Principles of Track Geometry

Presented by:

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Individual Geometry

Topics

- Gage
- Curves and Curve Alignment
- Superelevation
- Crosslevel Variance and Deviation
- Vertical Profile
- Runoff from a raise
Gage, Alignment, Profile, and Crosslevel Variations
Gage and Alignment Variations
Crosslevel and Alignment Variations
Surface and Profile Deviations
§ 213.13 Measuring track not under load.

When unloaded track is measured to determine compliance with requirements of this part, the amount of rail movement, if any, that occurs while the track is loaded must be added to the measurements of the unloaded track.
### Classes of Track

<table>
<thead>
<tr>
<th>Class</th>
<th>Operating Speeds (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Freight</td>
</tr>
<tr>
<td></td>
<td>FROM</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
</tr>
</tbody>
</table>
§ 213.53 Gage.

(a) Gage is measured between the heads of the rails at right-angles to the rails in a plane five-eighths of an inch below the top of the rail head.

(b) Gage shall be within the limits prescribed in the following table—

<table>
<thead>
<tr>
<th>Class of track</th>
<th>The gage must be at least—</th>
<th>But not more than—</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excepted track.</td>
<td>N/A</td>
<td>4'10 1/4&quot;</td>
</tr>
<tr>
<td>Class 1 track</td>
<td>4'8&quot;</td>
<td>4'10&quot;</td>
</tr>
<tr>
<td>Class 2 and 3 track</td>
<td>4'8&quot;</td>
<td>4'9 3/4&quot;</td>
</tr>
<tr>
<td>Class 4 and 5 track</td>
<td>4'8&quot;</td>
<td>4'9 1/2&quot;</td>
</tr>
</tbody>
</table>
Gage Deviations
Gage Deviations
Gage – Distance between the rail heads measured 5/8” below top of rail

56 ¾” static

1/4” dynamic movement on base plate shoulder

1/2” dynamic lateral movement of plate on tie surface

56 ¾” static gage

1/4” dynamic base movement

1/2” dynamic plate movement

57 ½” total gage for FRA Compliance

§ 213.13 Measuring track not under load.

When unloaded track is measured to determine compliance with requirements of this part, the amount of rail movement, if any, that occurs while the track is loaded must be added to the measurements of the unloaded track.
Subpart C - Track Geometry
§213.53 Gage

Remember to look for evidence of lateral rail movement as required in §213.13.
Dynamic Gage Widening
<table>
<thead>
<tr>
<th>Rail Wt.</th>
<th>Base Gage Decimal (in.)</th>
<th>Base Gage Fraction (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>54.16</td>
<td>54 5/32</td>
</tr>
<tr>
<td>115</td>
<td>53.96</td>
<td>53 31/32</td>
</tr>
<tr>
<td>119</td>
<td>53.91</td>
<td>53 29/32</td>
</tr>
<tr>
<td>132</td>
<td>53.77</td>
<td>53 ¾</td>
</tr>
<tr>
<td>133</td>
<td>53.69</td>
<td>53 11/16</td>
</tr>
<tr>
<td>136</td>
<td>53.72</td>
<td>53 23/32</td>
</tr>
<tr>
<td>141</td>
<td>53.72</td>
<td>53 23/32</td>
</tr>
</tbody>
</table>
Measuring gage 5/8” below head of rail
Subpart C - Track Geometry
§213.53 Gage

Particular attention should be given to track gage in turnouts or locations where high lateral train forces are expected or evident.

These areas include the curved closure rails, the toe and heel of frogs, the curved track behind the frog and several feet ahead of the switch points.
Checking Gage in a Turnout at Multiple locations
# 213.143 Guard Check and Face Gage

The guard check and guard face gages in frogs shall be within the limits prescribed by the following table:

<table>
<thead>
<tr>
<th>Class of Track</th>
<th>Guard Check gage may not be less than</th>
<th>Guard Face gage may not be more than</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>4’ 6 1/8”</td>
<td>4’ 5 1/4”</td>
</tr>
<tr>
<td>Class 2</td>
<td>4’ 6 ¼”</td>
<td>4’ 5 1/8”</td>
</tr>
<tr>
<td>Class 3 &amp; 4</td>
<td>4’ 6 3/8”</td>
<td>4’ 5 1/8”</td>
</tr>
<tr>
<td>Class 5</td>
<td>4’ 6 ½”</td>
<td>4’ 5”</td>
</tr>
</tbody>
</table>
Wheel Back to Back

53" +/-

Gage 56½"

>53 1/4"

Guard Face Gage
(May not be more than)
Wheel Back to Back

53” +/-

Gage 56 1/2”

<54 1/8” For Class 1

Guard Check Gage
(May not be less than)
Guard Check

If Guard Check less than Minimum, wheel will strike point of frog
Wheel Striking point of Frog; Guard check less than minimum
Flangeway Clearance Minimum 1 ½”
213.133 (c)
Guard Check - Gage Line of frog to Guard Line

Minimum = 54 1/2”

Guard Face - Distance Between Wing Rail and Guard Line

Maximum = 53 ”
Guard Face may not be more than 53” for Class 5.

Guard Check may not be less than 54 1/2” for Class 5.
Guard Check is less than 54 1/2”

Note wheels crowding frog point
Guard Face is greater than 53”
Checking minimum Flange way Clearance of 1 ½”
Issues with Gage

• Tight Gage
  – Can induce hunting at lower speed ranges
  – Wears wheels and rail at accelerated rate

• Wide Gage
  – Indication of weak ties and fasteners
  – Can allow greater wheelset angles of attack
  – Reduces safety margin for rail roll and wheel drop in
Curves and Curve Geometry

A high percentage of all derailments occur on curved track, including turnouts! It is important to understand curve geometry and how it affects car performance.
Curves and Curve Geometry

2 characteristics of curves

Elevation

Alignment
A curve is defined as a path along the edge of a circular arc defined by a circle of a given radius.
Railroad Definition of a Curve

Degree of curve is the angle $\phi$ subtended by a 100 ft. Chord.
Estimating degree of curvature using a 62 ft. chord

Degree of curve can be Estimated by using a 62 ft. Chord and measuring the Mid-ordinate offset
Midordinate offset in inches is approximately equal to the degree of curve.

3” mid-ordinate offset would be equal to a 3 degree curve.

Estimating degree of curvature using a 62 ft. chord.
Stringlining using 62 ft. Chord

18 Degree Curve
Radius of curve = \( \frac{5730'}{\text{Degree of curve}} \)
### Degree of Curve & Radius

<table>
<thead>
<tr>
<th>Degree of Curve</th>
<th>Mid-Ordinate of a 62’ Chord</th>
<th>Radius of Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1”</td>
<td>5730’</td>
</tr>
<tr>
<td>2</td>
<td>2”</td>
<td>2865’</td>
</tr>
<tr>
<td>3</td>
<td>3”</td>
<td>1910’</td>
</tr>
<tr>
<td>5</td>
<td>5”</td>
<td>1146</td>
</tr>
<tr>
<td>10</td>
<td>10”</td>
<td>573’</td>
</tr>
</tbody>
</table>
Curve Geometry

Entry Spiral

Exit Spiral

Train Direction

Full Body of Curve

PTS

PSC

PCS

PST
Full - PSC or PCS

Level - PST or PTS

Spiral Ln. = 450’

Point of Spiral
PSC 5°01’46” 3 ½” Elevation

1” Elevation

1/2” Elevation
Well Marked Track Geometry Designations
Loss of vertical load account car twist at outer rail, trail truck, third axle. This is most frequently derailing wheel.

Most Likely Derailing Wheel in Entrance Spiral
Most Likely Derailing Wheel in Exit Spiral

Loss of vertical load account car twist at outer rail, lead truck, first axle. This is most frequently derailing wheel. Also, lateral forces are highest on lead truck.
Back to Back Reversing Curves

Curve 1 LH

Curve 2 RH

Minimum tangent length at least truck center spacing; (45-66 ft.)
Lack of sufficient intervening tangent between back to back reverse curves
Summary of Curve Derailment Issues

- Most frequent type of derailment in body of curve is rail rollover; wheel climb due to crosslevel and alignment defects.
- Most frequent type of derailment in entry spiral is wheel climb of wheel on trail truck, third axle, on high rail.
- Most frequent type of derailment in exit spiral is wheel climb of wheel on lead truck, first axle, on high rail.
- Insufficient tangent between reversing curves can cause trucks to bind, resulting in wheel climb or gage spreading.
§ 213.55  Track alinement.

(a) Except as provided in paragraph (b) of this section, alinement may not deviate from uniformity more than the amount prescribed in the following table:

<table>
<thead>
<tr>
<th>Class of Track</th>
<th>Tangent Track</th>
<th>Curved Track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The deviation of the mid-offset from a 62-foot line [1] may not be more than --</td>
<td>The deviation of the mid-ordinate from a 31-foot chord [2] may not be more than --</td>
</tr>
<tr>
<td>1</td>
<td>5&quot;</td>
<td>N/A³</td>
</tr>
<tr>
<td>2</td>
<td>3&quot;</td>
<td>N/A³</td>
</tr>
<tr>
<td>3</td>
<td>1⅛&quot;</td>
<td>1⅛&quot;</td>
</tr>
<tr>
<td>4</td>
<td>1½&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>5</td>
<td>¾&quot;</td>
<td>½&quot;</td>
</tr>
</tbody>
</table>

[1] The ends of the line must be at points on the gage side of the line rail, five-eights of an inch below the top of the railhead. Either rail may be used as the line rail, however, the same rail must be used for the full length of that tangential segment of track.

[2] The ends of the chord must be at points on the gage side of the outer rail, five-eights of an inch below the top of the railhead.

[3] N/A - Not Applicable
In Classes 3 through 5, both the 31-foot and 62-foot chords must be used, and corresponding measurements must be calculated to determine compliance with the required alinement thresholds. If alinement defects are found using both the 31-foot and the 62-foot chord, the inspector should report the item as one defect and note that the defect does not comply with the requirements for the second chord, e.g., “1\%\frac{1}{4} inches alinement deviation on curved track for 62-foot chord. Note: 1\%\frac{1}{8} inches alinement deviation for 31-foot chord at this location.”
§213.55 Alinerment - Stringlining

The chord (string) is stretched and held tight between two points on the rail, \( \frac{5}{8} \) inch below the top running surface of the rail. Measure the MCO between the rail and the string with a graduated ruler, using blocks to compensate for shallow curvature and special trackwork, if necessary.
Alignment Deviations
Measuring Alignment with 62’ Chord - Stringlining

15 ½ ft. stations

62’ Chord

Midordinate Measurement

4” = 4 Degree Curve
Curve Alignment Geometry

Station

Ordinate Measurements 1/8" Increments

3” Deviation from 11” midordinate
Checking Alignment Deviations in Spirals

Place the measured values in a graph and plot the spiral.

Deviation from Design
18 units at Sta. 5 = 1 1/8”
12 units = ¾”
Deviation from uniformity = 6 units (3/8”)
Stringlining in the field using 62’ Chord
Using Spring clamps to Stringline when no help available
### § 213.55 Alinement.

Alinement may not deviate from uniformity more than the amount prescribed in the following table:

<table>
<thead>
<tr>
<th>Class of track</th>
<th>Tangent track</th>
<th>Curved track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The deviation of the mid-offset from a 62-foot line(^1) may not be more than— (inches)</td>
<td>The deviation of the mid-ordinate from a 31-foot chord(^2) may not be more than— (inches)</td>
</tr>
<tr>
<td>Class 1 track</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Class 2 track</td>
<td>3</td>
<td>3 (N/A)</td>
</tr>
<tr>
<td>Class 3 track</td>
<td>1(\frac{3}{4})</td>
<td>1(\frac{1}{4})</td>
</tr>
<tr>
<td>Class 4 track</td>
<td>1(\frac{1}{2})</td>
<td>1</td>
</tr>
<tr>
<td>Class 5 track</td>
<td>3(\frac{1}{4})</td>
<td>1(\frac{1}{2})</td>
</tr>
</tbody>
</table>

\(^1\) The ends of the line shall be at points on the gage side of the line rail, five-eighths of an inch below the top of the railhead. Either rail may be used as the line rail, however, the same rail shall be used for the full length of that tangential segment of track.

\(^2\) The ends of the chord shall be at points on the gage side of the outer rail, five-eighths of an inch below the top of the railhead.

\(^3\) N/A—Not Applicable.
To Establish Uniformity, measure out Nine 31’ stations, 4 ahead of and 4 behind the Station of concern. Measure the Mid-chord offset Of each station using a 62’ chord. Average the nine Stations and this determines Uniformity. The difference Between the MCO at the station of concern, and the Average uniformity is the “deviation from Uniformity”.

Determining compliance with FRA Alignment Standard using 9 point averaging method
As a reference, the following table summarizes the acceptable proper chords, station spacing, and number of stations to determine alignment compliance.

<table>
<thead>
<tr>
<th>Alignment Stations</th>
<th>Class</th>
<th>Chord (feet)</th>
<th>Total No. Stations</th>
<th>Station Spacing (feet)</th>
<th>Curve Length (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curve</td>
<td>1-2</td>
<td>62</td>
<td><strong>9 or</strong></td>
<td>31</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62</td>
<td>17</td>
<td>15½</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>3-5</td>
<td>31</td>
<td>17</td>
<td>15½</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62</td>
<td><strong>9 or</strong></td>
<td>31</td>
<td>248</td>
</tr>
<tr>
<td>Tangent</td>
<td>1 - 5</td>
<td>62</td>
<td>17</td>
<td>15½</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
A 31’ chord may pick up short wavelength deviations

62’ chord may not pick up short wavelength deviations

Why use a 31 ft. chord in certain situations?

1. Short wavelength deviations
2. Higher degree curves, easier to measure
3. Must use 31’ chord for Class 3-5
4. Easier to measure in high winds
§ 213.57 Curves; elevation and speed limitations.

(a) The maximum elevation of the outside rail of a curve may not be more than 8 inches on track Classes 1 and 2, and 7 inches on track Classes 3 through 5. The outside rail of a curve may not be lower than the inside rail by design, except when engineered to address specific track or operating conditions; the limits in § 213.63 apply in all cases.

Paragraph (a) does not imply that more than 6 inches of superelevation is recommended in a curve; rather the paragraph limits the amount of crosslevel in a curve to control the unloading of the wheels on the high rail, especially at low speeds.
§ 213.57 Curves; elevation and speed limitations.

(b) The maximum allowable posted timetable operating speed for each curve is determined by the following formula—

\[
V_{\text{max}} = \sqrt{\frac{E_a + E_u}{0.0007D}}
\]

\(V_{\text{max}}\) = Maximum allowable posted timetable operating speed (m.p.h.).

\(E_a\) = Actual elevation of the outside rail (inches).\(^1\)

\(^1\)Actual elevation, \(E_a\), for each 155-foot track segment in the body of the curve is determined by averaging the elevation for 11 points through the segment at 15.5-foot spacing. If the curve length is less than 155 feet, the points are averaged through the full length of the body of the curve.

\(E_u\) = Qualified cant deficiency\(^2\) (inches) of the vehicle type.

\(^2\)If the actual elevation, \(E_a\), and degree of curvature, \(D\), change as a result of track degradation, then the actual cant deficiency for the maximum allowable posted timetable operating speed, \(V_{\text{max}}\), may be greater than the qualified cant deficiency, \(E_u\). This actual cant deficiency for each curve may not exceed the qualified cant deficiency, \(E_u\), plus 1 inch.

\(D\) = Degree of curvature (degrees).\(^3\)

\(^3\)Degree of curvature, \(D\), is determined by averaging the degree of curvature over the same track segment as the elevation.
§ 213.57  Curves; elevation and speed limitations.

\[ E_a = \text{Actual elevation of the outside rail (inches)}. \]

Actual elevation, \( E_a \), for each 155-foot track segment in the body of the curve is determined by averaging the elevation for 11 points through the segment at 15.5-foot spacing. If the curve length is less than 155 feet, the points are averaged through the full length of the body of the curve.
To Establish Elevation, measure out Eleven 15.5 ft. stations spaced 15.5 ft. apart. Average the Eleven Stations and this determines Elevation for curve.

Determining compliance with FRA Elevation Standard using 11 point averaging method
§ 213.57  Curves; elevation and speed limitations.

(c) All vehicles are considered qualified for operating on track with a cant deficiency, $E_u$, not exceeding 3 inches. Table 1 of appendix A to this part is a table of speeds computed in accordance with the formula in paragraph (b) of this section, when $E_u$ equals 3 inches, for various elevations and degrees of curvature.
Curve elevation
§ 213.57 Curves; elevation and speed limitations.

Reverse Elevation

Both §213.63 and this section limit the amount of reverse elevation (outside rail lower than the inside rail).

The outside rail of a curve may not be lower than the inside rail by design, except when engineered to address specific track or operating conditions.
§ 213.59  Elevation of curved track; runoff.

(a) If a curve is elevated, the full elevation shall be provided throughout the curve, unless physical conditions do not permit. If elevation runoff occurs in a curve, the actual minimum elevation shall be used in computing the maximum allowable posted timetable operating speed for that curve under § 213.57(b).

\[ V_{max} = \sqrt{\frac{E_a + E_u}{0.0007D}} \]

§ 213.59  Elevation of curved track; runoff.

(b) Elevation runoff shall be at a uniform rate, within the limits of track surface deviation prescribed in § 213.63, and it shall extend at least the full length of the spirals. If physical conditions do not permit a spiral long enough to accommodate the minimum length of runoff, part of the runoff may be on tangent track.
Superelevation in a curve

Normally, between 0.0 to 6.0 inches of elevation is added to outer rail to counterbalance effects of centrifugal forces based on normal train speeds.
A balanced (equilibrium) condition implies the vertical forces on each rail are equal. Figure 8 illustrates the three types of balance conditions.

4° Curve - 5" Superelevation

10 MPH  
Overbalance

42 MPH  
Equilibrium  
Figure 8

85 MPH  
Underbalance
At equilibrium, there are equal vertical weights on both high and low rail.
To determine Equilibrium Speed for Curve

Eq. Elevation = .0007 (D) (V^2)

For 5 degree curve; 30 MPH

Eq. El. = .0007 (5) (30^2)

Eq. El. = .0007 (5) (900)

Eq. El. ~ 3.00”

1” Unbalance = 3.00 – 1.00 = 2.00”
To determine Maximum Speed for Curve

For 5 degree curve; 3" Elevation
3" cant deficiency

\[ V_{\text{max}} = \sqrt{\text{Elevation} + \text{Cant Deficiency}} / .0007 \times D \]

\[ = \sqrt{6"} / .0007 (5) \]

\[ = 41 \text{ MPH} \]
Curve Superelevation Issues
Superelevation - The **Old** Way

- Traditionally maximum superelevation put into curves
- Allowed for fast train speeds
- No clear understanding of wheel/rail interface mechanics
At Equilibrium; Equal Vertical Load on High & Low Rail
Running Under Balance Speed

Spalling on Low Rail; Pumping at Joints
Running over Balance Speed

Gage Corner Shelling; Gage Face Wear
The Problem with Excess Superelevation

• Increased Vertical Loads on Low Rail
  – Increased lateral creep forces
  – Increased spalling on low rail
  – Increased derailment potential due to low rail rollover/gage widening derailments

• Increased potential for wheel climb on high rail due to rocking and track twist
Low Rail Spalling
Low Rail Rollover/Gage Widening
The Problem with Excess Superelevation

Excessive cutting on the low side due to too much elevation actually increases elevation and worsens situation

Plate Cutting (Exaggerated)
The Problem with Excess Superelevation

A curve with too much elevation will also gain even more due to excess ballast pressures on low side
Not Enough Superelevation...

- Increased high rail gage face wear
- Increased derailment potential due to wheel climb (High Lateral Pressure)
- Increased potential of car overturning
- Increased gage corner shelling
Gage Corner Shelling
Typical Scenarios to Watch For:

1) Elevation for once a day Amtrak
2) Elevations on ruling grades
3) Elevations close to speed restrictions
Elevation for Amtrak vs. Freight

For a 2 Degree Curve:

Amtrak  79 MPH = 6” SE
Freight   50 MPH = 2 1/2” SE
Elevation vs. Ruling Grade

45 MPH

4°
4°
8°
6°

12 MPH
Elevations Close to Speed Restrictions

50 MPH  25 MPH

3°  10°
Optimized Superelevation

An amount of superelevation that will minimize centrifugal force influence for a predominance of train tonnage for Normal operating speeds.
The Key Question...

What speed do you use to adjust superelevation?
Correct Superelevation for Curve & Velocity

\[ EL_{EQ.} = 0.00067 \times D \times V^2 \]

4 D. Curve

\[ V = 30 \text{ MPH} \]

\[ EL = 0.00067 \times (4) \times (30 \times 30) \]

\[ EL_{EQ.} = 2.4 \text{ “} \]

Elevation = ?
Typical train speed distribution over a given territory with 30 MPH maximum speed

Average Speed 23 MPH
Correct Superelevation for Curve & Velocity

\[ EL\ EQ. = 0.00067\ DV^2 \]

4 D. Curve

\[ V = 30\ MPH \]

\[ EL = 0.00067 \times 4 \times (30\times30) \]

\[ EL\ EQ. = 2.4\ \text{“} \]

1 “ Unbalance \[ \rightarrow 2.4” - 1.0” = 1.4” \]
Correct Superelevation for Average Train Speed
On track with 30 MPH Timetable Speed

\[ EL_{EQ.} = 0.00067 \cdot D \cdot V^2 \]

4 D. Curve
\[ V = 23 \text{ MPH} \]

\[ EL = 0.00067 \times 4 \times (23 \times 23) \]

\[ EL_{EQ.} = 1.4 \text{ "} \]
Railroad Practice

• Because not all trains make timetable speed, many railroads underbalance curves 1” to 2” depending on the statistical spread of train speeds.

• If you consistently run 0-5 MPH under timetable speed, then ~1” underbalance may be appropriate.

• If you consistently run 5-10 MPH under timetable speed, then ~1.5” underbalance may be appropriate.
Superelevation Derailment Issues

- Superelevation is added to curves to allow trains to operate at normal track speed without placing abnormally high lateral and vertical forces against the high rail.
- Insufficient elevation can lead to overturning of cars.
- Excessive elevation places adverse vertical forces on the low rail of curves, which can result in broken rails, broken joints, low rail rollover, and wheel climb on high rail.
- Many curves in North America are currently over-elevated given operating train speeds. Short lines are especially vulnerable to this condition.
- When operating in over-elevated curves, derailment risk increases when encountering significant track perturbations which may be FRA/TC compliant.
Superelevation Derailment Check List

• Determine actual train speed, timetable train speed, and design speed for curve.
• Calculate equilibrium elevation for actual speed of train.
• If train was operating at 3” or more of over-elevation, elevation may be primary cause of derailment, or major secondary cause.
• In general, curves in excess of 4” of elevation are at risk when operating at 10 MPH or lower.
• Over-elevated curves can contribute to following type of derailments:
  – Wheel lift-off on high rail when encountering marginal track twist
  – Harmonic rock and roll
  – Low rail rollover; wide gage
  – Broken low rail or joint bar
• Under-elevation of curves can contribute to the following types of derailments:
  – Wheel climb or rail rollover of high rail of curve
  – Car Overturning
## Superelevation Chart (typical)

### Superelevation of Curves

<table>
<thead>
<tr>
<th>Speed in Miles Per Hour</th>
<th>Degree of Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>20</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>25</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>30</td>
<td>1/2 1/2 1/2 1/2</td>
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<tr>
<td>35</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>40</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>45</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>50</td>
<td>1/2 1/2 1/2 1/2</td>
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<tr>
<td>55</td>
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<td>60</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>65</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>70</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>75</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
<tr>
<td>80</td>
<td>1/2 1/2 1/2 1/2</td>
</tr>
</tbody>
</table>

**Limits on Superelevation**

The Chief Engineer - M of W must approve the
1. **4°** Superelevation on curves greater than
   required to maintain maximum authorized speed
2. **4°** Superelevation on non-signaled branch if maximum authorized speed of 30 miles per hour
3. **4°** Superelevation on grades where freight operate below 25 miles per hour.

**Maximum S**

- 6° - Passenger
- 5° - Freight

**Adjusted to Nearest 1/8 Inch**

- 2° unbalanced for speed including 60 MPH
- 2° unbalanced for speed

**Note:**

- E = 0.000045V²D
- Based on S = 0.000045V²D
- Where S = Superelevation
- V = Speed in Miles
- D = Degree of Curve

**Equilibrium EL**

- 0.00007V²D
- Where E = Equilibrium EL

**WRI 2015**
Appendix A to Part 213—Maximum Allowable Curving Speeds

This appendix contains four tables identifying maximum allowing curving speeds based on 3, 4, 5, and 6 inches of unbalance (cant deficiency), respectively.

Table 1—Three Inches Unbalance

<table>
<thead>
<tr>
<th>Elevation of outer rail (inches)</th>
<th>0</th>
<th>1/2</th>
<th>1</th>
<th>1 1/2</th>
<th>2</th>
<th>2 1/2</th>
<th>3</th>
<th>3 1/2</th>
<th>4</th>
<th>4 1/2</th>
<th>5</th>
<th>5 1/2</th>
<th>6</th>
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</thead>
<tbody>
<tr>
<td>Degree of curvature</td>
<td>0°30′</td>
<td>93</td>
<td>100</td>
<td>107</td>
<td>113</td>
<td>120</td>
<td>125</td>
<td>131</td>
<td>136</td>
<td>141</td>
<td>146</td>
<td>151</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>0°40′</td>
<td>80</td>
<td>87</td>
<td>93</td>
<td>98</td>
<td>104</td>
<td>109</td>
<td>113</td>
<td>118</td>
<td>122</td>
<td>127</td>
<td>131</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>0°50′</td>
<td>72</td>
<td>77</td>
<td>83</td>
<td>88</td>
<td>93</td>
<td>97</td>
<td>101</td>
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<tr>
<td></td>
<td>1°00′</td>
<td>65</td>
<td>71</td>
<td>76</td>
<td>80</td>
<td>85</td>
<td>89</td>
<td>93</td>
<td>96</td>
<td>100</td>
<td>104</td>
<td>107</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>1°15′</td>
<td>59</td>
<td>63</td>
<td>68</td>
<td>72</td>
<td>76</td>
<td>79</td>
<td>83</td>
<td>86</td>
<td>89</td>
<td>93</td>
<td>96</td>
<td>99</td>
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<td>62</td>
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<td>69</td>
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<td>82</td>
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<td>87</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>1°45′</td>
<td>49</td>
<td>53</td>
<td>57</td>
<td>61</td>
<td>64</td>
<td>67</td>
<td>70</td>
<td>73</td>
<td>76</td>
<td>78</td>
<td>81</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>2°00′</td>
<td>46</td>
<td>50</td>
<td>53</td>
<td>57</td>
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<td>63</td>
<td>65</td>
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<td>73</td>
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<td>3°30′</td>
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<td>52</td>
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<tr>
<td></td>
<td>5°00′</td>
<td>29</td>
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<td>49</td>
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<td></td>
<td>5°30′</td>
<td>28</td>
<td>30</td>
<td>32</td>
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<tr>
<td></td>
<td>6°30′</td>
<td>26</td>
<td>28</td>
<td>30</td>
<td>32</td>
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<td>37</td>
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<tr>
<td></td>
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<td>21</td>
<td>22</td>
<td>24</td>
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<td>35</td>
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<td>11°00′</td>
<td>20</td>
<td>21</td>
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<tr>
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<td>12°00′</td>
<td>19</td>
<td>20</td>
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<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
</tr>
</tbody>
</table>
§ 213.63 Track surface.

(a) Except as provided in paragraph (b) of this section, each track owner shall maintain the surface of its track within the limits prescribed in the following table:

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>The runoff in any 31 feet of rail at the end of a raise may not be more than</td>
<td>3 1/2</td>
</tr>
<tr>
<td>The deviation from uniform profile on either rail at the mid-ordinate of a 62-foot chord may not be more than</td>
<td>3</td>
</tr>
<tr>
<td>The deviation from zero crosslevel at any point on tangent or reverse crosslevel elevation on curves may not be more than</td>
<td>3</td>
</tr>
<tr>
<td>The difference in crosslevel between any two points less than 62 feet apart may not be more than *</td>
<td>3</td>
</tr>
<tr>
<td>*Where determined by engineering decision prior to June 22, 1998, due to physical restrictions on spiral length and operating practices and experience, the variation in crosslevel on spirals per 31 feet may not be more than</td>
<td>2</td>
</tr>
</tbody>
</table>

1 Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

2 However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 1/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Vertical Profile
Crosslevel Variations/Deviation
Curve Superelevation and Crosslevel
2 Key Words used in the FRA Regulations

1. Variation or Difference
2. Deviation

They sound similar, but have different; yet, important, meanings.
This is a variance or difference in two Crosslevel measurements over 62’. Variations are relative differences between any two measurements.

This is a deviation from zero Crosslevel; or a deviation from where the Crosslevel should be. Deviations are singular measurements.
§ 213.13  Measuring track not under load.

When unloaded track is measured to determine compliance with requirements of this part, the amount of rail movement, if any, that occurs while the track is loaded must be added to the measurements of the unloaded track.
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The difference in crosslevel between any two points less than 62 feet apart may not be more than

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*Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 3/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Crosslevel Variations

Any two Crosslevel measurements less than 62’ apart
Crosslevel Variations

Crosslevel Variance 1 ½” over 62 ft.
Difference in Crosslevel between any two points less than 62 ft. apart may not be more than...  

<table>
<thead>
<tr>
<th>Track Class Difference</th>
<th>Track Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1“</td>
<td>1</td>
</tr>
<tr>
<td>2 ¼”</td>
<td>2</td>
</tr>
<tr>
<td>2“</td>
<td>3</td>
</tr>
<tr>
<td>1 ¾”</td>
<td>4</td>
</tr>
<tr>
<td>1 ½”</td>
<td>5</td>
</tr>
</tbody>
</table>
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1 Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

2 However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 1/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Crosslevel Deviations

Deviation from Zero Crosslevel at any point on tangent, or reverse crosslevel in curves may not be more than

<table>
<thead>
<tr>
<th>Class</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3”</td>
</tr>
<tr>
<td>2</td>
<td>2”</td>
</tr>
<tr>
<td>3</td>
<td>1 ¾”</td>
</tr>
<tr>
<td>4</td>
<td>1 1/4”</td>
</tr>
<tr>
<td>5</td>
<td>1”</td>
</tr>
</tbody>
</table>

-2.5” Xlevel
Wheel Unloading/Lift due to Crosslevel Variation Between rear and front trucks
Unloading occurs on opposite diagonal corner

Wheel drops down in Low spot at joint

Wheel Unloading/Lift due to Crosslevel Variation Between rear and front trucks
Measuring Crosslevel with level board
Measuring Crosslevel Under Load
Tamp Spike up Under Base of Joint

Run Train over Joint; Measure Maximum Deflection
MEASURED CROSSLEVEL 1"

1/2" SPACE (Hanging Tie) 3/8" SPACE

MEASURED CROSS LEVEL
SPACE UNDER TIE PLATE 1"
SPACE UNDER TIE 3/8"

ACTUAL CROSSLEVEL UNDER LOAD 1/2"

MEASURING CROSSLEVEL NOT UNDER LOAD

MEASURING CROSSLEVEL NOT UNDER LOAD

§ 213.13 Measuring track not under load.

When unloaded track is measured to determine compliance with requirements of this part, the amount of rail movement, if any, that occurs while the track is loaded must be added to the measurements of the unloaded track.
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</tr>
<tr>
<td>The difference in crosslevel between any two points less than 62 feet apart may not be more than *12</td>
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*Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

*However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 1/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Staggered Jointed Rail
In this case, **Deficient Track Crosslevel**, could be considered a potential **Primary Derailment Cause**.

---

However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1-1/4 inches in all of six consecutive pairs of joints, as created by 7 low joints. Track with joints staggered less than 10 feet shall not be considered as having staggered joints. Joints within the 7 low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.

(Footnote 2 is applicable September 21, 1999.)
§ 213.63 Track surface.

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<th>5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3 1/2</td>
<td>3</td>
<td>2</td>
<td>1 1/2</td>
<td>1</td>
</tr>
<tr>
<td>The deviation from uniform profile on either rail at the mid-ordinate of a 62-foot chord may not be more than</td>
<td>3</td>
<td>2 3/4</td>
<td>2 1/4</td>
<td>2</td>
<td>1 1/4</td>
</tr>
<tr>
<td>The deviation from zero crosslevel at any point on tangent or reverse crosslevel elevation on curves may not be more than</td>
<td>3</td>
<td>2</td>
<td>1 3/4</td>
<td>1 1/4</td>
<td>1</td>
</tr>
<tr>
<td>The difference in crosslevel between any two points less than 62 feet apart may not be more than*</td>
<td>3</td>
<td>2 1/4</td>
<td>2</td>
<td>1 3/4</td>
<td>1 1/2</td>
</tr>
</tbody>
</table>

*Where determined by engineering decision prior to June 22, 1998, due to physical restrictions on spiral length and operating practices and experience, the variation in crosslevel on spirals per 31 feet may not be more than 2 1/4 1 1/4 1 3/4 1 3/4

1 Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

2 However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 1/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
VARIATION IN CROSSLEVEL ON SPIRALS

CLASS 4 TRACK

31 FEET

THE DIFFERENCE BETWEEN TWO LEVEL BOARD READINGS SHOULD NOT EXCEED 1"

VARIATION IN CROSSLEVEL ON SPIRALS IN ANY 31' MAY NOT BE ANY MORE THAN

<table>
<thead>
<tr>
<th>CLASS OF TRACK</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2&quot;</td>
<td>1 3/4&quot;</td>
<td>1 1/4&quot;</td>
<td>1&quot;</td>
<td>3/4&quot;</td>
</tr>
</tbody>
</table>
# Class 5 Spiral - PTS to PSC

<table>
<thead>
<tr>
<th>Station (31 ft.)</th>
<th>Design Elevation</th>
<th>Level Board Reading</th>
<th>Elevation Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>½”</td>
<td>3/8”</td>
<td>3/8”</td>
</tr>
<tr>
<td>3</td>
<td>1”</td>
<td>⅜”</td>
<td>3/8”</td>
</tr>
<tr>
<td>4</td>
<td>1 ½”</td>
<td>1”</td>
<td>1/4”</td>
</tr>
<tr>
<td>5</td>
<td>2”</td>
<td>1 ⅛”</td>
<td>1/8”</td>
</tr>
<tr>
<td>6</td>
<td>2 ½”</td>
<td>1 ⅞”</td>
<td>3/4”</td>
</tr>
</tbody>
</table>
§ 213.63 Track surface.

(a) Except as provided in paragraph (b) of this section, each track owner shall maintain the surface of its track within the limits prescribed in the following table:

<table>
<thead>
<tr>
<th>Track surface (inches)</th>
<th>Class of track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>The runoff in any 31 feet of rail at the end of a raise may not be more than</td>
<td>3 1/2 3 2 1 1/2 1</td>
</tr>
<tr>
<td>The deviation from uniform profile on either rail at the mid-ordinate of a 62-foot chord may not be more than</td>
<td>3 2 3/4 2 1/4 2 1 1/4</td>
</tr>
<tr>
<td>The deviation from zero crosslevel at any point on tangent or reverse crosslevel elevation on curves may not be more than</td>
<td>3 2 1 3/4 1 1/4 1</td>
</tr>
<tr>
<td>The difference in crosslevel between any two points less than 62 feet apart may not be more than</td>
<td>3 2 1 3/4 2 11/2</td>
</tr>
</tbody>
</table>

*Where determined by engineering decision prior to June 22, 1998, due to physical restrictions on spiral length and operating practices and experience, the variation in crosslevel on spirals per 31 feet may not be more than 2 1 3/4 2 1 1/4 1 3/4 1/2.

*Except as limited by § 213.57(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in crosslevel within 62 feet between that point and a point with greater elevation may not be more than 1 1/2 inches.

However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 1 1/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Vertical Profile Deviations
Vertical Bounce Derailments are most often due to combinations of vertical track profile variations acting in concert with vehicles possessing poor vertical damping characteristics.
Vertical profile deviation caused by poor subgrade

Stretch 62 ft. chord/string; measure vertical offset at center of chord
DEVIATION FROM UNIFORM PROFILE

1 1/4" IS MAXIMUM ALLOWED IN CLASS 5

HEAD OF RAIL

(3" MINUS 1" = 2"

2" IS MAXIMUM ALLOWED IN CLASS 4

THE DEVIATION FROM UNIFORM PROFILE ON EITHER RAIL AT THE MID-ORDINATE OF A 62' CHORD MAY NOT BE MORE THAN

<table>
<thead>
<tr>
<th>CLASS OF TRACK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>3&quot;</td>
</tr>
</tbody>
</table>
Checking Vertical Profile with 62’ Chord
§ 213.63 Track surface.

(a) Except as provided in paragraph (b) of this section, each track owner shall maintain the surface of its track within the limits prescribed in the following table:

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<td>The difference in crosslevel between any two points less than 62 feet apart may not be more than</td>
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</tr>
</tbody>
</table>

*Where determined by engineering decision prior to June 22, 1998, due to physical restrictions on spiral length and operating practices and experience, the variation in crosslevel on spirals per 31 feet may not be more than

1/2

2However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the crosslevel differences shall not exceed 11/4 inches in all of six consecutive pairs of joints, as created by seven low joints. Track with joints staggered less than 10 feet apart shall not be considered as having staggered joints. Joints within the seven low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote.
Frost Heaves Causing a raise in the track due to track degradation
YOU NEED A 4 1/2" RUNOFF FROM A RAISE

93 ft MINIMUM RUNOFF FOR CLASS 4

31 ft

31 ft

31 ft

NEWLY RAISED TRACK

UNRAISED TRACK

1 1/2" + 1 1/2" = 3"

1 1/2" + 1 1/2" + 1 1/2" = 4 1/2"

THE RUNOFF IN ANY 31' OF TRACK AT THE END OF A RAISE MAY BE NO MORE THAN

<table>
<thead>
<tr>
<th>CLASS OF TRACK</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 1/2&quot;</td>
<td>3&quot;</td>
<td>2&quot;</td>
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<td>1&quot;</td>
</tr>
</tbody>
</table>

PRINCIPLES COURSE • MAY 19, 2015

WRI 2015
Multiple Defects in Succession

§ 213.1 Scope of part.

(a) This part prescribes minimum safety requirements for railroad track that is part of the general railroad system of transportation. The requirements prescribed in this part apply to specific track conditions existing in isolation. Therefore, a combination of track conditions, none of which individually amounts to a deviation from the requirements in this part, may require remedial action to provide for safe operations over that track. This part does not restrict a railroad from adopting and enforcing additional or more stringent requirements not inconsistent with this part.
Track Geometry Recording
Cars
TGC
The End
Track Geometry