



American Railway Engineering and  
Maintenance-of-Way Association

## CHAPTER 2

# TRACK MEASURING SYSTEMS<sup>1</sup>

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<sup>1</sup> The material in this and other chapters in the *AREMA Manual for Railway Engineering* is published as recommended practice to railroads and others concerned with the engineering, design and construction of railroad fixed properties (except signals and communications), and allied services and facilities. For the purpose of this Manual, RECOMMENDED PRACTICE is defined as a material, device, design, plan, specification, principle or practice recommended to the railways for use as required, either exactly as presented or with such modifications as may be necessary or desirable to meet the needs of individual railways, but in either event, with a view to promoting efficiency and economy in the location, construction, operation or maintenance of railways. It is not intended to imply that other practices may not be equally acceptable.

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## INTRODUCTION

The Chapters of the AREMA Manual are divided into numbered Parts, each comprised of related documents (specifications, recommended practices, plans, etc.). Individual Parts are divided into Sections by centered headings set in capital letters and identified by a Section number. These Sections are subdivided into Articles designated by numbered side headings.

**Page Numbers** – In the page numbering of the Manual (2-2-1, for example) the first numeral designates the Chapter number, the second denotes the Part number in the Chapter, and the third numeral designates the page number in the Part. Thus, 2-2-1 means Chapter 2, Part 2, page 1.

In the Glossary and References, the Part number is replaced by either a “G” for Glossary or “R” for References.

**Document Dates** – The bold type date (Document Date) at the beginning of each document (Part) applies to the document as a whole and designates the year in which revisions were last made somewhere in the document, unless an attached footnote indicates that the document was adopted, reapproved, or rewritten in that year.

**Article Dates** – Each Article shows the date (in parenthesis) of the last time that Article was modified.

**Revision Marks** – All current year revisions (changes and additions) which have been incorporated into the document are identified by a vertical line along the outside margin of the page, directly beside the modified information.

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**Annual Updates** – New manuals, as well as revision sets, will be printed and issued yearly.



## Part 1

# Definitions<sup>1</sup>

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<sup>1</sup> References, Vol. 88, 1987, pp. 54, 120; Vol. 91, 1990, p. 53; Vol. 93, 1992, p. 45; Vol. 94, 1994, p. 51.

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## SECTION 1.1 DEFINITIONS OF RAIL SURFACE CONDITIONS

## 1.1.1 GENERAL (1994)

- The purpose of this section is to provide a uniform set of definitions for various surface conditions so that specifications for their measurement and reporting can be drawn up.
- These definitions include rail conditions that can be addressed by rail maintenance techniques as opposed to track geometry maintenance techniques.
- The running surface anomalies can be divided into two broad categories: corrugations and discrete anomalies.

## 1.1.2 CORRUGATIONS (1994)

- Corrugations are rail head anomalies that appear on the surface of the rail in a repeatable i.e. periodic, manner along the length of the rail. They appear as “waves” or regularly spaced (periodic) discontinuities on the surface of the rail head. These waves are not always uniformly spaced, but rather tend to vary about some average wavelength.
- Corrugations are classed according to their wavelength, the peak to peak (or valley to valley) distance between the corrugation waves. These peak to peak distances are often measured with a straight edge in the field. The corresponding depth of the corrugation, which is commonly measured using a taper gage and straight edge, is the difference in height between the peak and the valley of the waves.

## 1.1.3 DISCRETE ANOMALIES (1994)

Discrete anomalies appear on the surface of the rail head in a random or arbitrary manner, i.e. without any characteristics of repeatability. These conditions often appear singularly. These conditions include:

- Engine or Wheel Burns.* Discrete anomaly on the surface of the rail head caused by slipping or sliding of locomotive wheels. Usually found in pairs, with one on each rail. Can be of any depth, and usually .5 to 1.0 square inches in surface area.
- Battered and/or Mismatched Joints.*



(1) Degradation of the ends of the rails, in the region of the joint bars, associated with repeated impact of wheels on the ends of the rails. Usually extend up to 18 inches from the rail ends in both directions. Batter also refers to any degradation of welded repairs at the ends of the rail.

(2) Mismatched joint refers to a joint in which the rail ends are not properly matched so as to produce a discontinuity in the running surfaces of the rail.

c. *Weld Irregularities.*

(1) Non-uniformity of the running surface of the rail at welds, both plant and field welds. High welds are local high points at the weld usually the result of improper finishing of the weld at either the plant or field. Welds are often left nominally high (e.g. 0.020 inch) at the plant. Battered welds represent a degradation of the rail surface at the weld due to repeated impact loading by traffic. These conditions are usually located initially in the fusion zone or heat-affected zone of the weld, but can be extended beyond this region as degradation progresses.

(2) These conditions also include misalignment (vertical and/or lateral) of the rails such as that resulting in peaked or dipped welds in the vertical plane.

d. *Rail Head Damage.* Miscellaneous local damage to the surface of the rail such as caused by defective rolling stock (broken wheels, wheel flats, dragging equipment, etc.), derailments, or mishandling.

e. *Spalling or Flaking (Shelly Spots).* A localized degradation at the running surface of the rail, most commonly found at the gage corner of the high rail. This condition manifests itself initially as head checks (i.e. micro-cracks) at the gage corner which propagate and coalesce into larger areas which in turn break out of the rail surface. These surface cracks can also be found on the top of the rail, often in the low rail of curves.

f. *Shelling (Gage Corner Shelling).* A progressive internal separation that develops beneath the cold worked region in the gage corner of the rail head. This separation propagates longitudinally along the rail, and may crack out at any level on the gage side, generally near the upper gage corner. The shell can turn into a transverse defect (detail fracture).

g. *Surface Batter/Crushed Head.* A flattening of the surface of the rail head, resulting in a downward distortion of the surface. Crushed head is distinguished from surface batter in that the entire head must have sagged. This is often associated with the presence of internal rail defects such as horizontal split head.

h. *Plastic Flow (Lipped, Flowed Rail).* A condition of deformation or flow of the rail steel at the field or gage sides of the rail head. Usually associated with very high contact stresses. The plastic flow is generally most noticeable on the field side of low rails in curves.

i. *Rail Surface Roughness.* A condition of very fine non-uniformity or undulations (non-periodic) of the rail head of new rail. Usually associated with the mill scale layer of new rail. Usually too small to be detected by conventional straight edge and taper gage measurements.

j. *Mill Defects.* Anomalies in the surface of the rail head due to improper rolling of the rail. Often does not manifest itself until after the rail has been in service. Includes mill scale, lines, seams, grooves, etc.

### 1.1.4 RAIL WEAR TERMINOLOGY (2002)

Rail wear is defined as the deviation in the dimensions of the rail head from the new rail section specifications (see [Chapter 4, Section 1.1](#) for new rail weight section specifications). These deviations result from friction and contact stresses. The following definitions are commonly used to define points of reference and rail wear.

a. **Top of Rail Centerline Point** – A point where the top of the rail intersects the centerline of the rail ([Figure 2-1-1](#)).

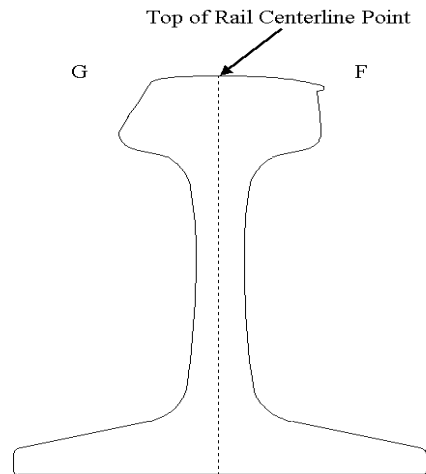


**Figure 2-1-1. Top of Rail Centerline Point**

- b. Gage Face Wear (Side Wear) – The difference in the horizontal dimension between the new rail section and the worn rail section at a depth below the top of rail centerline point, on the gage side of the rail. The two depths commonly used in North America are:

(1) 5/8 inch below the Top of the Worn Rail Centerline Point ([Figure 2-1-2](#)).

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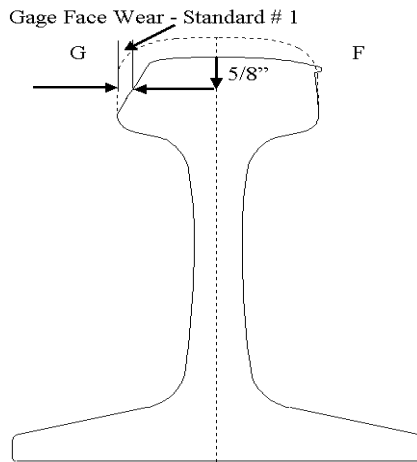


**Figure 2-1-2. Gage Face Wear Definition 1**

- (2) A fixed distance down from the top of the new rail section centerline point. One fixed distance is used or is assigned to each rail section ([Figure 2-1-3](#)).

b.

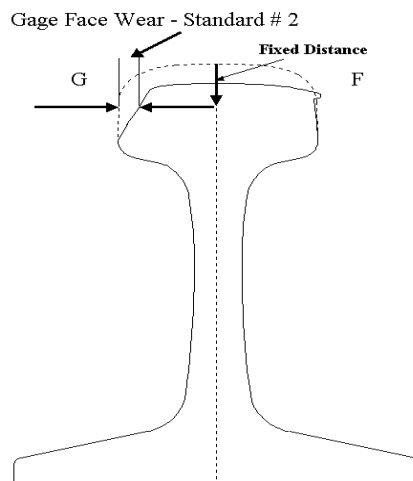


**Figure 2-1-3. Gage Face Wear Definition 2**

- c. Field Face Wear (Field Side Wear) – The difference in the horizontal dimension between the new rail section and the worn rail section at a depth below the top of rail centerline point, on the field side of the rail. The two depths commonly used in North America are:

- (1) 5/8 inch below the Top of the Worn Rail Centerline Point ([Figure 2-1-4](#)).

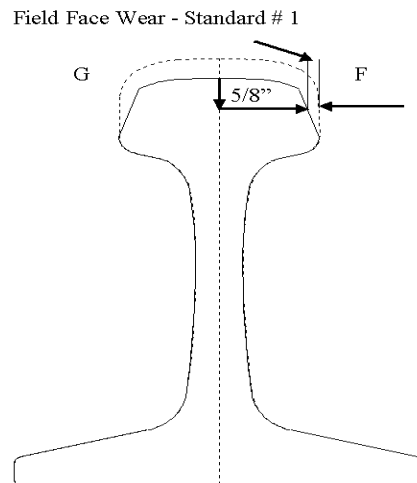


**Figure 2-1-4. Field Face Wear Definition 1**

- (2) A fixed distance down from the top of the new rail section centerline point. One fixed distance is used or is assigned to each rail section ([Figure 2-1-5](#)).

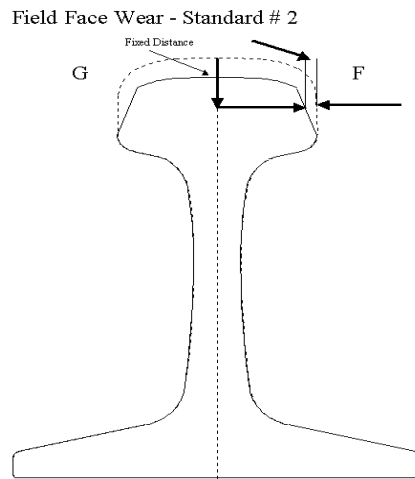


**Figure 2-1-5. Field Face Wear Definition 2**

- d. Vertical Head Wear (Top Wear) – The difference in the vertical dimension between the new rail section and the worn rail section at the Top of Rail Centerline Point ([Figure 2-1-6](#)).

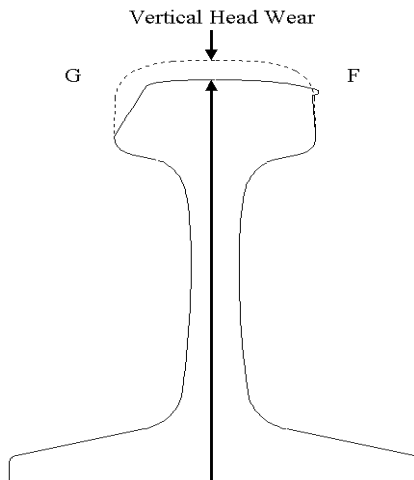


**Figure 2-1-6. Vertical Head Wear**

- e. Rail Height – The dimension of the vertical height of the rail measured along the centerline of the rail from the base of the rail up to the Top of the Rail Centerline Point (Figure 2-1-7).

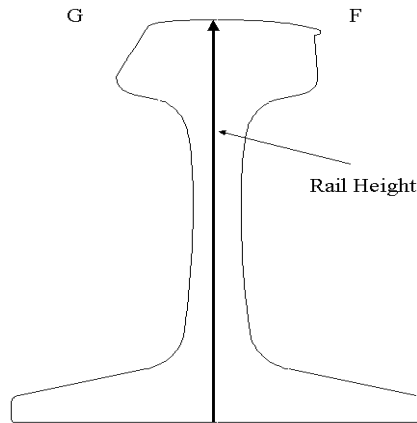


**Figure 2-1-7. Rail Height**

- f. Rail Head Width – The horizontal distance from the gage side to the field side of the rail head at a depth below the Top of Rail Centerline Point. The two depths commonly used in North America are:
- (1) 5/8 inch below the Top of the Worn Rail Centerline Point (Figure 2-1-8).

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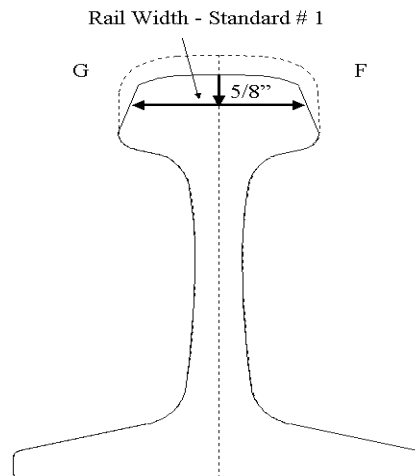


**Figure 2-1-8. Rail Width Definition 1**

- (2) A fixed depth down from the top of the new rail section centerline point. One fixed depth is used or is assigned to each rail section ([Figure 2-1-9](#)).

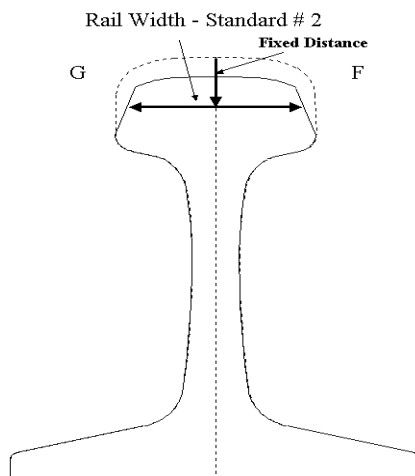


**Figure 2-1-9. Rail Width Definition 2**

- g. Horizontal Wear (Rail Head Width Wear) – The horizontal dimension difference between the new rail head width and the worn rail head width as defined in [\(f\)](#) above.
- h. Lip (Plastic Flow) as defined in [Article 1.1.3 \(h\)](#). Lip is measured horizontally from the worn rail section side face at a depth of 5/8-inch below the top of the worn rail centerline point to the extreme point on the lip ([Figure 2-1-10](#)).

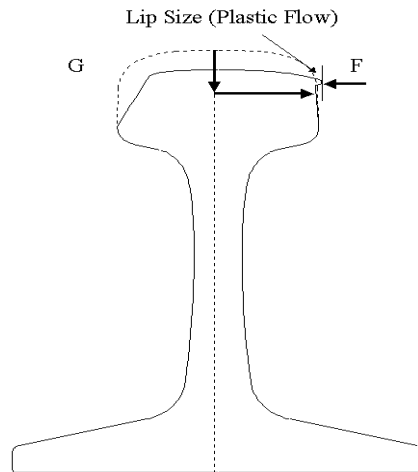


**Figure 2-1-10. Lip**

- i. Rail Head Area Lost – The difference in cross-sectional rail head area between the new rail section and the worn rail section that lies on or within the new rail profile ([Figure 2-1-11](#)).

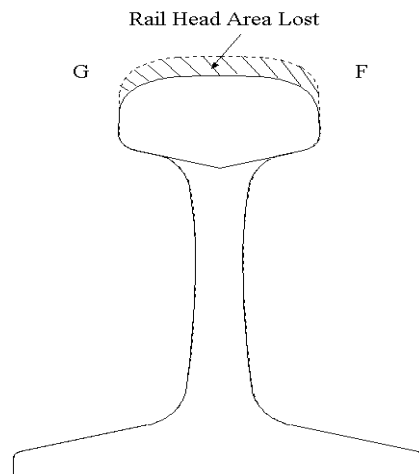


**Figure 2-1-11. Rail Head Area Lost**

- j. Rail Head Area Remaining – The remaining cross-sectional rail head area of the worn rail that lies on or within the new rail profile ([Figure 2-1-12](#)).

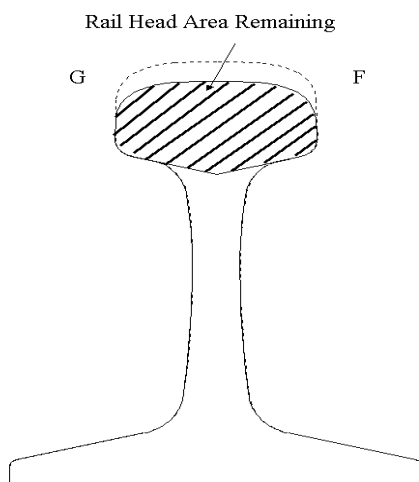


**Figure 2-1-12. Rail Head Area Remaining**

- k. **Percent Head Loss** – The percentage of the cross sectional rail head area lost as compared with the new section rail head area.

### 1.1.5 RAIL HEAD PROFILE (1990)

Transverse (cross-sectional) geometry of the rail head extending from one bottom fillet radius to the other bottom fillet radius of the rail head.

### 1.1.6 RAIL PROFILE QUALITY INDEX DEFINITIONS (2009)

- a. *Template*: A desired geometric shape of the gage face and top of rail surfaces of the transverse section of a rail.
- b. *Template Alignment*: A process for positioning a template relative to a measured rail profile.
- c. *Difference Curve*: A numeric representation of the deviation of a measured rail profile from an aligned template.
- d. *Zones*: A portion of a template in which deviations are evaluated.
- e. *RPQI*: A Rail Profile Quality Index (*RPQI*) is a numeric value calculated from the difference curve to indicate how closely the measured rail profile matches the desired shape of the rail.
- f. *SRPQI*: A Segment Rail Profile Quality Index (*SRPQI*) is a numeric value that summarizes individual *RPQI*s over a given track segment.

## SECTION 1.2 DEFINITION OF TRACK QUALITY INDEX (TQI)

### 1.2.1 TRACK QUALITY INDEX (1990)

A number, derived from a formula, used to represent observed track data, and which relates to the ability of the track to perform its function.



## SECTION 1.3 COMPILATION OF VARIOUS TRACK GEOMETRY PARAMETERS AND RELATED ELEMENTS, USED WHEN DESCRIBING TRACK GEOMETRY



### 1.3.1 GENERAL (1994)

- a. The purpose of this section is to describe the various track geometry parameters used by the railroads to describe track geometry. Included in this compilation is terminology for associated elements like rail, center line, etc.
- b. Track geometry describes the position that each rail, or the track center line, occupies in space.
- c. By projecting the track geometry into various planes, track geometry parameters can be specified. These parameters can be measured and used to describe track geometry.
- d. Depending upon which plane they reside in, track geometry parameters can be grouped as follows:
  - (1) parameters in the horizontal plane (a level plane defined by the horizon).
  - (2) parameters in the longitudinal vertical plane (a vertical plane through each rail or the track axis).
  - (3) parameters in the transverse vertical plane (a vertical plane normal to each rail or the track axis).
  - (4) parameters in the track plane (a plane located 5/8 inch below the top of both rails along the track axis).



### 1.3.2 THE HORIZONTAL TRACK GEOMETRY (1994)

The horizontal track geometry is called Alignment ([Figure 2-1-13](#)). Alignment is the projection of the track geometry of each rail or the track center line onto the horizontal plane. When alignment describes a rail, a line along the rail gage side, 5/8 inch below the top of the rail, is used for the projection. The following terms are used when describing alignment:

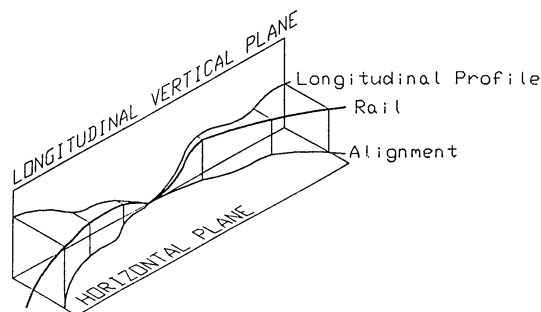


**Figure 2-1-13. The Horizontal and Longitudinal Vertical Track Geometry**

- a. Curvature.
- b. Line.
- c. Degree of Curve.
- d. Curve Radius.
- e. Horizontal Space Curve.
- f. Versine.

### 1.3.2.1 Measurements

The following measurements are used to quantify Alignment.

- a. *Absolute Horizontal Space Curve*. Absolute geophysical location of alignment which can be measured with conventional land surveying equipment, such as theodolite, transit, or unconventional land surveying equipment using electronic equipment and/or NAVSTAR Global Positioning System (GPS).
- b. *Chord Measurements*. A chord is a straight line between two points of the alignment. The chord measurement is the horizontal projected distance between a point on the chord and a point on the alignment, perpendicular to the chord. Chords can be measured using the string lining method. This method consists of stretching a string between two points on the rail and then measuring the offset between the rail and a point on the string (see Manual for reference). String lining methods can be performed manually (static) or with moving equipment (moving chord), using the offsets of three different points with respect to a reference plane.

The following terms are synonyms for chord measurements:

- (1) Versine.
- (2) Offset, Asymmetrical Offset, Symmetrical Offset, Mid-offset.
- (3) Ordinate, Asymmetrical Ordinate, Symmetrical Ordinate, Mid-ordinate.
- c. *Degree of Curve*. The angle subtended at the center of a simple curve by a 100-foot chord, which can be measured using either conventional (transit) or unconventional (NAVSTAR GPS) land surveying equipment, or the string lining method, using a 62-foot long chord. (The value of the mid-ordinate (mid-chord offset), in inches, of a 62-foot chord equals the degree of curve) computed from the measurement of truck yaw in relation to the car frame, or computed from the car body yaw rate and the vehicle's longitudinal velocity.
- d. *Horizontal Rate of Change*. The horizontal difference between two alignment measurements of two points a preselected distance apart, measured with conventional land surveying equipment, such as theodolite, transit or unconventional land surveying equipment using electronic equipment and/or NAVSTAR Global Positioning System (GPS).
- e. *Quasi Horizontal Space Curve*. Absolute geophysical location of alignment with its mean removed. The mean is calculated from alignment over a preselected distance.
- f. *Tangential Deflection*. The angle between the chord and the tangent to the curve at one end point of the chord as measured using a theodolite, transit, electronic equipment or NAVSTAR Global Positioning System (GPS).
- g. *Tangential Offset*. The distance measured perpendicular to the tangent between a point on the curve and the tangent as measured using a theodolite, transit, electronic equipment or NAVSTAR Global Positioning System (GPS).

### 1.3.3 THE LONGITUDINAL VERTICAL TRACK GEOMETRY (1994)

- a. The longitudinal vertical track geometry is called Longitudinal Profile ([Figure 2-1-13](#)).
- b. Longitudinal Profile is the track geometry of each rail or the track center line projected onto the longitudinal vertical plane. When Longitudinal Profile describes a rail, a line along the top of the rail is used for the projection.
- c. The following terms are used when describing Longitudinal Profile:
  - (1) Profile, Surface, Top Vertical Alignment.
  - (2) Dip, Sag, Hump.
  - (3) Grade, Slope.
  - (4) Ramps, Runoff.
  - (5) Vertical Space Curve.
  - (6) Vertical Curve.

#### 1.3.3.1 Measurements

The following measurements are used to quantify Longitudinal Profile.

- a. *Absolute Vertical Space Curve.* Absolute elevation of each geophysical location of the Longitudinal Profile usually measured with conventional land surveying equipment, such as theodolite, transit, or unconventional land surveying equipment using electronic equipment and/or NAVSTAR Global Positioning System (GPS).
- b. *Chord Measurements.* A chord is a straight line between two points of the Longitudinal Profile. The chord measurement is the vertical projected distance between a point on the chord and a point on the Longitudinal Profile, perpendicular to the chord. Chord measurements can be made using the string lining method. This method consists of stretching a string between two points on the rail and then measuring the offset between the rail and a point on the string (see Manual for reference). String lining methods can be performed manually (static) or with moving equipment (moving chord), using the offsets of three different points with respect to a reference plane.
- c. The following terms are used when describing chord measurements:
  - (1) Versine.
  - (2) Offset, Asymmetrical Offset, Symmetrical offset, Mid-offset.
  - (3) Ordinate, Asymmetrical Ordinate, Symmetrical Ordinate, Mid-ordinate.
  - (4) Dip or Hump is used on one rail only.
- d. *Dip, Sag, Hump.* The deviation of the vertical parameter of both rails from uniformity over a specified distance. Dip, Sag and Hump can be measured by string lining both rails (see above) with the starting point (end of the string) in the same transverse plane. The smaller of the offsets (both offsets must have the same sign) represents the dip, sag or hump, or by measuring the vertical displacement of the four journal box points with reference to the car frame.
- e. *Grade, Slope.* The elevation difference between two points of the Absolute Vertical Space Curve a preselected distance apart. Grade and slope can be measured using the same methods shown under *absolute*



*vertical space curve*, or by measuring the inclination of the car frame over a horizontal reference plane with corrections to compensate for the vehicle's vertical accelerations and car body pitch.

- f. *Ramp, Vertical Runoff.* The established change of elevation from one point to another along the track. These can be measured using the same methods shown under Absolute Vertical Space Curve.
- g. *Vertical Rate of Change.* The vertical difference between two Longitudinal Profile measurement of two points a preselected distance apart, and is measured the same as grade or slope.

### 1.3.4 THE TRACK GEOMETRY IN THE TRANSVERSE VERTICAL PLANE (1994)

- a. *Superelevation* (Figure 2-1-14). The difference in elevation between the top of one rail and the top of the other rail measured along a line perpendicular to the track center line. Superelevation can be measured using a levelboard, pendulum or inclinometer, or a gyroscope with compensation for vehicle speed and car body movement.

The following terms are synonyms for superelevation:

- (1) Elevation.
- (2) Cant.
- (3) Crosslevel.

- b. *Twist.* The difference in superelevation between two points a fixed distance apart along the track (twist base). Twist (or warp) can be measured by computing the difference between two levelboard measurements taken at each end of the twist base or computed from the measurements of vertical displacements of the journal box points with respect to the car frame.

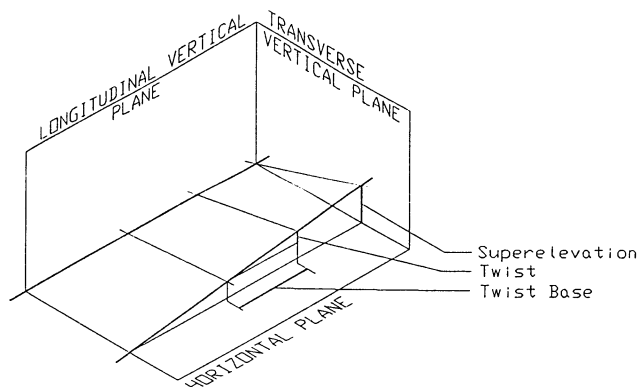


**Figure 2-1-14. The Track Geometry in the Transverse Vertical Plane**

#### 1.3.4.1 Measurements

The following measurements are used to quantify the track geometry parameters in the transverse vertical plane:

- Actual Value.
- Deviation from Design Value or Standard.
- Deviation from Average (relative).
- Rate of Change: The difference between two measurements a preselected distance apart.

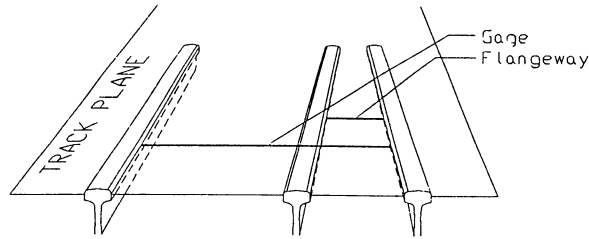


Figure 2-1-15. The Track Geometry in the Track Plane

### 1.3.5 THE TRACK GEOMETRY IN THE TRACK PLANE (1994)

Two parameters are used to describe track geometry in the track plane (Figure 2-1-15), Gage and Flangeway Width.

- Gage (Gauge)*. The distance (measured normal to the track axis) between the inside of the rail heads. Gage can be measured with a ruler, measuring tape or gage board. It can also be measured by a geometry car using linear displacement devices coupled to rail contact devices (swords or measuring wheels), or with a non-contact system based on magnetic induction, optics or lasers.
- Flangeway Width (Gap)*. The distance (measured normal to the track axis) between the running rail and the restraining or guard rail. This is measured with a ruler, measuring tape or gage board, or by track geometry cars with linear displacement devices coupled to rail contact devices (swords or measuring wheels).

#### 1.3.5.1 Measurements

The following measurements are used to quantify the track geometry parameters in the track plane: Actual Value

- Deviation from Design.
- Deviation from Average (relative).
- Rate of Change: The difference between two measurements a preselected distance apart.

### 1.3.6 RELATED TERMINOLOGY (1994)

The following terms are for general use in Part 1, Definitions. Refer to the Glossary located at the end of the chapter for definitions.

|                 |                  |                   |
|-----------------|------------------|-------------------|
| Center Line     | Gage Side        | Platform Height   |
| Curve, Compound | Grade Rail       | Power Rail        |
| Curve, Easement | Guard Check Gage | Power Rail Gage   |
| Curve, Reverse  | Guard Face Gage  | Power Rail Height |
| Curve, Simple   | Guard Rail       | Reference Rail    |
| Curve, Vertical | High Rail        | Running Rail      |
| Field Side      | Inner Rail       | Tangent           |

Flangeway Depth  
Gage Line

Outer Rail  
Platform Gage

Track  
Track Axis



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American Railway Engineering and  
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## Part 2

# Track Measuring Vehicles<sup>1</sup>

— 2009 —

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<sup>1</sup> References, Vol. 93, pp. 45, 50.3; Vol. 97, p. 31.

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## SECTION 2.1 DESCRIPTION OF A GENERIC TRACK GEOMETRY MEASURING VEHICLE

## 2.1.1 GENERAL (1992)

- a. The Track Geometry Measuring Vehicle is a single vehicle or complement of vehicles whose purpose is to measure and record the track geometry (refer to [Part 1, Definitions, Section 1.3, Compilation of Various Track Geometry Parameters and Related Elements, Used When Describing Track Geometry](#)) in real-time, and to display this measurement ([Figure 2-2-1](#)).
- b. Most Geometry Measuring Vehicles record distance as a consecutive number of scan distance intervals, converted into milepost and feet or kilometers and meters, providing an accurate means of locating points and known monuments or events along the track. Automatic Location Detector System (ALD) complements the distance detection.
- c. The measured geometry parameters are compared to preset values to evaluate compliance to predefined standards. Points on the track that exceed these preset values are in exception and are listed as defects. Pin-pointing these defects can be facilitated by some means of marking.

- d. The use of a magnetic tape or a floppy/hard disk system for storing of the raw, calculated or analyzed data obtained by the Geometry Measuring Vehicle allows the data to be used to determine short term and long term track degradation analysis. This is done by comparing the data of the current test with previous tests and noting the difference.
- e. The use of highly advanced electronic devices and high speed computers allow the data to be collected at speeds up to 160 mph (250 kmh), with scan intervals of one (1) per foot or four (4) per meter. These processors are used in conjunction with high speed analog to digital converters, printer/plotters, monitors and mass storage devices.

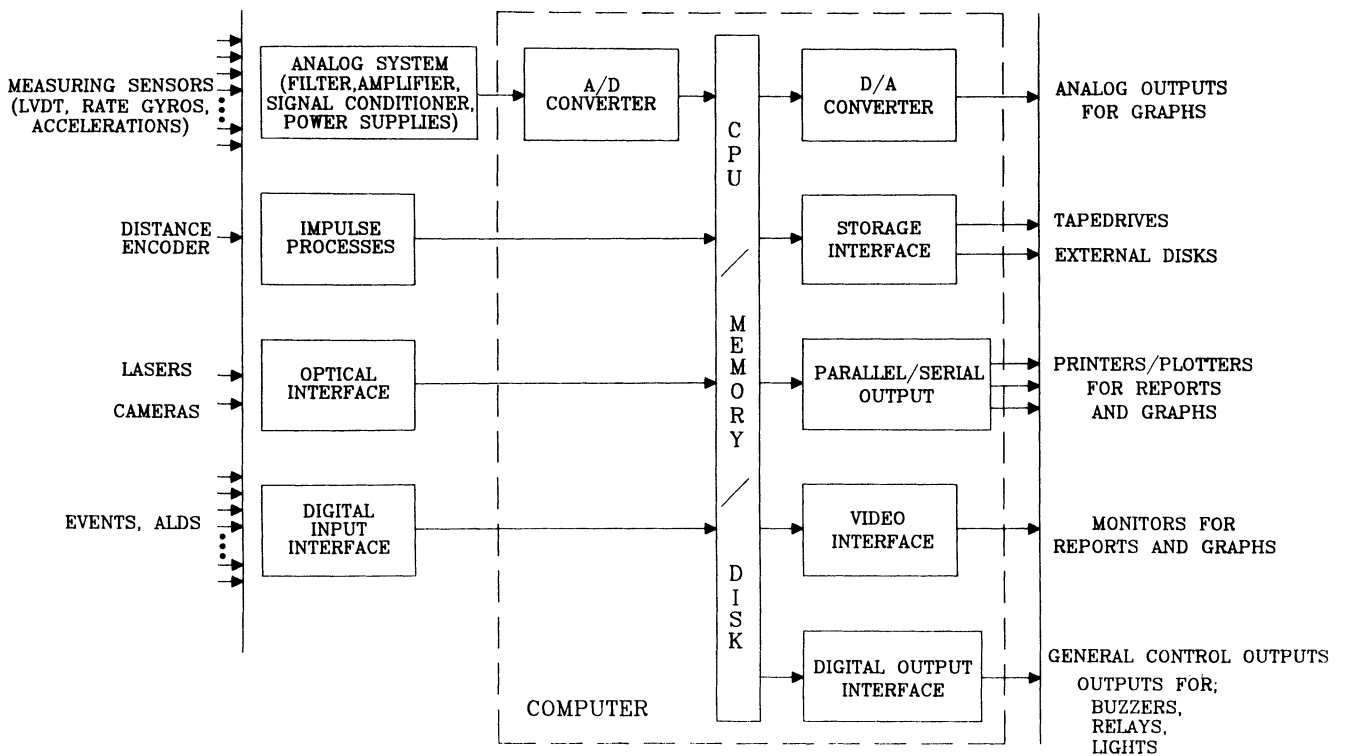


Figure 2-2-1. Measuring Vehicle Hardware – Block Diagram

- f. A typical system consists of the following:
- (1) *Distance Encoder*. An optically coupled mechanical or magnetic pick up device that emits a specified number of pulses per revolution of a drive shaft. A preset number of pulses is equivalent to a known distance.
  - (2) *Input/Output Device*. This device usually counts the encoder pulses and causes the input channels to be scanned at uniform distance intervals. It also allows the computer to control outside logic devices.
  - (3) *Measurement Device*. Can be either a contact or non-contact device.
    - (a) Most contact devices are coupled to a linear voltage displacement transducer (LVDT) that outputs an electrical value equivalent to the displacement of the measuring device value, relative to its null (zero) point.
    - (b) Most non-contacting devices are based either on integrations of accelerations (created by a moving mass) or optical/camera systems.

- (4) *Analog to Digital Converter*. This device changes the electrical signal from the measuring device to a binary (digital) format supported by a computer.
- (5) *Printer/Plotter*. This device provides hard copy results of a measuring test. On most geometry measuring vehicles, the defects, their location and a graph represent the measured geometry outputs.
- (6) *Monitor*. This device displays operational commands and raw, calculated or analyzed data, and allows intercommunication with the Central Processing Unit.
- (7) *Mass Storage*. These devices store the raw, calculated or analyzed data on some type of medium like tape, hard disk or static ram memory. By storing the data, a playback of a test run can be performed.
- (8) *Central Processing Unit*. This device is the center of the system, controlling all external peripherals and performing many hundreds of thousands of computations per second.
- (9) *Track Geometry Parameters*. The most common geometry parameters measured by most of the geometry vehicles are:
  - (a) Alignment.
  - (b) Longitudinal Profile.
  - (c) Gage.
  - (d) Superelevation.
  - (e) Parameters calculated from these measurements.

Geometry vehicles can be additionally equipped with measuring devices for third (power) rails, catenary wire parameters or clearance measurements.



## SECTION 2.2 RECOMMENDED PRACTICE CONDITIONS FOR GAGE RESTRAINT MEASUREMENT



### 2.2.1 TERMS (1996)

The following terms apply to the systems which have been employed to measure track gage strength. Refer to the Glossary located at the end of the chapter for definitions.



AAR Track Loading Vehicle (AAR TLV) Load Severity

AAR TLV Loading Conditions Loaded Gage

FRA Gage Restraint Measurement System (GRMS) Loaded Gage Under Traffic



FRA GRMS Loading Conditions Projected Loaded Gage (PLG)

FRA Gage Widening Ratio Neutral Loading Condition

FRA Projected Loaded Gage-24 (PLG24) Track Loading Device



Gage Restraint Measurement System (GRMS) Track Loading Vehicle (TLV)

Gage Widening Ratio (GWR) Unloaded Gage

L/V Ratio



### 2.2.2 BACKGROUND (1996)

- a. Gage restraint measurement is accomplished by making two gage measurements at the location in track where the gage restraint is to be measured. The first gage measurement is made with no significant loads applied. The second gage measurement is made with significant vertical loads applied to each rail and a significant gage-spreading lateral load applied between the rails.
- b. The change in gage between the unloaded state and the loaded state indicates the gage restraint strength of the track. A large change in gage caused by a small lateral force indicates a track with weak lateral restraint; a small change in gage with a large lateral force applied indicates a location with strong lateral restraint. The overall measurement process has been adapted to operate on a continuous basis.

### 2.2.3 CONSIDERATIONS FOR PERFORMING LATERAL RESTRAINT MEASUREMENTS (1996)

#### 2.2.3.1 MEASUREMENT SYSTEM DESIGN CONSIDERATIONS

- a. The unloaded gage measurement can be made with either mechanical contact systems or with non-contact sensors of various types. The unloaded gage measurement must be made in an area of the track which is essentially free of other vehicle-imposed loads in order to assure a truly unloaded measurement. The operation of the overall measurement system must assure that each unloaded measurement is made to correspond with a loaded measurement taken at essentially the same point in the track.

- b. The test loads to accomplish the loaded gage measurement are typically applied through flanged wheels on a telescoping axle. The inertial forces associated with rapidly moving the load applying components limit the ability of these systems to operate at high speeds. Existing systems have operated successfully in the 30 mph range.
- c. The loaded gage is determined either with non-contact sensors or by measuring the distance which the axle telescopes to keep the flanges tight against the rail. The loaded gage measurement must be made at a point as near as possible to the point of load application to assure that measured deflections can be most accurately attributed to the measured applied loads. Each gage reading and the vertical and lateral forces at the loaded point are measured and recorded.
- d. The corresponding unloaded and loaded gage measurements must be performed in a consistent manner so that factors such as rail lipping do not introduce error between the unloaded and loaded gage measurements.
- e. The amount the rail head deflects as a result of the test loads depends on how much force is applied, how strong or weak the rail restraint condition is, and how much vertical and lateral load is being applied to the surrounding tie/fastener system. For the safety of test operations, test loads should not continue to be applied when loaded gage reaches 58 inches. Non-test vertical loads applied adjacent to the location under test will cause additional friction forces at the test point and will cause the measured lateral deflection to decrease. The presence of non-test variable vertical or lateral loads near the measurement point can be a significant source of error in the measurement process. The measurement process can be compensated for known adjacent vertical loads.
- f. Any additional lateral load applied in the area surrounding the test location will cause the measured lateral deflection to change and can result in measurements which are not comparable with other measurement systems. Limitations must be placed on the distances, magnitudes, and variabilities of the adjacent non-test loads to make the deflection measurement consistent and repeatable.

### 2.2.3.2 Magnitude of Applied Test Loads

- a. To be adequate for the purposes of determining gage restraint, the vertical test load must be sufficient to remove all free play between the base of the rail and the supporting tie plates, to properly represent the condition of the track under traffic conditions. The minimum recommended vertical wheel load for measurement is 10,000 pounds. This level will provide adequate seating of the rail. In addition to the need for adequate rail seating, when nominal vertical loads below this level are applied, dynamic variations in both lateral and vertical loading make it difficult to maintain a lateral load sufficient to assure that the minimum load severity of 3.0 kips is maintained without exceeding the 1.25 L/V derailment limit.
- b. The lateral gage-spreading load must be sufficient to overcome all frictional resistance generated by the applied vertical loads and therefore to remove all lateral free play in the rail/fastener/tie plate/tie system, and to assure that some lateral force remains to apply a “proof test” load against the fastening system. The loading conditions recommended herein are based on a nominal rail to tie friction coefficient of 0.4.
- c. If the applied lateral force is too large, damage to the tie and fastener system could result and/or derailment of the test vehicle can result. If the applied lateral force is too small, track strength will not be adequately tested and a misleading indication of strong track may result.
- d. The relationships between applied vertical and lateral test loads which indicate the recommended range of loading regimes for continuous gage restraint testing are labelled Zone II in [Figure 2-2-2](#). The loading regimes in Zone II provide sufficient vertical force to seat the rail and sufficient lateral force to assure that the fastener system is exercised, while limiting L/V ratios to acceptable levels and preventing permanent track damage due to excessive lateral forces.
- e. The loading regimes contained in Zone IV have been found through field experience to be acceptable for continuous gage restraint testing. However, operations using load combinations in this zone must be



conducted with caution, since L/V ratios exceed 0.8. Experience to date has shown that careful control of wheelset contour and lubrication of the wheel/rail contact point can permit successful testing in this zone.



- f. The loading regimes in Zone III provide less than 3,000 pounds of lateral force in excess of the force reasonably likely to be needed to overcome friction between the tie plate and the tie surface, assuming a coefficient of friction at that interface of 0.4. Testing in Zone III may fail to detect weak locations in the track. The loading regimes in Zone I in general represent conditions in which 10,000 or more pounds of force in excess of friction are applied to the fasteners, and unrecoverable deflection may result. The small area at the left of Zone I and adjacent to Zone IV is a regime in which L/V ratios exceed 1.25. Testing in this area is not recommended due to unacceptable risk of wheel-climb derailment of the test wheelset.
- g. The regimes in Zone V do not have the minimum required 10,000-lb vertical load. A minimum of 10,000 pounds of vertical load is recommended for the following reasons.
  - (1) Analysis and experience has shown that a 10,000-lb vertical load is necessary to seat the rail and tie plate to reliably engage the fasteners. For Nominal vertical loads less than 10,000 lb it becomes impractical to maintain the necessary lateral load without exceeding the 1.25 L/V ratio derailment limit
  - (2) From a practical standpoint, when the nominal vertical load falls below 10,000 lb the lateral and vertical loads must be prevented from varying more than 1,000 lb each to assure maintenance of a load severity above 3,000 pounds while not exceeding the derailment limit at an L/V of 1.25.

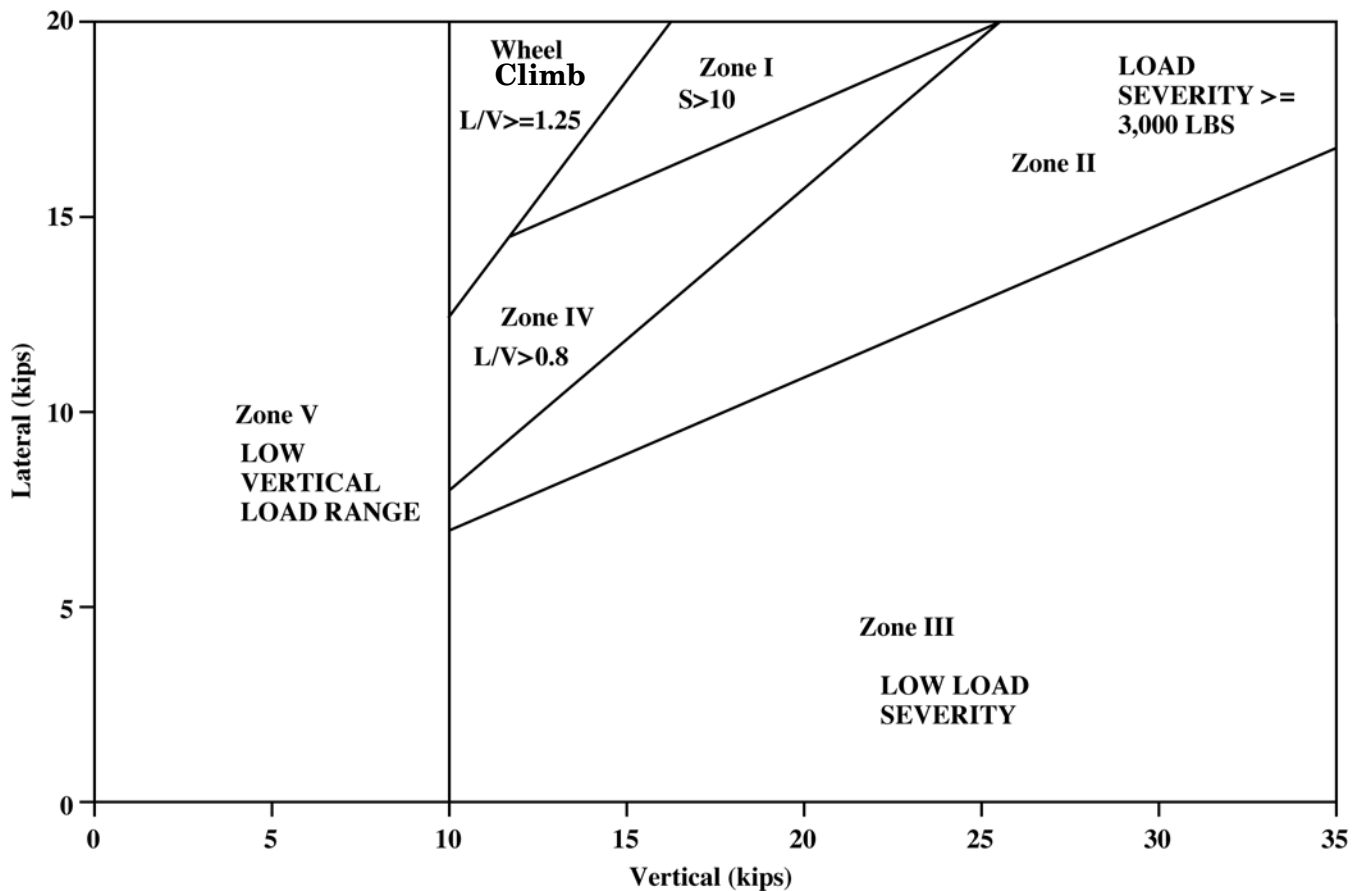


Figure 2-2-2. Gage Restraint Test Loads

- h. Gage restraint research and testing to date has clearly indicated that loaded track gage can change extremely rapidly from point to point, often within only 1 to 3 feet along the track. This means that any test system must have rapid response capacity to handle changes in load and rapid movements of the load applying system as it responds to rapidly changing track gage and track strength conditions, and to sustain substantial test loads despite the rapidly changing conditions in the track.
- i. Test systems with inadequate mechanical capacity will produce erratic test loads. When such loads are too low, any extrapolation to higher test loads will be exaggerated and may result in false alarms for safety thresholds. Any system which overcompensates for low loads may inadvertently overload and damage the track as the system rapidly moves from an area of weak track into an area of stronger track. High capacity, very rapid response, and control of maximum force levels are essential for satisfactory gage restraint measurement.
- j. The high variability of track gage and the rapid mechanical responses of the testing system mean that a rapid-response load measuring sensor system is also essential to assure accurate measurement of track gage strength. Experience has shown that systems which use averaging techniques or which do not measure at or near the point of load application may fail to record significant rapid changes in applied test loads. All load values stated in this recommended practice are instantaneous values applied and/or measured at the point and time of load application.
- k. Experience has shown that a significant weak location in track may exist over an area of only three ties, and test systems may have difficulty in maintaining lateral load specifically at such weak locations which cause the test system to encounter rapidly widening gage. It is strongly recommended that any test system

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identify locations where insufficient test loads occur at any planned sample point, to avoid the possibility of systematically missing critical locations of track weakness in gage restraint.



- I. The following specific practices are recommended to assure a consistent and repeatable gage strength measurement:
  - (1) The unloaded gage measurement must be taken at a point at least 5 feet (3.1 m) behind or 10 feet (6.2 m) in front of any load applying source greater than 350 lb in either the lateral or vertical direction.
  - (2) The applied vertical load must be at least 10,000 lb on each rail.
  - (3) The loaded gage shall be measured within 1 foot (0.31 m) of the load application point.
  - (4) Application of gage widening loads must be immediately reduced or discontinued when loaded gage reaches or exceeds 58 inches for the safety of test operations. The testing system shall identify and report any sampled location at which this occurs.
  - (5) No vertical or lateral load shall be applied to the track for 10 feet leading the test load application point and for 5 feet trailing the test load application point.
  - (6) The instantaneous applied loads must fall within the loading regimes indicated as Zone II on Figure 1, and may lie within Zone IV if operating precautions are taken to assure the safety of test operations. The testing system shall identify and report any sampled location where loads fall in Zone III or Zone V as a location at which the test was not valid due to inadequate lateral load to fully exercise the fastener system.
  - (7) A continuous measurement requires that the track be sampled at an interval less than or equal to the distance between points providing gage restraint support, such as cross ties or fastenings to a continuous track support medium. A sample at one foot intervals has been found acceptable on conventional track structures.

### 2.2.3.3 Issues Under Ongoing Study

- a. The following issues are under continuing study:
  - (1) calibration requirements and procedures for measurement instrumentation;
  - (2) recommended time intervals between inspections; and
  - (3) recommending specific extrapolation relationships to anticipated gage readings at load levels higher than those actually measured.
- b. Thresholds which delimit safe or unsafe levels of gage restraint are beyond the scope of this recommended practice.

## 2.2.4 SYSTEM QUALIFICATION AND CALIBRATION PROCEDURE (2007)

### 2.2.4.1 Purpose

The purpose of this procedure is to validate the performance of Gage Restraint Measurement Systems (GRMS). Following this procedure will assure a reasonable confidence that the system conforms to [Section 2.2](#). The qualification procedure consists of a series of operating tests of the GRMS over a test zone.

### 2.2.4.2 Fundamental Parameters

Gage restraint measurement requires documentation of basic parameters measured at a single location along the track. The measurements are unloaded gage, loaded gage, vertical loads, and the gage-widening lateral load. These are the basis for other computed parameters or indices to assess lateral track gage strength condition.

### 2.2.4.3 Test Zone

A good test zone would consist of at least a three-mile section of track that contains a left, and right curve of two to three degrees or more with balanced super elevation and a one-mile section of tangent. It would have wood crossties, cut spike fasteners and good rail condition (lip free CWR and little or no gage wear) with a maximum static unloaded gage variation of .5 in/15 ft. Major maintenance (i.e., surfacing, tie renewal, rail, out-of-face) will not have been performed within the previous three months. The zone should allow operation of the vehicle at maximum design speed.

### 2.2.4.4 Test Matrix

The sample test matrix ([Table 2-2-1](#)) provides the framework for the evaluation procedure and documentation. The tests should be performed in the order specified in [Table 2-2-1](#) to minimize the influence of a prior test on a current test result. The GRMS should be fully calibrated according to manufacturer procedures before starting the evaluation tests. After choosing the test zone, the GRMS should be operated over the entire test zone at nominal loads to exercise the track and take out the slack in the fasteners. If a bi-directional GRMS vehicle is to be evaluated, [Article 2.2.4.4.7](#) addresses the considerations for developing the test matrix.

#### 2.2.4.4.1 Tachometer Verification

Measure and mark a section of at least 1000 feet of tangent track. The GRMS vehicle should be operated at 5mph over the marked section and the distance measured by the vehicle noted. Once tachometer calibration has been performed, the vehicle should make 3 additional passes and document tachometer repeatability to be within manufacturer specifications.

#### 2.2.4.4.2 Static Load Verification

Loads applied by the GRMS vehicles should be verified using a load-cell equipped measuring fixture. The fixture configuration should be such that the load cells must measure the loads between the point of application on the vehicle and the rails. The load should be applied at approximately 5 even increments throughout the measurement range (minimum defined by [Figure 2-2-2](#) and maximum defined by the manufacturer's specifications). The test should be conducted with both increasing and decreasing loads to determine hysteresis or friction in the system. The hysteresis and the average difference between the load measured by the fixture and the vehicle should be noted as the system accuracy and compared with the manufacturer's specifications.

#### 2.2.4.4.3 Unloaded Gage Accuracy

For unloaded gage accuracy evaluation, the system should be stopped for an instrument verification (IV) at eight locations of which three are in the tangent, two in the spiral, and three in the body of the curve. Each location must be separated by a minimum of 15 feet. At these locations an IV shall be conducted utilizing a known standard of gage measurement. If unloaded gage measurement is by a contact measuring system, the IV should be made at points on either side of the contact point as close as possible to the contact point and averaged. The measurement must have a resolution of 1/32<sup>nd</sup> of an inch or better. The differences between the system recorded measurement and the IV measurement are then calculated. The maximum and minimum differences are removed from the data set and the average of the remaining data is recorded as the system accuracy to be compared with manufacturer's specifications.

