California High-Speed Train Project

TECHNICAL MEMORANDUM

Alignment Standards for Shared Use Corridors (Specific to Los Angeles to Anaheim) TM 1.1.6

Prepared by: *Signed document on file*_________ __17 Dec 07_
George Harris Date

Checked by: *Signed document on file*_________ __17 Dec 07_
John Chirco, Infrastructure Lead Date

Approved by: *Signed document on file*_________ __17 Dec 07_
Ken Jong, PE, Engineering Manager Date

Released by: *Signed document on file*_________ __3 Jan 08 _
Anthony Daniels, Program Director Date

Revision	Date	Description
0	17 Dec 07	Initial Release for Review

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 memorandums. Technical Leads for each subsystem is 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: *Signed document on file*_________ _17 Dec 07_
Print Name: Eric Scotson Date

Infrastructure: *Signed document on file*_________ _17 Dec 07_
Print Name: John Chirco Date

Operations: *Signed document on file*_________ _17 Dec 07_
Print Name: Paul Mosier Date

Maintenance: *Signed document on file*_________ _17 Dec 07_
Print Name: Paul Mosier Date

Rolling Stock: *Signed document on file*_________ _17 Dec 07_
Print Name: Terry Brunner Date

TABLE OF CONTENTS

ABSTRACT 1

1.0 INTRODUCTION 2

1.1 PURPOSE OF TECHNICAL MEMORANDUM 2

1.2 STATEMENT OF TECHNICAL ISSUE 2

1.3 GENERAL 2
1.3.1 DEFINITION OF TERMS 3
1.3.2 UNITS 4

2.0 DESIGN STANDARDS AND GUIDELINES 4

2.1 GENERAL 4

2.2 LAWS AND CODES 5

3.0 ALIGNMENT CRITERIA 6

3.1 GENERAL 6

3.2 HORIZONTAL ALIGNMENT 7
3.2.1 CURVATURE 7
3.2.2 SUPERELEVATION 9
3.2.3 UNBALANCED SUPERELEVATION 10
3.2.4 DETERMINATION OF APPLIED SUPERELEVATION AND UNBALANCED SUPERELEVATION 10
3.2.5 SPIRAL TYPES AND APPLICATION TO CURVES 11

3.3 VERTICAL ALIGNMENT 16
3.3.1 GRADES 16
3.3.2 VERTICAL CURVES 17
3.3.3 VERTICAL CURVE / HORIZONTAL CURVE COMBINATIONS 18

3.4 CLEARANCES 18

4.0 SUMMARY AND RECOMENDATIONS 23

5.0 SOURCE INFORMATION AND REFERENCES 23

6.0 DESIGN MANUAL CRITERIA 23

6.1 INFORMATION FOR INCLUSION IN DESIGN MANUAL 23
6.1.1 TRACK CENTERS 23
6.1.2 CLEARANCES 24
6.1.3 GENERAL ALIGNMENT REQUIREMENTS: 25
6.1.4 MINIMUM RADII 25
6.1.5 SUPERELEVATION 26
6.1.6 SPIRALS: 27
6.1.7 GRADES AND VERTICAL CURVES: 28

X.1 APPENDIX: DISCUSSION OF SOURCE OF STANDARDS 30

ABSTRACT

The California High Speed Train System is being proposed as a high speed steel wheel on steel rail train operation that will provide service throughout the state of California with end terminals in Sacramento, San Francisco, Fresno, Bakersfield, Los Angeles, Anaheim and San Diego. There are several locations where the proposed California High-Speed Rail (CHSR) line will operate adjacent to or within a shared right-of-way with conventional passenger railroad lines and freight railroad lines. One such location is the rail corridor that serves freight and passenger customers between Los Angeles and San Diego referred to as the LOSSAN Corridor. Within this corridor, high-speed trains are expected to operate at speeds up to 125 mph.

This technical memorandum presents design guidance for the segment of the proposed High Speed Rail line between Los Angeles Union Station (LAUS) and Anaheim. It defines the geometric design requirements to be used in the basic design in order to achieve a safe and reliable operating railway that meet applicable regulatory requirements and achieve CHSTP functional, programmatic, operational, and performance requirements within the corridor. The general basis of alignment design will be to follow best practices as described in the Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual) and the standards given in this document.

Guidance for the design of high speed train operations outside of the LOSSAN corridor will be provided in a separate document.

4.0 SUMMARY AND RECOMENDATIONS

The recommended Alignment Criteria for the Los Angeles Union Station to Anaheim Shared Use Corridors with 125 mph (max) operating speed is summarized in Section 6.0

As noted in the introduction, the primary objective in setting alignment is to develop as smooth an alignment as the various requirements for location in stations, mountain crossings, major stream crossings, environmental and political constraints permit. Horizontal curves, in particular, should be set larger than “Desirable” values where ever it is practical to do so. Going below “Desirable” values for the various portions of the alignment should not be treated lightly. Very seldom will an alignment as finally designed and built be better than that set out initially. Quite frequently points will be “locked in” very early in the study process. This is particularly true for the horizontal component of alignment.

Use of Minimum and Exceptional values should be held back to the greatest extent practical for use in the adjustments due to unanticipated constraints that will always occur.

It is very easy to get into a “can’t see the forest for the trees” situation. At frequent intervals the designer should step back and look at things globally. This means plotting condensed profiles and looking at the layout over long segments. When transitioning from low speed areas to high speed areas, the operating characteristics of both presently available trains and characteristics of trains with anticipated improvements in power, acceleration and braking. Remember, sudden jumps in speed simply do not happen with trains.

There should be a relationship between horizontal and vertical alignment standards. That is, there is not point in using vertical curves designed for 125 mph adjacent to curve or other constraining elements that will permanently restrict speeds to a much lower value. However, the speed used in developing vertical curves should never be lower than that possible under “Exceptional” conditions on adjacent horizontal curves.

It is not possible for a document such as this to anticipate all eventualities nor is it possible for it to be a textbook in alignment design practices nor is it intended to be used as a substitute for good engineering judgment.

5.0 SOURCE INFORMATION AND REFERENCES

Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)

Federal Railroad Administration Code of Federal Regulations (CFR)

- CFR Part 213, Track Safety Standards, generally and also in particular Subpart G -Train Operations at Track Classes 6 and Higher
- CFR Part 214, Railroad Workplace Safety

California Department of Transportation, Manuals and Standards

Public Utilities Commission of the State of California General Orders

6.0 DESIGN MANUAL CRITERIA

6.1 INFORMATION FOR INCLUSION IN DESIGN MANUAL

The following information applies to shared use Corridors where the shared use is other passenger train and does not include freight trains only. Corridors to be exclusively used by equipment designed and constructed for high speed operation above 125 mph shall be designed to a set of criteria specific to that purpose.

6.1.1 Track Centers

Main Track track centers without poles between them:

- Desirable: 16’-6” (where speeds are under 100 mph, may be 15’-0”)

- Minimum: 15’-0”
- Exceptional: 14’-0”

Main Track track centers with catenary poles between them:

- Desirable: 30’-0”
- Minimum: 26’-0”
- Exceptional: 22’-0”

Main Track track center to nearest station or yard track track center without poles between them:

- Desirable: 25’-0”
- Minimum: 22’-0”
- Exceptional: 20’-0”

Main Track track center to nearest station or yard track track center with poles between them:

- Desirable: 30’-0”
- Minimum: 28’-0”
- Exceptional: 24’-0”

Station and Yard Track track centers without poles, walkways, or service roads between them:

- Desirable, Minimum and Exceptional: 14’-0”

Station and Yard Track track centers with catenary poles between them:

- Desirable: 24’-0”
- Minimum: 22’-0”
- Exceptional: 20’-0”

Station and Yard Track track centers with walkways between them:

- Desirable: 18’-0”
- Minimum: 16’-0”
- Exceptional: 15’-0”

Station and Yard Track track centers with “golf cart” service roads between them:

- Desirable: 22’-0”
- Minimum and Exceptional: 20’-0”

Desirable track centers on curves shall be increased on curve by twice the amount of increase required to an adjacent fixed structure, less 12 inches. Minimum and Exceptional track centers on curves shall be increased on curve by twice the amount of increase required to an adjacent fixed structure, less 6 inches.

6.1.2 Clearances

Clearance requirements will be described in greater detail in a separate document. The following is provided for insofar as it may affect the alignment design.

Offsets between main track or station track track centers and center of Catenary poles, based on an assumed pole diameter of not more than 18 inches.

- Desirable: 14’-0”
- Minimum: 12’-0”
- Exceptional: 11’-0”

Offsets between yard and other track track centers and center of Catenary poles, based on an assumed pole diameter of not more than 18 inches.

- Desirable: 12’-0”
- Minimum: 11’-0”

- Exceptional: 10’-0”

Clearances to walls, bridges, tunnels, etc., shall be as shown on typical sections. The Clearance requirement of the AREMA Manual Chapter 28, Figures 28-1-1 and associated discussion in Chapter 28 shall govern where more specific guidance is not provided.

6.1.3 General Alignment Requirements:

The basic principle in alignment design is to provide as smooth a line as practical with the minimum number of changes in direction and profile. Where changes in direction and profile occur, they should be as gentle as practical.

Minimum segment length: $L_{feet} = V_{mph} \times 44/30 \times t_{sec}$

Table 6.1-1: Minimum Segment Lengths at Various Speeds

Design Speed	Minimum Length, feet for times of		
	Desirable 1.8 seconds	Minimum 1.5 seconds	Exceptional 1.0 seconds
125 mph	330	275	184
100 mph	264	220	147
79 mph	209	174	116
60 mph	158	132	88
V mph	2.64 V	2.20 V	1.47 V

Segment length requirement will govern only where other design considerations for the various elements does not require longer segment lengths.

6.1.4 Minimum Radii

The maximum speed allowable with certain combinations of degree of curve or curve radius and superelevation and unbalance are shown in the following tables.

Table 6.1-2: Maximum Degree of Curve for Various Superelevations and Speeds

Super-elevation	Unbalance	Design Maximum Speeds			
		125 mph	100 mph	79 mph	60 mph
3	3	0d 32m 50s	0d 51m 20s	1d 22m 00s	2d 20m
4	3	0d 38m 20s	1d 00m 00s	1d 36m 00s	2d 45m
4	4	0d 43m 50s	1d 08m 30s	1d 49m 45s	3d 10m
5	3				
5	4	0d 49m 20s	1d 27m 00s	2d 03m 15s	3d 30m
6	3				
6	4	0d 54m 50s	1d 25m 30s	2d 17m 00s	3d 57m

Table 6.1-3: Minimum Radius of Curve for Various Superelevations and Speeds

Super-elevation	Unbalance	Design Maximum Speeds			
		125 mph	100 mph	79 mph	60 mph
3	3	10,500 ft	6,500 ft	4,000 ft	2,500 ft
4	3	9,000 ft	5,800 ft	3,600 ft	2,200 ft
4	4	8,000 ft	5,000 ft	3,200 ft	1,900 ft
5	3				
5	4	7,000 ft	4,500 ft	2,800 ft	1,700 ft
6	3				
6	4	6,500 ft	4,000 ft	2,500 ft	1,500 ft

At high speeds the distance between curves shall be that required by the minimum segment length. At low speeds, vehicle end offsets and angles between ends determines how close together reversing curves can be placed.

Minimum space between reverse curves is as follows:

- Desirable: 100 feet
- Minimum: 75 feet, but may be less, but not less than the following:
  - For degree curves: If both curves are the same: Tan = 1.5 D^2, or if the degree of curves are different: Tan = 0.75 D_1^2 + 0.75 D_2^2, but not less than 25 feet.
  - For radius curves: If both radii are the same: Tan = 48,000,000 / R^2, or if the radii are different: Tan = 24,000,000 / R_1^2 + 24,000,000 / R_2^2 but not less than 25 feet.
- Exceptional: 70 feet, but may be less, but not less than the following:
  - For degree curves: If both curves are the same: Tan = 0.92 Deg^2, or if the degree of curves are different, Tan = 0.46 D_1^2 + 0.46 D_2^2, but not less than 25 feet.
  - For radius curves: If both radii are the same: Tan = 30,000,000 / R^2, or if the radii are different: Tan = 15,000,000 / R_1^2 + 15,000,000 / R_2^2 but not less than 25 feet.
- Should either curve have a degree of 8 degrees 50 minutes or larger, or if using radius, 660 feet radius or smaller, 10 feet shall be added to the Minimum or Exceptional distance calculated, regardless of the radius of the other curve.
- If one of these curves is in a turnout, the end of the curve shall be defined as being at the point of frog for a curve on the frog end of the turnout and 20 feet ahead of the point of the switch for a curve on the switch end of a turnout for standard geometry Union Pacific or BNSF turnouts or 10 feet ahead of the point of switch for improved geometry turnouts.

If the curves have spirals, the ST (spiral to tangent) and TS (tangent to spiral) points may be set closer than these minimum distances down to a length of zero if there are spirals on both curves. The maximum length reduction shall be one-half of the length of each spiral.

For curves in the same direction, the distances between curves shall be the same as for reverse curves except that the Exceptional shall be either greater than 25 feet or it shall be zero. Combining spirals shall be used if either curve would require a spiral based on the paragraph on spirals on small radius curves.

6.1.5 Superelevation

Balancing superelevation shall be calculated by one of the following formulae, depending upon how the curve is defined:

- Degree Curves: SE = 0.0007 V^2 D (curve in degrees, speed in mph and SE in inches)
- Radius Curves: SE = 4.0 V^2 / R (radius in feet, speed in mph and SE in inches)

Curves shall not be superelevated to balance the design speed or even the calculated average or maximum operating speed. A certain amount of unbalance, usually considered to be 1.0 inches for the normal operating speed of trains, not the speed limit, is desirable for ride comfort and smooth running of the vehicles through the curve.

The design value of superelevation to be applied to the curve will be influenced by:

- Maximum Speed Limit
- Calculated normal and maximum speeds of high speed trains
- Calculated normal and maximum speeds of other passenger trains

Design superelevation shall be calculated for each track. It is neither necessary nor in many locations desirable that all tracks of the line have the same superelevation on a given curve.

The maximum superelevation shall be:

- On tracks which have both high speed and other passenger trains, but no freight trains:

  - Desirable: 4 inches (3 inches where actual speed of some trains will be or may likely be low)
  - Limiting: 5 inches (4 inches where actual speed of some trains will be or may likely be low)
  - Exceptional: 6 inches (4.5 inches where actual speed of some trains will be or may likely be low)
- On tracks which will have high speed trains only:
  - Desirable: 5 inches (3 inches where actual speed of some trains will be or may likely be low)
  - Limiting: 6 inches (4 inches where actual speed of some trains will be or may likely be low)
  - Exceptional: 7 inches (4.5 inches where actual speed of some trains will be or may likely be low)

Superelevation shall be applied by lifting the outer rail of each track. The top of rail profile line will be the top of rail of the low rail for the track.

Unbalance:

- Preferred minimum unbalance: 1.0 inch
- Desirable limit of unbalance: 3.0 inches
- Limiting unbalance: 4.0 inches (by FRA exemption only)
- Exceptional unbalance: 4.0 inches (by FRA exemption only)
- Limiting and Exceptional unbalance shall be reduced by 0.25 inches if any part of the curve is on a crest vertical curve that is shorter than Desirable values. (The use of shorter vertical curves than those in this document will require this value to be increased.)

6.1.6 Spirals:

Two types of spirals shall be used. Clothoid (straight rate of change) spiral for low and medium speed curves and Half-sine (variable rate of change) spirals for high speed curves.

Half-Sine Spirals (variable rate transitions) shall be used on all tracks designed for:

- Ballasted tracks: Curves having design maximum speeds of 80 mph or more
- Non-ballasted tracks: Curves having design maximum speeds of 60 mph or more
- Curves associated with turnouts having design maximum speeds of 110 mph or more

Half Sine Spiral:

Local Radius through the Spiral:

$$R_{loc} = 2\ R_{curve} / (1 - \cos(\pi\ L_{loc} / L_{tot}))$$

Local Superelevation through the Spiral:

$$SE_{loc} = 0.5\ SE_{curve} (1 - \cos(\pi\ L_{loc} / L_{tot}))$$

Clothoid Spiral:

Local Radius through the Spiral:

$$R_{loc} = R_{curve} / (L_{tot} / L_{loc})$$

Local Superelevation through the Spiral:

$$SE_{loc} = SE_{curve} (L_{loc} / L_{tot})$$

Clothoid Spirals (constant rate transitions) will be used on all tracks having lower design speeds

Spiral Lengths: The length of the spiral shall be the longest length determined by calculating the various length requirements, which are:

- Length needed to achieve Attenuation Time
- Length determined by allowed rate of change in superelevation
- Length determined by allowed rate of change in unbalanced superelevation
- Length determined by limitation on twisting over vehicle and truck spacing length

Table 6.1-4: Minimum Length of Spiral

Clothoid (Linear Change) Spirals				
Spiral Design Factor	Desirable (0.3 g)	Minimum (0.4 g)	Exceptional (0.5 g)	Associated with turnouts
Superelevation	1.47 Ea V	1.17 Ea V	0.98 Ea V	0.75 Ea V
Unbalance	1.63 Eu V	1.22 Eu V	0.98 Eu V	0.75 Eu V
Twist	90 Ea	75 Ea	62 Ea	62 Ea
Minimum Segment	2.64 V	2.20 V	1.47 V	1.33 V
Half-Sine (Variable Change) Spirals *				
Spiral Design Factor	Desirable	Minimum	Exceptional	Associated with turnouts
Superelevation	1.63 Ea V	1.30 Ea V	1.09 Ea V	- -
Unbalance	2.10 Eu V	1.57 Eu V	1.26 Eu V	- -
Twist **	140 Ea	118 Ea	98 Ea	- -
Minimum Segment	2.64 V	2.20 V	1.47 V	- -

* Longer lengths of half-sine spirals are due to the variability in the ramp rate.

** Provides maximum twist rates identical to clothoids. As a practical matter, this limitation never governs due to use of this type spiral only on high speed tracks.

After calculation and selection of length based on the governing requirement, the spiral length should then be rounded to a convenient value for further calculation and use in the alignment. Rounding may be either up or down for “Desirable” values so long as the downward rounding does not reduce any of the required desirable lengths by more than 5%. Rounding may be either up or down for “Minimum” values so long as the downward rounding does not reduce any of the required minimum lengths by more than 1.0%. Rounding shall only be in the upward direction for “Exceptional” and “Associated with Turnouts” values.

Spirals on Large Radius Curves: Should the radius be such that for the maximum design speed the required superelevation and unbalanced superelevation both be under 1.0 inches and the “Minimum Segment” length for the spiral is more than twice the length required for any other factor, clothoid spirals may be used instead of half-sine spirals regardless of track type or design speed. Should the required superelevation be zero (balancing superelevation for the maximum speed be less than 0.75 inches) and the calculated offset of the curve due to application of the spiral be less than 0.05 feet in ballasted track or less than 0.02 feet in non-ballasted track, spirals may be omitted. (these values subject to revision)

Reverse Curves: Should there be insufficient distance between curves to provide a tangent segment of the minimum required length, the spirals shall be extended so as to provide a reversing curve. A straight distance between curves that would be run in less than 0.2 seconds at the normal operating speed may be left between spiral ends if beneficial to design and construction.

6.1.7 Grades and Vertical Curves:

Grade Limits:

- Desirable grades shall be as low as reasonably practical, with a limit of 1.00%
- Maximum Grades: above 1.00% and shall be as low as practical up to 1.70%

- Exceptional Grades: above 1.70% and shall be as low as practical up to 3.00%

Vertical Curves: The calculated length should normally be rounded up to the nearest 100 feet of length, or 50 feet if the greater number is impractical. Desirable values may be rounded down, so long as the length is not reduced by more than 5.0%.

- Vertical curves shall be parabolic defined in accordance with standard US railroad practice.
- There is no upper limit on vertical curve length or radius. Provision of the minimum segment length for vertical curves connecting grades with small differences in grade can result in a vertical curve with a very large radius / small rate of change.
- Unless it is determined that the speeds can never be made to achieve these limits, the speed to use in the following formulae shall be no less than 125 mph or higher for passenger trains
- Vertical curve lengths on lines carrying passenger trains only shall be:
  - Desirable VC Length: The longer of $LVC_{feet} = 2.64\ V$ or $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.40\ ft/sec^2$, but not less than 400 $\Delta\%$
  - Minimum VC Length: The longer of $LVC_{feet} = 2.20\ V$ or $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.60\ ft/sec^2$, but not less than 200 $\Delta\%$
  - Exceptional VC Length: The longer of $LVC_{feet} = 1.47\ V$ or $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.80\ ft/sec^2$, but not less than 100 $\Delta\%$
- For a 125 mph design speed, these formulae resolve to:
  - Desirable VC Length: The longer of $LVC_{feet} = 840\ \Delta\%$ or 350 feet
  - Minimum VC Length: The longer of $LVC_{feet} = 560\ \Delta\%$ or 300 feet
  - Exceptional VC Length: The longer of $LVC_{feet} = 420\ \Delta\%$ or 200 feet

Where lines carrying passenger trains and lines carrying freight trains closely parallel each other in profile the longest vertical curve length determined by the separate calculation for each type of traffic shall determine the vertical curve length to be used for all tracks.

Vertical curve lengths on lines closely paralleling freight lines shall be:

- Unless it is determined that the speeds can never be made to achieve these limits, the speed to use in the following formulae shall be no less than 75 mph or higher for freight trains
- Desirable VC Length: $LVC_{feet} = 2{,}000\ \Delta\%$ in sags and $1{,}000\ \Delta\%$ in summits, unless the formula $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.08\ ft/sec^2$ requires a longer VC.
- Minimum VC Length: $LVC_{feet} = 1{,}000\ \Delta\%$ in sags and $500\ \Delta\%$ in summits, unless the formula $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.10\ ft/sec^2$ requires a longer VC.
- Exceptional VC Length: $LVC_{feet} = 500\ \Delta\%$ in sags and $400\ \Delta\%$ in summits, unless the formula $LVC_{feet} = 2.15\ V^2\ (\Delta\% / 100) / 0.10\ ft/sec^2$ requires a longer VC.
- Industrial trackage and other low-speed tracks which will not carry trains consisting of more than a few cars at a time may have shorter vertical curves, down to as short as 50 $\Delta\%$ or 50 feet, whichever is longer.
- For a 75 mph freight train design speed, these formulae resolve to:
  - Desirable VC Length: $LVC_{feet} = 2{,}000\ \Delta\%$ in sags and $1{,}500\ \Delta\%$ in crests
  - Minimum and Exceptional VC Length: $LVC_{feet} = 1{,}200\ \Delta\%$

X.1 APPENDIX: DISCUSSION OF SOURCE OF STANDARDS

Table 1.3-1 and Figure 1.3-1: Speeds After Unrestrained Acceleration for Various Distances: By calculation using the following: High speed trains based on Shinkansen 700T train resistance. Power for 700T for the 300 km/h case and higher power and acceleration from Shinkansen information found on the web for the 220 mph case. Amtrak acceleration based on a standard train and train resistance based on modified Davis formula.

FRA track standards and the California PUC GOs can be found on the internet.

Certain BNSF and UPRR information is available on their respective web sites. However, as work progresses more information will be needed which will have to be obtained from their respective engineering departments.

3.1 General: Alignment segment length requirements are from the Taiwan High Speed Rail Corporation Design Specification, and are presumably from either SNCF or DB. The 1.0 second standard is “reverse engineered” from DB high speed turnout designs, was the actual design practice in THSRC, and has proven to provide a high quality ride on station entries and exits.

3.2.1 Curvature: Curvature tables are by calculation.

Curves with small central angles: based on run time requirements and known practices.

Minimum curve radius: Based on use of no less than 190 m radius in Europe and 200 m radius in Japan, and the use of 190 m radius in Taiwan with Japanese equipment, and Japanese concerns that were not backed by any technical analysis that anything under 200 m would cause difficulties with the equipment.

Distances between small radius curves: Formulae based on information provided in AREMA Manual, Chapter 5, Part 3.5.1 and similar information in DB AG standards, and calculation based on the position of both Shinkansen and American coach ends on small radius curves not adjacent to other curves.

3.2.2 Superelevation: In addition to calculations based on basic mechanics and information in the AREMA Manual Chapter 5, Part 3.1., the Half Sine Spiral is explained in the Northeast Corridor High-Speed Rail Passenger Service Improvement Program (NECIP) Task 19.2, Review of Lengths and Comfort Criteria for Spirals, and Japanese publications, also some information on variable rate spirals is UIC 703, also notes on common practice in AREMA Manual Chapter 5, Part 3.2.1, particularly Figure 5-3-2.

3.2.3 Unbalanced Superelevation: Minimum desired unbalance on curves based on discussions with Kowloon Canton Railways operations and engineering personnel, direct observation of the ride quality at various speeds on certain curves in the Taiwan High Speed Railway, know practices in other systems. 4.0 inch maximum is from the FRA.

3.2.5.2 Application of the Two Types of Spirals and Spiral Formulae: Half Sine Formulae from the Taiwan High Speed Rail Design Specification. Break point between Clothoid and Half-Sine spirals based on Japanese Shinkansen practice for non-ballasted track and a compromise between Japanese and Taiwan standards for ballasted track.

3.2.5.2 Determination of Spirals Lengths: For clothoid spirals: Desirable and Minimum values based on AREMA Chapter 5, Part 3.1, and the NECIP report, and Japanese preferred twist rates. Exceptional and With Turnouts based on European values and AREMA twist rates. For Half-Sine Spirals, standards based on Japanese information.

Half Sine Formulae from the Taiwan High Speed Rail Design Specification. Break point between Clothoid and Half-Sine spirals based on Japanese Shinkansen practice for non-ballasted track and a compromise between Japanese and Taiwan standards for ballasted track.

3.2.5.2 Grades: Limits based on normal American practices. Use of 3.00% instead of 2.50% or 2.20% for the Exceptional given the presence of Amtrak and Metrolink trains is based on the realities of California mountain railroading and known grades on the Redondo Junction Flyover, but is beyond the limit of normal practice for locomotive hauled trains. Compensation for grades is based on AREMA Manual Chapter 5, Part 3.7.1. The radius formula is a rounded mathematical conversion of the degree formula. Application of compensation has considerable variation in practice. That included here appears to be appropriate for the situation.

3.3.2 Vertical Curves: Vertical Curve practices are based on AREMA Manual, Chapter 5, Part 3.6. Selected values for vertical acceleration are based on Part 3.6.g, and for the higher exceptional value, knowledge of practice. It is inadvisable to go much beyond the current acceleration limit in the AREMA recommendations for passenger service without strong evidence that it raises no issues with American passenger equipment. The current AREMA already results in much shorter vertical curves than the recommendations that prevailed in the Manual for many years. The designated fixed change values for freight vertical curves were formerly the AREMA Recommended Practice and are still used by many railroad companies. Variations of these fixed rate freight values are also in line with US railroad company practices, either current or in the recent past. (Recall that many companies have disappeared in mergers, and with that their practices.)