AREMA
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Maintenance-of-Way Association

Chap TOC
VOL 1
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Part 2

Track Measuring Vehicles[1]

— 1996 —

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[1] 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 3-1).

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.

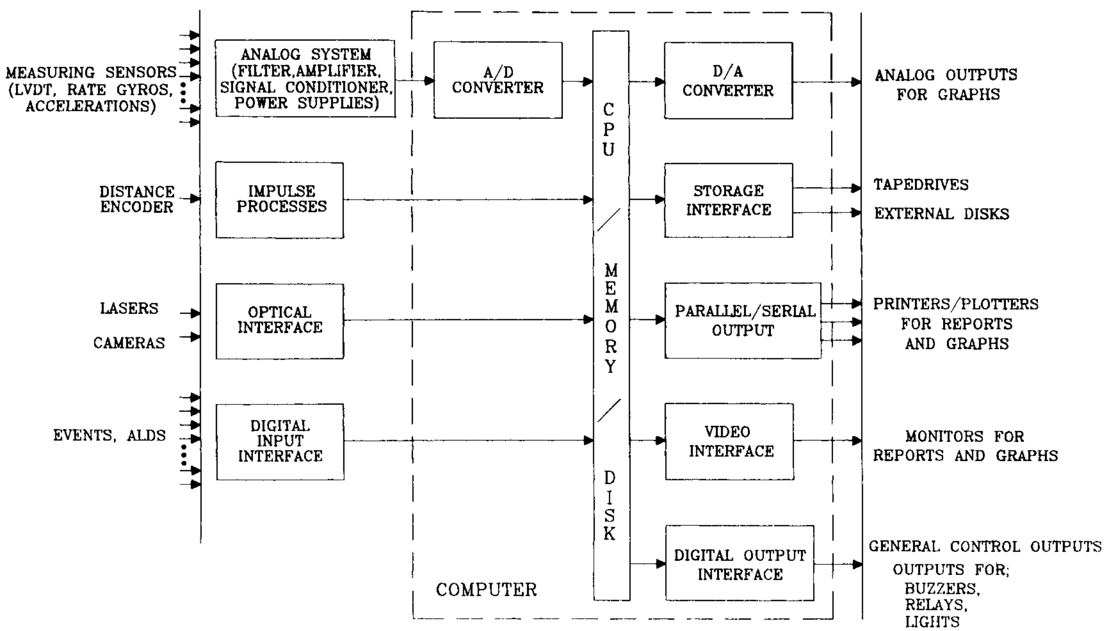

Figure 3-1. Measuring Vehicle Hardware – Block Diagram

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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.

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SECTION 2.2 RECOMMENDED MINIMUM PERFORMANCE GUIDELINE FOR RAIL TESTING

2.2.1 INTRODUCTION (1992)

a. Rail testing must be performed both reliably and economically. On the one hand the rail flaw detection system, comprising both test car and its operator, must strive to correctly identify all rail defects representing a significant risk of rail failure. On the other hand, this must be done at a testing speed that is compatible with train operations and at a price that is commensurate with the service.

b. 100% accuracy in testing is not within the capabilities of current equipment. Nor is it possible to provide near real time quality control feedback to the operator. Given the current state of the art, the risk of rail failure is best controlled with a three-step approach. This consists of:

(1) Assessment and calibration of test cars against standard test specimens in a controlled environment.

(2) Regular assessment of the performance of rail test cars and operators in regular testing service.

(3) Adjustment of rail testing cycles to account for reliability of testing.

c. Before a correct evaluation of the capabilities of a rail test car can be made, it is first necessary to have a baseline of comparison. Initial calibration of testing equipment is best performed by having test cars run over a test section of rails having known defects.

2.2.2 PERFORMANCE GUIDELINE FOR REGULAR TESTING (1992)

a. It is recommended that a Performance Guideline be decided upon to ensure that rail test contractors or the Railway's own operators understand the performance expected of them under day-to-day operations. The Performance Guideline should specify the minimum acceptable performance in terms of the number of valid defects in track that are not reported or otherwise missed. Table 2-1 presents a sample Performance Guideline. It tabulates the percentage of actual in-track defects that can be expected to be located in a single test by a test car maintained in reasonable condition and operated by an experienced operator in service over a typical mix of track conditions.

b. If a test car and its operator performs to a standard that exceeds the Performance Guideline of Table 2-1, the Railway can be satisfied that testing frequencies common in the industry will provide acceptable management of risk. If the Railway measures performance that is inferior to this guideline, the equipment and/or operator should be scrutinized. If it is decided to retain the testing system in question, testing intervals should be tightened to achieve the same net risk of service failures.

c. The guideline could therefore be used as the basis of an agreement between the rail testing operator and the Railway as to minimum acceptable performance. A Railway might choose to incorporate Table 2-1, or its own variation thereof into a contract, so that inferior performance by a contractor would constitute violation of contract terms.

d. The purpose of the Performance Guideline of Table 2-1 is therefore to provide a means for a Railway that does not possess a similar standard to recognize when test performance has fallen to a level that need not be accepted.

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Table 2-1. Recommended Minimum Performance Guideline for Rail Testing

Defect Type (Note 1)	Size (Length or % of head area fractured)	Reliability Ratio (% of such defects properly indicated as flaws in any single test)	
		Category I (Note 2)	Category II (Note 3)
1. Transverse Defects in the Rail Head e.g. transverse fissure compound fissure, engine burn fracture, welded burn fracture	5 – 10% 10 – 20% 21 – 40% 41 – 80% 81 – 100%	65% 85% 90% 98% 99%	55% 75% 85% 95% 99%
2. Detail fracture from shelling or Head Check	10 – 20% 21 – 40% 41 – 80% 81 – 100%	65% 85% 95% 98%	55% 75% 85% 95%
3. Defective welds – Plant Welds (Head)	3 – 5% 5 – 10% 11 – 20% 21 – 40% 41 – 80% 81 – 100%	65% 75% 85% 90% 95% 99%	— 65% 75% 85% 95% 99%
– Plant Welds (Web)	½ – 1 inch 1 – 2 inch more than 2 inches	75% 90% 99%	65% 90% 95%
– Field Welds (Head)	5 – 10% 11 – 20% 21 – 40% 41 – 80% 81 – 100%	75% 80% 85% 95% 99%	65% 70% 80% 90% 95%
– Field Welds (Web)	½ – 1 inch 1 – 2 inch more than 2 inches	75% 90% 99%	65% 85% 95%
4. Longitudinal Defects in the Rail Head e.g. horizontal split head vertical split head	2 – 4 inch long 4 – 36 inch more than 4 inches	80% 95% 99%	70% 95% 99%
5. Web Defects (Note 4) e.g. head and web separation split web	2 – 4 inch more than 36 inches	95% 98%	90% 95%

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Table 2-1. Recommended Minimum Performance Guideline for Rail Testing (Continued)

Defect Type (Note 1)	**Size (Length or % of head area fractured)**	**Reliability Ratio (% of such defects properly indicated as flaws in any single test)**	
		Category I (Note 2)	**Category II (Note 3)**
6. Piped rail	more than 8 inches any size with non-vertical orientation, evidence of bulged web or progression into weld	85% 85%	– 75%
7. Web Defects in Joint Area (Note 4) e.g. bolt hole crack, head and web separation	½ – 1 inch 1 – 2 inches 2 – 4 inches more than 4 inches	75% 75% 90% 99%	65% 65% 85% 99%

Note 1: In all testing, not more than 5% of defects indicated can be “false alarms,” i.e. with no perceptible rail defect as verified statistically by rail breaking tests.
No more than 25% of detected defects may be classified in the wrong defect size class.
Note 2: CATEGORY I track includes all main track with annual tonnage equal to or exceeding 3 MGT/yr, or with trains speeds equal to or exceeding 40 mph.
Note 3: CATEGORY II track includes all sidings and track with annual tonnage less than 3 MGT/yr and train speeds less than 40 mph.
Note 4: Defects most have progressed more than halfway through the web.

2.2.3 MEASURING AGAINST THE PERFORMANCE GUIDELINES (1992)

The Performance Guideline is based upon two performance measures which must be balanced. These are:

a. Missed Detection of a Defect:

- A defect of detectable size and type was not found and/or not reported.

  Typically this would be seen as a rail service failure within an unacceptable short interval which, upon examination, was estimated to have been of detectable size at time of testing.

b. False Alarms:

- A defect was reported that did not exist or did not represent a risk of rail failure sufficient to merit a rail plug.

  This would typically be found in a program of breaking open a sample of rails marked by a rail test car. Examples of “false alarms” would be a rail with shatter cracks that had been interpreted as a transverse defect or a poor rail end buildup by welding that was interpreted as a horizontal split head.

  In a regular test environment, precise verification of the performance of a rail testing system against these statistics is not possible, as it requires a knowledge of how many rail defects went undetected. Nonetheless, estimates can be made through parallel testing with two or more different cars and by reviewing ratios of service to detected rail failures.

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2.2.4 VERIFICATION OF RELIABILITY RATIO FOR MISSED DEFECTS (1992)

2.2.4.1 Verification through Parallel Testing

a. As there is no absolute method of verifying rail test reliability, some railways incur the additional cost of parallel, or redundant, testing over substantial mileages. This would involve deliberately scheduling two or more test cars over the same length of track, without changing out rails until inspected by both test cars. The test cars could represent two different operators of the same basic equipment, or they could be different systems or contractors. When a defect is detected by the lead car, its location is referenced but any marking is on the underside of the rail head so that it cannot be seen by the following car. Each car alternates as the lead car to avoid biasing the results. All defects detected by either car are then examined with hand probes. If there is any further doubt as to the presence of a defect, the rail specimen is broken open for examination.

b. After elimination of falsely-reported defects from the sample, the total of all defects found by either car is used as an estimate of N, the population of defects of detectable size within the test segment, i.e.

N = verified defects found by Car A
+ verified defects found by Car B
– common defects found by both Cars A and B

The overall Reliability Ratio, R for each test car is then calculated as

$$R = \% \text{ of all valid defects that were found by Car A} = \frac{\text{No. of verified defects found by Car A}}{N}$$

c. If a sufficient number of defects are found of a particular type and size, the Reliability Ratio can also be specific to the defect class, enabling direct comparison with the column in Table 2-1 entitled: “% of such defects properly indicated as flaws in any single test.”

2.2.4.2 Verification from Service Failures and Visual Defects Ratios

a. In the case of medium to large defects, test reliability can also be inferred from the ratio of service to detected failures. For example, in a territory tested by a particular test car, a railway may have reported 15 service failures from large transverse defects within a given year. This is equivalent to “missed detections.” The total number of detected TD’s in the same territory over the same year, say 500, can be assumed to represent the remainder of the population of defects of detectable size within the track in the year. Both the detected defects and the inferred total defect population may be adjusted to account for false alarms if an adjustment factor can be inferred from rail breaking tests. In the following example, it is assumed that typically 15% of transverse defects reported are not valid defects.

b. Therefore, in this example, the Reliability Ratio for large transverse defects, R_{TDL}, would be:

$$R_{TDL} = \frac{500(1-0.15)}{500(1-0.15)+15} = 97\%$$

which would not meet the performance Guideline for a Category I track, which would be 98% for Transverse Defects of size 41%-80% of head area.

c. To produce a fair tally of “misses,” service/visual defects must have occurred within a reasonable interval after testing. The interval decided upon must account for the possible growth of the defect after the test. For example, one railway uses the assumption that any service failure should have been classified as

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"LARGE" if it has failed within 5 MGT of the test, "MEDIUM TO LARGE" if it has failed within 10 MGT of the test and "SMALL TO LARGE" if it has failed within 20 MGT of the test. Failures that have occurred more than 20 MGT from the test are not counted as misses.

2.2.4.3 False Reporting of Defects

a. The standard for false reporting (false alarms) can be measured by selecting a sample of rails that have been marked as defective in the field and have been removed from track. The defect can usually be verified on site by hand held ultrasonic probes. It is useful to have the test car operator present, or the contractor's representative if it is a contract service. If there is any doubt as to the size or the presence of the defect, the rail sample can be shipped to a location where it can be broken open for examination.

b. In this way, a tally can be made of the percent of rails that did not contain a defect, or contained a flaw that would be considered to be of a type or size that had been previously agreed among all parties to constitute no risk of failure.

SECTION 2.3 RECOMMENDED PRACTICE CONDITIONS FOR GAGE RESTRAINT MEASUREMENT

2.3.1 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)

AAR TLV Loading Conditions

FRA Gage Restraint Measurement System (GRMS)

FRA GRMS Loading Conditions

FRA Gage Widening Ratio

FRA Projected Loaded Gage-24 (PLG24)

Gage Restraint Measurement System (GRMS)

Gage Widening Ratio (GWR)

L/V Ratio

Load Severity

Loaded Gage

Loaded Gage Under Traffic

Projected Loaded Gage (PLG)

Neutral Loading Condition

Track Loading Device

Track Loading Vehicle (TLV)

Unloaded Gage

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2.3.2 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.

2.3.3 CONSIDERATIONS FOR PERFORMING LATERAL RESTRAINT MEASUREMENTS (1996)

2.3.3.1 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.

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2.3.3.2 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 3-2. 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.

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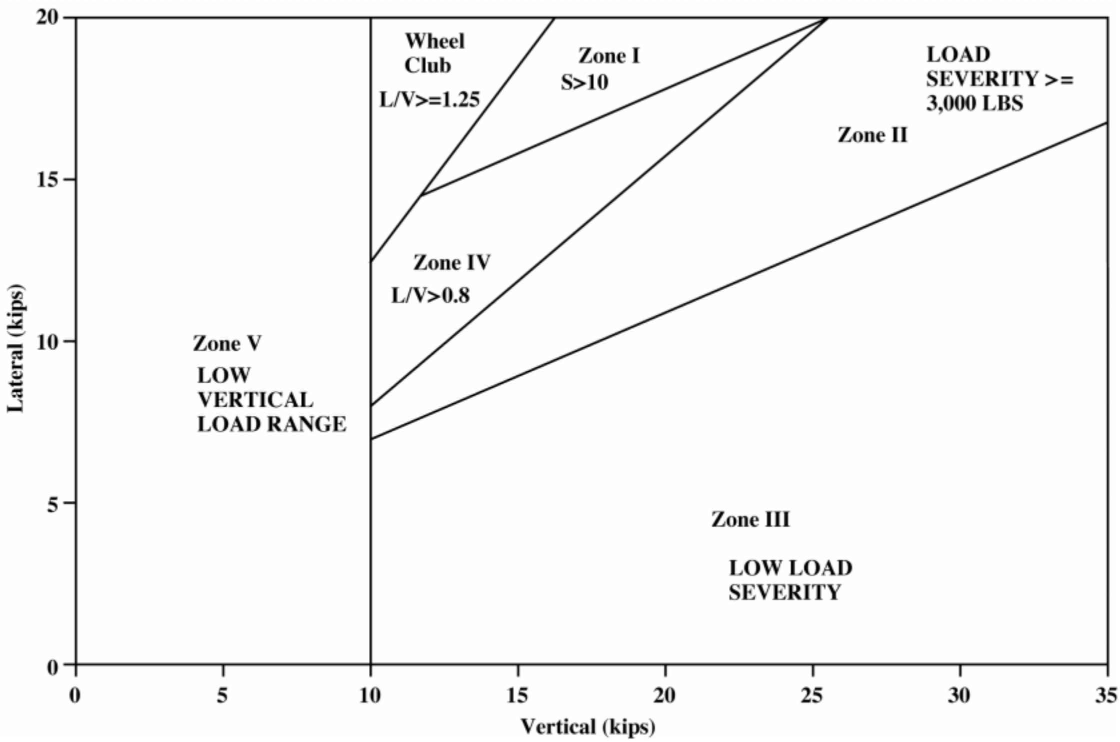

Figure 3-2. Gage Restraint Test Loads

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

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system 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.

l. 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 exceed 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.

2.3.3.3 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.

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