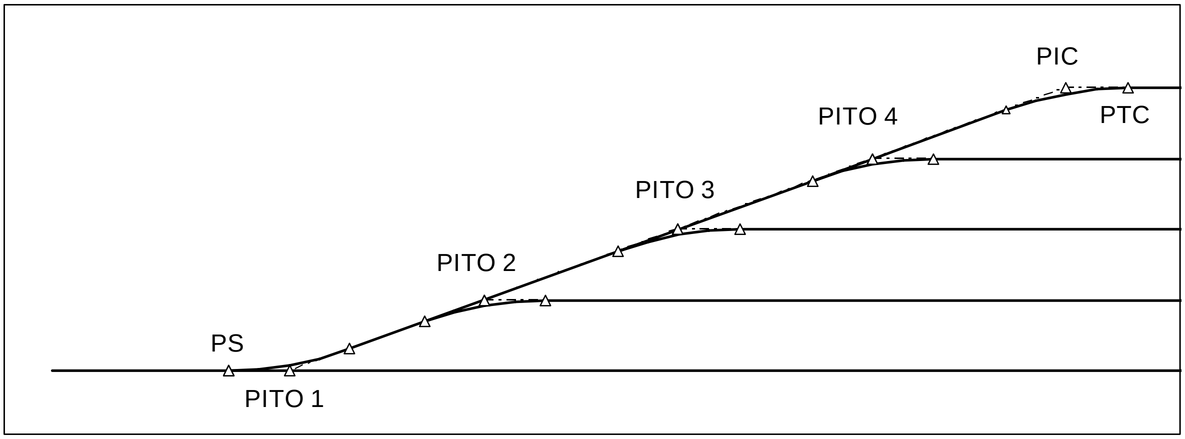
Number 20 double (scissors) crossovers shall not be used.

6.4 TRACK LADDERS

6.4.1 Simple Ladders

A track ladder is a series of turnouts used to connect a group of parallel tracks to each other in conjunction with either an approach track or a stub end track to permit equipment to be accessed or shuttled between tracks. The most common form of connection of multiple parallel tracks is a straight ladder, also called a simple ladder. A simple ladder is a series of turnout connected end to end so as to access all the parallel tracks. Its primary advantage is its simplicity in design, construction and maintenance. Its disadvantage is its length when more than a few tracks are involved.

Figure 6.4.1: Simple Ladder (4 Tracks Illustrated)



Calculation of the points on these ladders is straightforward. The PS to PITO 1 dimension is a property of the turnout used. The PITO 1 to PITO 2 and PITO 2 to PITO 3 and so forth lengths parallel to the tracks are simply track spacing divided by the tangent of the frog angle of the turnout. PI to PI lengths along the ladder track are track spacing divided by the sine of the frog angle of the turnout. When summed and the length of the final curve tangent added, the length of the entire ladder is determined.

For the basic ladder connecting tracks at 15.00 centers using number 11 turnouts, the dimensions are as follows:

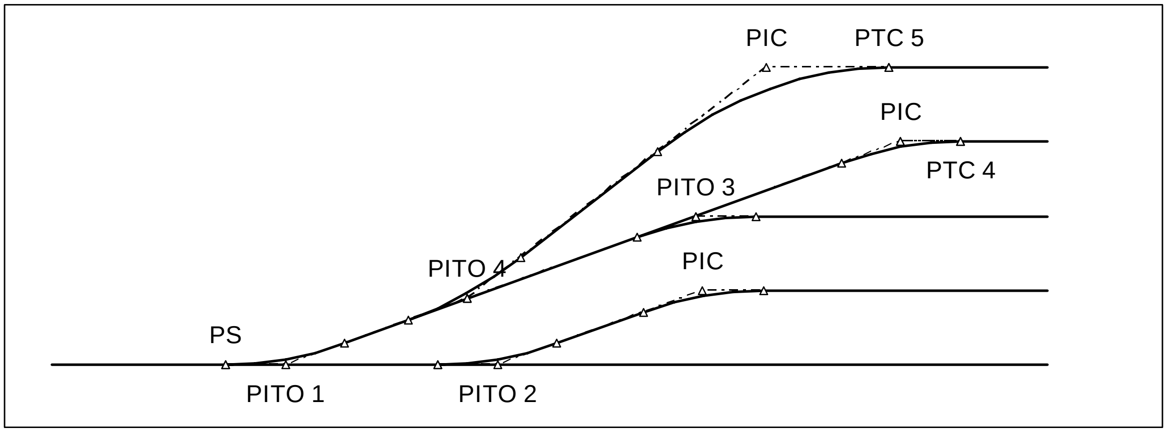
- Between PITO's parallel to the lead track: 164.66 feet
- Between PITO's on the ladder track: 165.34 feet
- Total distance, PS entry turnout to curve PT for the case illustrated: 745.01 feet
- Total PS to PS distance for double ended tracks with 1,500 feet clear length: 2990 feet
- Length utilized by ladder for each additional track: 329.33 feet

As can be seen, when more than a few tracks are involved, the total length of this arrangement quickly becomes impractical, particularly where track centers are large. Thus, the need for compound ladders to shorten the overall yard length.

6.4.2 Double Angle Ladders

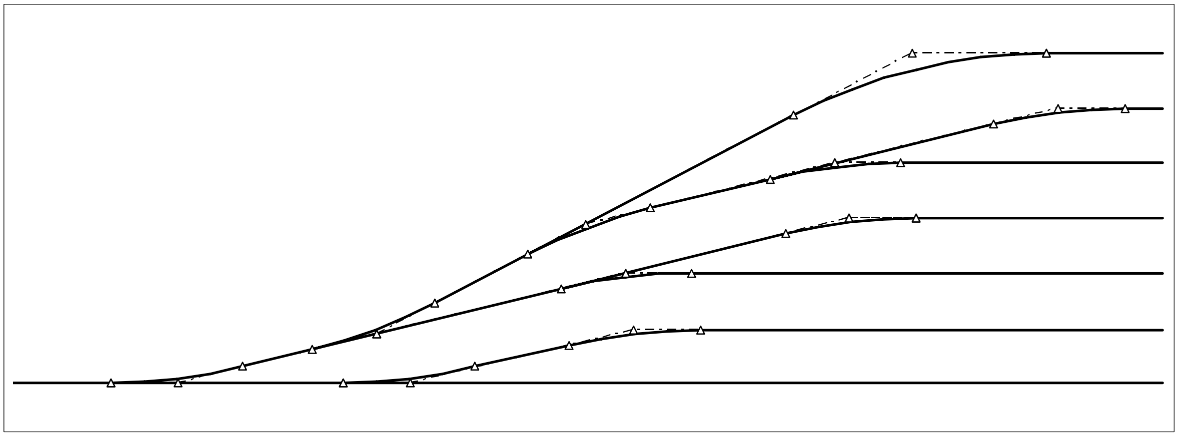
Considerable space can be saved by use of double angle ladder tracks, as the larger angle considerably reduce the length required to achieve the required offsets. First, look at the situation with the same number and spacing of tracks as used in the simple ladder illustration:

Figure 6.4.2: Double Ladder (4 Diverging Tracks Illustrated)



The single frog angle ladder using number 11 turnouts and 15.00 feet track centers was 745 feet long from first point of switch to the point of development of the full width. By taking only one track off the outside, the length is reduced to 580.35 feet, a saving in length of over 300 feet if the yard is double ended. The greater the number of tracks, the greater is the saving in length. To illustrate the nature of these savings, Figure 6.4.3 presents the situation with 6 diverging tracks.

Figure 6.4.3: Double Ladder (6 Diverging Tracks Illustrated)

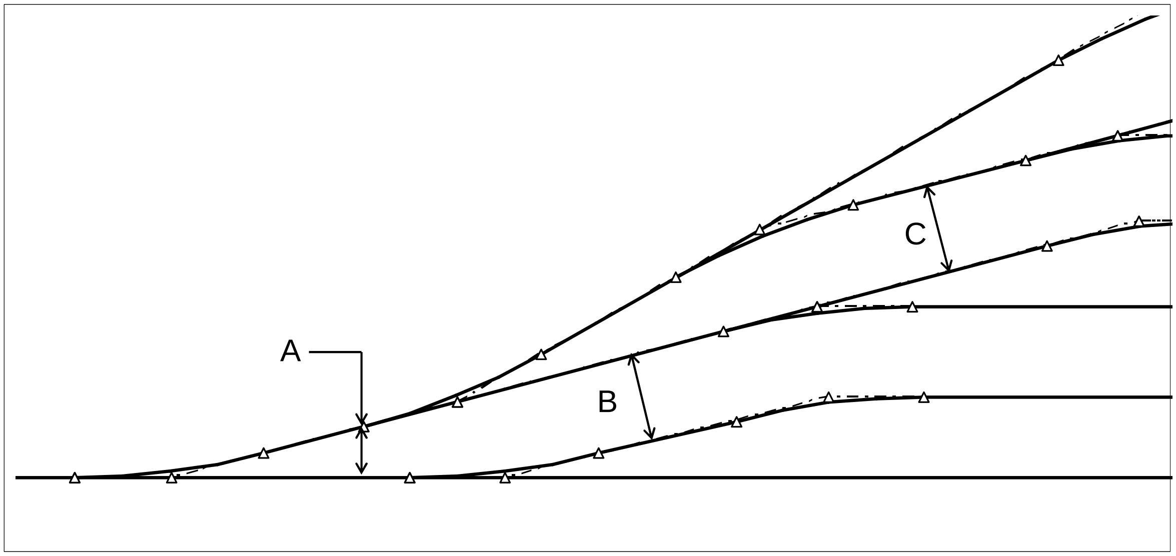


This method can be carried forward with additional tracks to what ever extent is necessary. For the illustrated six diverging track arrangement, the length form beginning point to end of last curve is 734.03 feet, using number 11 turnouts. The same number of tracks using a simple ladder would utilize 1074.34 feet. Thus, for a double ended arrangement, the length saving is 680 feet.

The greater the number of tracks, the greater is the savings in overall yard length. For large numbers of tracks, the arrangement can be carried at least one step further to go to a triple ladder.

The following considerations shall be used in the development of these designs:

Figure 6.4.4: Double Ladder (6 Diverging Tracks Illustrated)



A. Separation at switch point: Desirable: 9.00 feet, Minimum: 9.0 feet, Exceptional: 7.0

B. Space between track centers: Desirable, 20.0 feet, Minimum 18.0 feet, Less only if switch machine for second track is located on the straight side of turnout, then 15.0 feet

C. Space between track centers with switch points approximately opposite: Desirable 25.0 feet, if one can be turnout away, Minimum 20.0 feet; if both can be turned away, Exceptional: 18.0 feet.

The above considerations are required to provide space for the switch tie sets of adjoining turnouts to fit together without overlapping. While overlapping tie sets are constructible, these are undesirable because they create the need for non-standard, site-specific ties and fixtures that add to yard cost and complexity. These space requirements generally will provide adequate clearance for switch stands or switch machines to be located clear of adjacent tracks so that employees can operate and maintain them safely. However, the specifics of each yard layout may create localized conditions of interference. Ultimately the yard ladders must be laid out with dimensionally accurate switch machines and tie layouts, and adjacent roads and facilities must be overlaid to verify fit.