

Chapter 3

Track and Wheel Load Testing

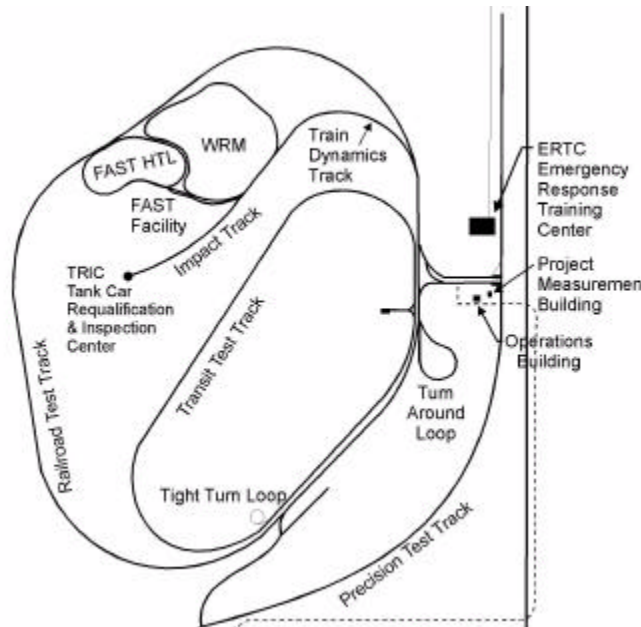
This chapter describes the track, truck, and testing equipment that were used by the Transportation Technology Center, Inc. (TTCI) for collecting the data that was analyzed throughout this research. Background information on the FAST (Facility for Accelerated Service Testing) track and HTL (Heavy Tonnage Loop) is provided. This chapter also includes a description of the truck design that was used for the tests, along with a description of the wheel forces and the parameters that were recorded at TTCI. Finally, the methods for measuring the wheel forces and the track parameters are described.

3.1 FAST Program and High Tonnage Loop

The Facility for Accelerated Service Testing (FAST) is a testing facility operated by the Transportation Technology Center, Inc. in Pueblo, Colorado. The FAST tracks allow for testing the durability of track components, such as the rail, rail fasteners, and cross-ties, by operating specially equipped test cars that subject the track to an increasing amount of accumulated traffic which is measured in Million Gross Tons (MGT). The original FAST program ended in 1988. Since that time, the program has been replaced by the Heavy Axle Load (HAL) program which is conducted on the High Tonnage Loop (HTL).

The HAL program has many of the same objectives as the original FAST program, but differs in several ways. The original FAST program used axle loads of under 33 tons, whereas the HAL program uses axle loads of 39 tons. As shown in Figure 3.1, the FAST track was originally the perimeter of the HTL and Wheel Rail Mechanism loop (WRM) before it was divided into

these two tracks. Therefore, the HTL is shorter than the original FAST track (2.7 miles for the HTL in contrast to the original 4.8 miles for FAST). The WRM and HTL tracks are now referred to as the FAST facilities.



**Figure 3.1. Test Tracks at Transportation Technology Center, Inc.
(Pueblo, Colorado)**

The operating speed of vehicles on the HTL is limited to 40 mph. As shown in Figure 3.2, the HTL is divided into test sections which allow information to be obtained about various track and vehicle characteristics. In particular, the HTL consists of tangent sections, spiral sections, curved sections (three 5-degree curves and one 6-degree curve) and turnouts which will be studied separately. In this study, section 3 (5 degree curve), section 7 (5 degree reverse curve), section 25 (6 degree curve), section 29 (Tangent with a soft subgrade), and section 33 (tangent) are of particular interest and have been highlighted.

High Tonnage Loop (HTL)

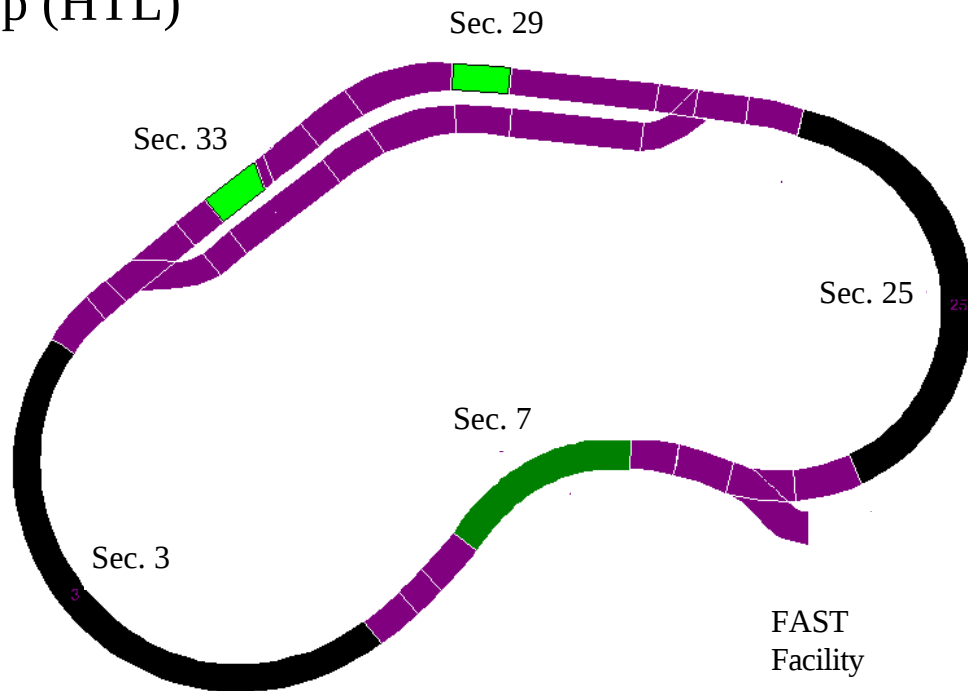


Figure 3.2. High Tonnage Loop (HTL) at the Transportation Technology Center, Inc. (Pueblo, Colorado)

In accordance with the HAL program, regular measurements were taken of the wheel loads and many parameters of the track. It is this regularity that has made the HTL data both available and valuable for this study.

3.2 Track Geometry Parameters

There are four basic rail parameters. These consist of gauge, alignment, profile, and crosslevel. Among these parameters, the alignment and profile measurements are defined separately for the right and left rail. As a result, six track geometry measurements are of interest to this study. As shown in

Figure 3.3, gauge is defined as the horizontal distance between two rails and is measured between the heads of the rails, at right angles to the rails, in a plane 5/8 inch below the top of the rail head, as shown in Figure 3.3. The nominal gauge for U.S. tracks is 1435 mm (56.5 inches), although a wide variety of other gauges are used around the world.

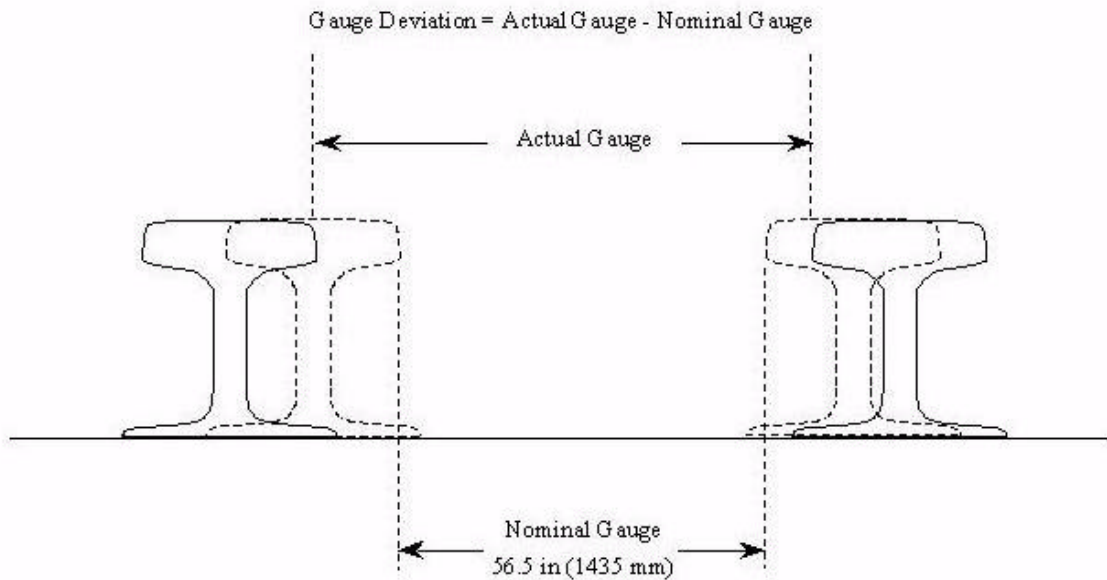


Figure 3.3. Track Gauge

As shown in Figure 3.4, alignment is defined as the average of the lateral position of each rail to the track centerline. Alignment is measured separately for the left and right rails in a manner similar to the gauge.

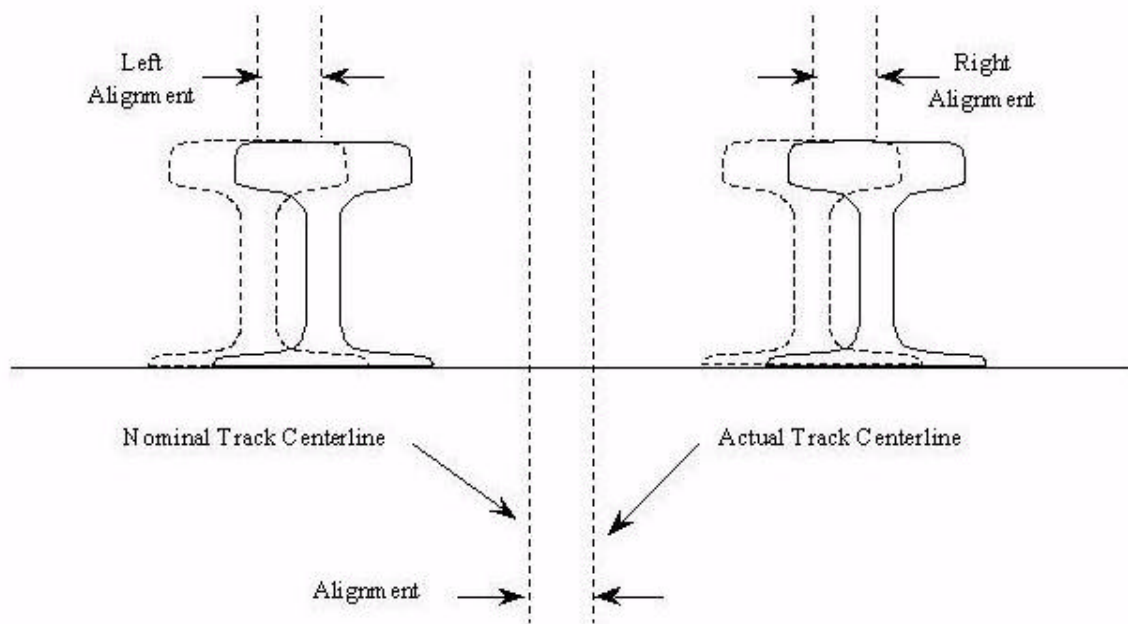


Figure 3.4. Left and Right Rail Alignments

Crosslevel (also called "Superelevation"), as Figure 3.5 shows, is the difference between the height of the two rails taken from a common datum.

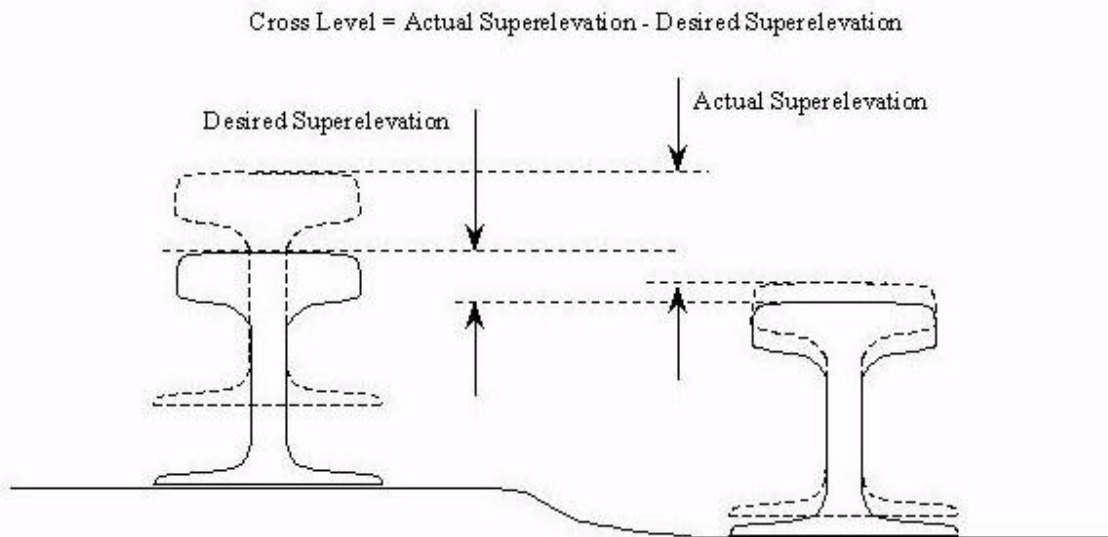


Figure 3.5. Crosslevel

Profile or Vertical Surface Profile is defined as the average height of the two rails. The left and right profiles are the vertical height of the left and right rails, shown in Figure 3.6.

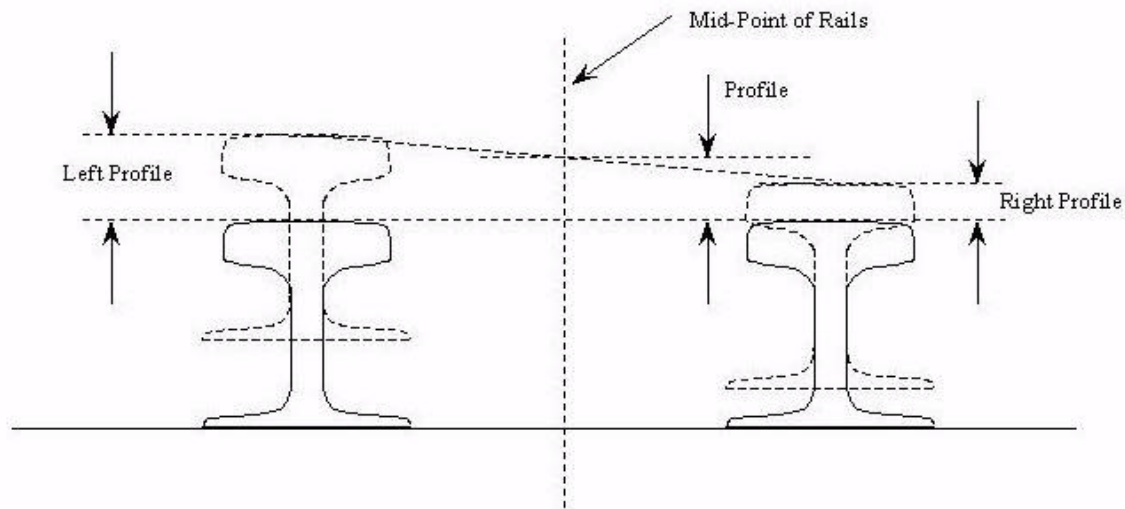


Figure 3.6. Left and Right Rail Profiles

Since the four aforementioned parameters are critical to the operation of a rail vehicle, the Federal Railroad Administration (FRA) uses them to determine the track class and allowable vehicle speed limit. As shown in Table 3.1, a class 3 track has a speed limit of 40 mph for freight vehicles. For this class, the gauge must be between 56 inches and 57 $\frac{3}{4}$ inches as shown in Table 3.1. Similar tolerances are held for the other parameters. When a parameter becomes out of tolerance, the track is reassigned to a slower class until the track has been maintained.

**Table 3.1. Federal Railroad Administration (FRA) Tangent Track
Safety Standards [22]**

Condensed FRA Track Safety Standards for Tangent Track							
Parameter	Class of Track						Item
	1	2	3	4	5	6	
Operating Speed Limit							
Freight	10 mph	25 mph	40 mph	60 mph	80 mph	110 mph	A
Passenger	15 mph	30 mph	60 mph	80 mph	90 mph	110 mph	
Gauge							
At least	4'8"	4'8"	4'8"	4'8"	4'8"	4'8"	
But not more than	4'9 ¾"	4'9 ½"	4'9 ½"	4'9 ¼"	4'9"	4'8¾"	
Alignment							
Deviation of mid offset of 62 ft chord not more than	5"	3"	1 ¾"	1 ¼ "	¾"	¾"	
Track Surface							
Deviation from uniform profile, either rail, mid-ordinate of 62 ft chord not more than	3"	2 ¾"	2 ¼ "	2"	1 ¼ "	½"	D
Deviation from zero cross level at any point on tangent not more than	3"	2"	1 ¾"	1 ¼ "	1"	½"	E
Difference in crosslevel between any two points less than 62 ft apart on tangents not more than	3"	2"	1 ¾"	1 ¼ "	1"	5/8"	F

3.3 Track Geometry Measurements

The six track geometry measurements were performed using a Plasser EM-80 track geometry measurement system, similar to the Ensco vehicle in Figure 3.7. This system consists of a self-propelled railcar that travels at a low speed along a track while taking measurements. This system provided measurements at a rate of one sample per foot. Only the track geometry measurements could be taken with this system since it required a special vehicle and slower operating speed than the nominal 40 mph operation speed that is used for wheel load measurements.



Figure 3.7. ENSCO Track Geometry Measurement Car [23]

Several different methods can be used to obtain the track geometry measurements. ENSCO has developed a laser-based device that can measure the track parameters under full vehicle dynamic loading without any contact with the rail. The Plasser EM-80 measurement car uses contact transducers to determine rail locations.

The Plasser EM-80 uses mid-chord measurements to determine the track parameters. This is achieved by collecting data at the contact transducers, and then creating chords from data points that are 31 feet apart. The track geometry parameters are then calculated as described above using the coordinates of the center of the chord as the location of the track. In this measurement scheme, the perceived track position at a specific point is determined by the data points that are 15.5 feet to the front and rear of the point being determined. This data point is, therefore, representative of the location of the center of the carbody. This process has an inherent low pass filtering effect in the frequency domain, but is accepted as a common way to calculate the track data. The track geometry data was further examined as will be described in Chapter 5. For further information on track geometry measurement techniques see References [22] and [23].

3.4 Rail Vehicle Design

Rail vehicles have many components that affect the performance of the vehicle and the vertical, lateral, and longitudinal loads which exist between the rails and wheels. As shown in Figure 3.8, a rail vehicle consists of a main body that is supported on two or more trucks (also referred to as "bogies"). Trucks come in many different designs and have a large effect on the performance of the vehicle.

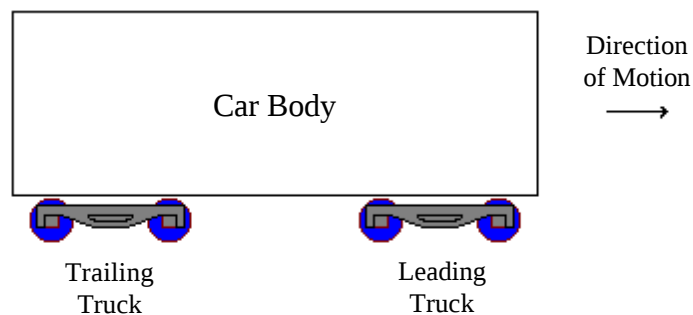


Figure 3.8. Typical Rail Vehicle

The three-piece truck is a common truck for freight applications. As shown in Figure 3.9, a three-piece truck consists of two side frames and a bolster. The side frames have bearing blocks which hold the axles on both sides. These connections allow the axles to pivot in a turn while still providing enough resistance to limit yaw oscillations on a tangent track. The side frames are connected to the carbody with the use of a bolster. There are a wide variety of secondary suspensions used to connect the side frames to bolsters. The secondary suspension accommodates any relative motion between the side frames and the bolster. The bolster is connected to the carbody with a fifth wheel design to accommodate the relative yaw motion between the trucks and the carbody in curves, switches, etc. For further information on the truck designs used on the HTL, the reader is referred to Reference [24].

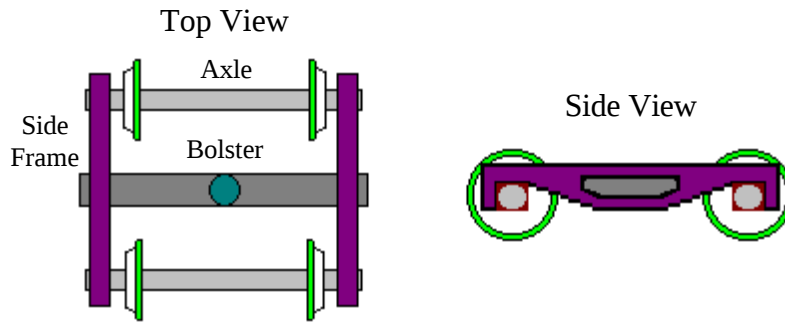


Figure 3.9. Three-piece truck

3.5 Wheel Notation

The notations used for the four-axle rail car used for this study are shown in Figure 3.10. Each truck is designated with a "1" or "2" depending on whether that truck is the leading or trailing truck. Similarly, each axle is assigned a "1" or a "2" depending on whether it is the leading or trailing axle in the truck. The lead truck on a vehicle typically has more critical dynamics than the trailing truck. Therefore, this study will focus on the lead truck. As such, the axles in this study will be designated as wheelset "11" or "12," where the first digit is the truck notation and the second number is the axle notation. As shown in Figure 3.10, the lead axle of the leading truck is designated as wheelset "11," and the trailing axle is designated as wheelset "12."

Further complications of the notation result from the fact that each axle has two wheels. Each wheel is designated as either side A or side B. In this study, wheels designated with an A are on the right side of the truck when facing the direction of motion, and wheels designated with a B are on the left side. With this notation, the leading right wheel of the lead truck would be referred to as wheel "A11."

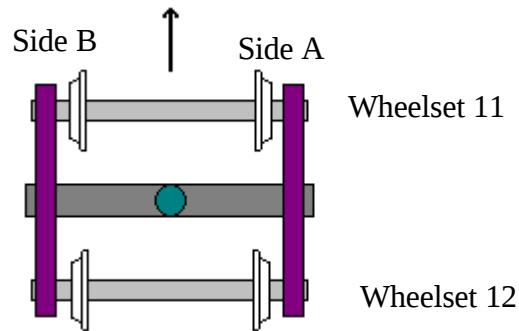


Figure 3.10. Three-Piece Truck Showing Wheel Notation

Each wheel is subjected to loads from the rail. In order to further define these loads, as shown in Figure 3.11, a coordinate system has been developed. For this coordinate system, the x or longitudinal axis lies forward in the direction of the track perpendicular to the axle. The z or vertical axis is in a direction perpendicular to the plane of the track. And the y or lateral axis lies parallel to the axle from left to right. This coordinate system is right-handed.

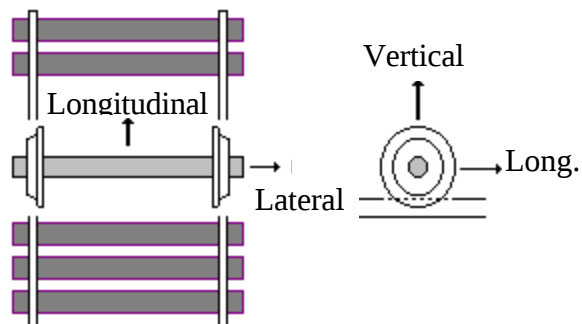


Figure 3.11. Single Wheelset Showing Axis Definition

When analyzing the wheel loads, the notation of the wheel position and the abbreviated axis name are usually combined. For example, a wheel load in the vertical axis acting on the right wheel of the leading axle of the leading truck will be referred to as VA11. Similarly, a lateral load acting on the left wheel of the trailing axle of the leading truck will be referred to as

LB12. Longitudinal forces are important for the study of creep and rail/wheel adhesion studies, but will not be discussed in this thesis.

3.6 Wheel Loads

Rail vehicles rely on the track to guide the wheels along straight and curved tracks. This demands a certain amount of force to be exerted by the rail onto the wheels. The load that is observed depends on the exact design of the rail vehicle, the wheel profile, the degree of curvature of the track, the type of ballast, and the track parameters described earlier.

All of the forces needed to support, accelerate, and turn a rail vehicle must pass from the rail to the wheel in the configuration shown in Figure 3.12. The forces between two curved surfaces are usually described using Hertzian contact force theory [22]. In this theory, an elliptical contact area, within the plane of tangent contact, supports all of the forces transmitted between the two bodies.

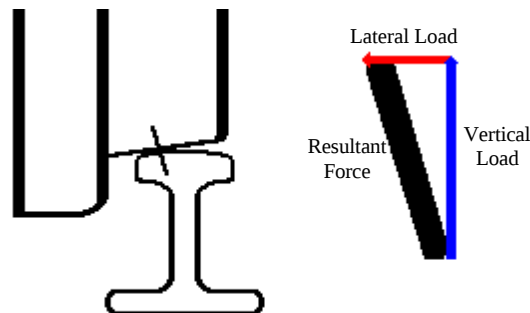


Figure 3.12. Wheel Rail Contact

The vertical load between the wheel and rail primarily consists of the weight of the vehicle and whatever dynamic load exists. On the High Tonnage Loop (HTL), the average vertical axle load is typically 39 Tons. The dynamic vertical loads resulting from the natural frequencies of the

subgrade, the track, and the vehicle can be schematically represented as shown in Figure 3.13. The complex coupling of the motion in various degrees of freedom creates a wide array of natural frequencies that are not demonstrated by this over-simplified sketch. A similar lateral dynamic loading occurs from the ballast and the vehicle suspension.

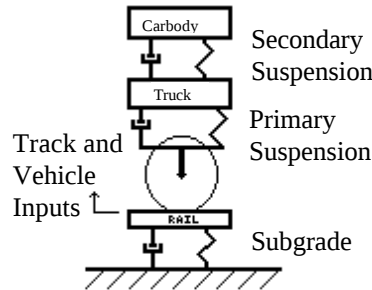


Figure 3.13. Schematic Representation of the Dynamic Vertical Loading of Rail Vehicle

3.7 Wheel Load Measurements

The vertical and lateral wheel loads are typically measured using Instrumented Wheelsets shown in Figure 3.14. Instrumented wheelsets are produced by TTCI and are used throughout the world. They are fabricated by attaching strain gages to stock wheelsets. The wheels are machined to ensure symmetry on the mounting surfaces. Each wheel uses six strain gage bridges. Two bridges are designed as lateral bridges, three for vertical measurements, and one is designed as a position bridge. Figures 3.15-3.17 show the strain gage locations on the wheels and the position of the bridges.

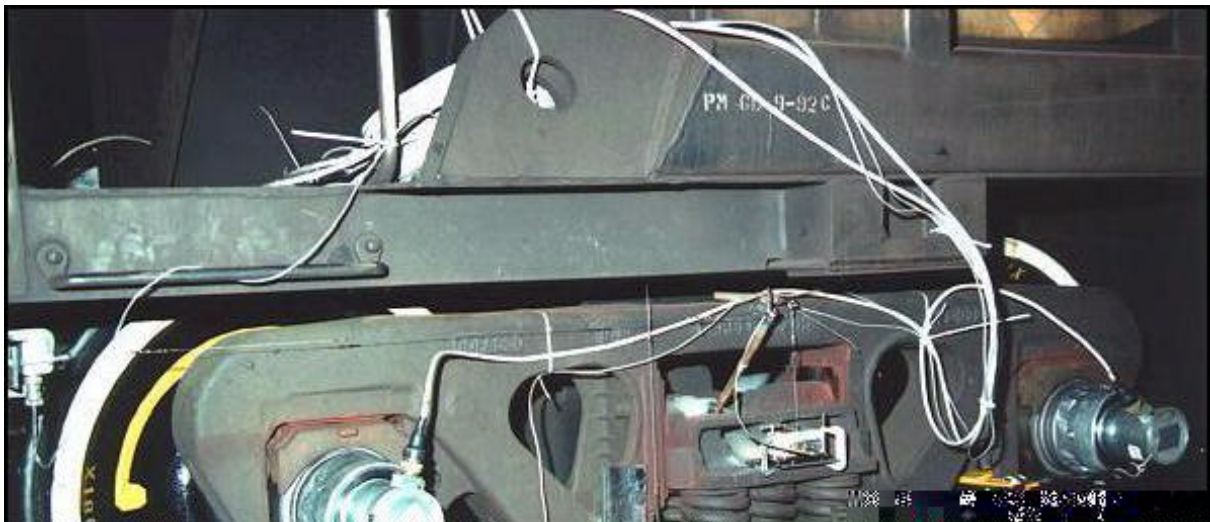


Figure 3.14. Instrumented Wheelsets [25]

The lateral bridges include eight strain gages each with two strain gages in each leg of a conventional four arm bridge. As shown in Figure 3.15, all of the strain gages are applied to the outside of the wheel at a radial distance of 12 inches. This distance is the location where the effect of the vertical load is minimized. The strain gages are placed in the bridges so that axisymmetric surface strains and rim heating effects are canceled out.

The three vertical bridges consist of 12 strain gages apiece, with three strain gages in each leg of a conventional four arm bridge. As shown in Figure 3.16, the gages are placed at a radius of 11.5 inches on the outside plate of the wheel, and 13.5 inches on the inside plate of the wheel. The strain gage position has been selected to minimize the effect of lateral load. Similar to the lateral bridges, this bridge arrangement cancels out any axisymmetric wheel strain effects.

The voltage outputs from the bridges are calibrated to produce the lateral and vertical forces exerted on the wheels. The bridges do not eliminate all of the coupling between the vertical and lateral forces. The interaction between these two forces is minimized through the strain gage configuration and further processed with a signal processing package. In this study, the wheel load data was collected at a sample rate of 512 samples per second. The data was further manipulated as described in Chapter 4.

Further information on the configuration and use of the instrumented wheelsets is described in References [26] and [27].

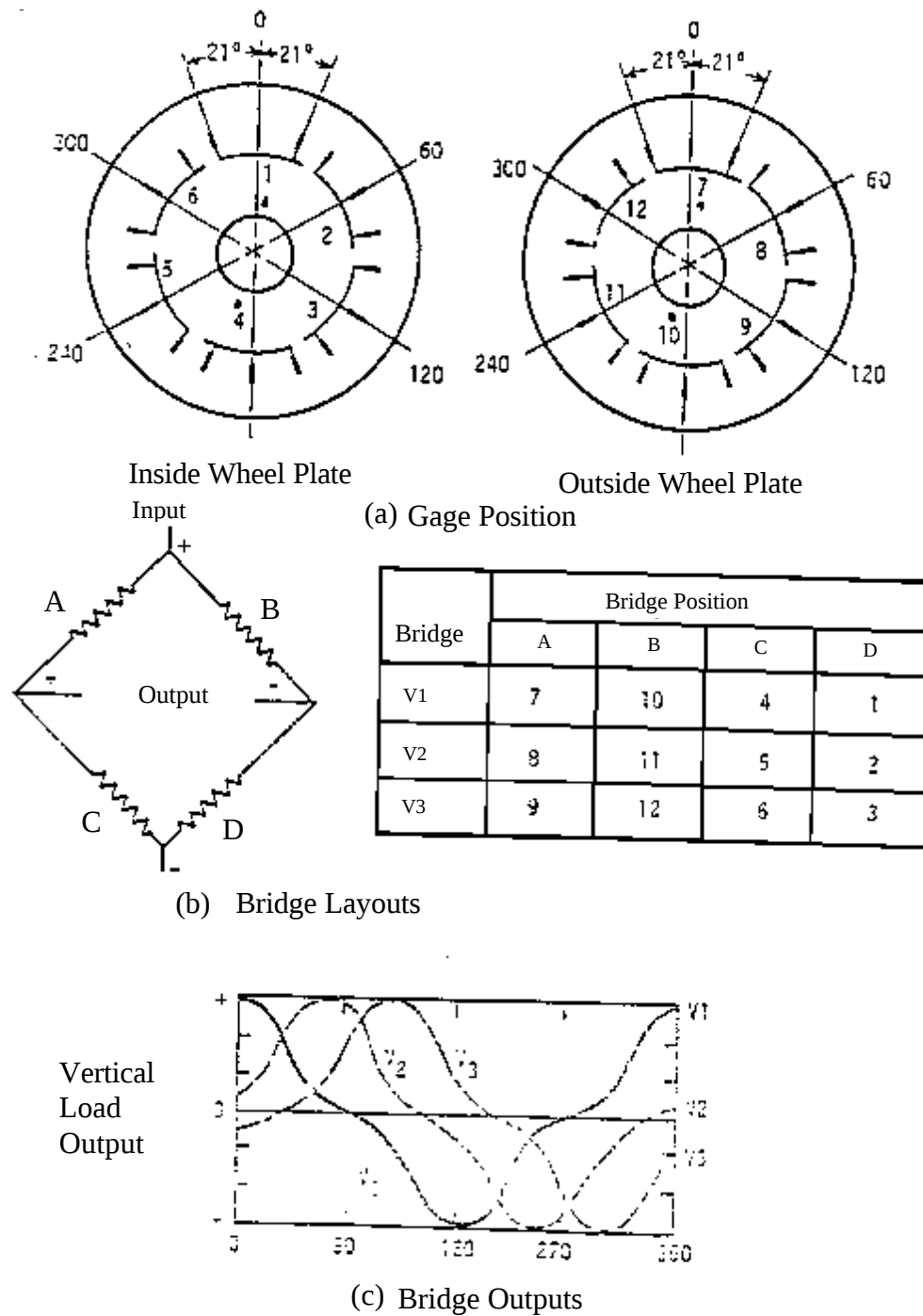


Figure 3.15. Strain Gage Configuration for Vertical Load Measurements on the TTCI Instrumented Wheelsets [26]

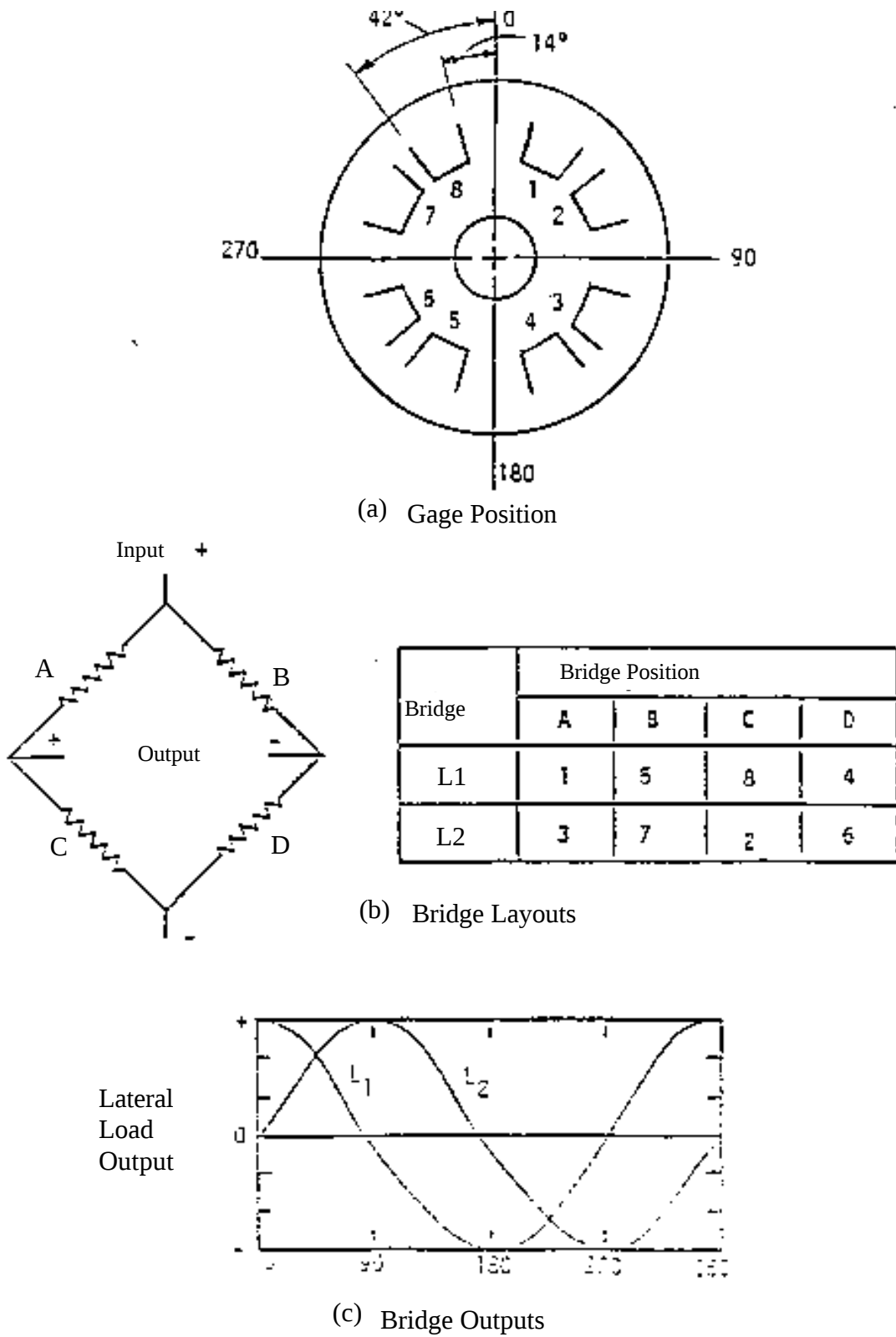
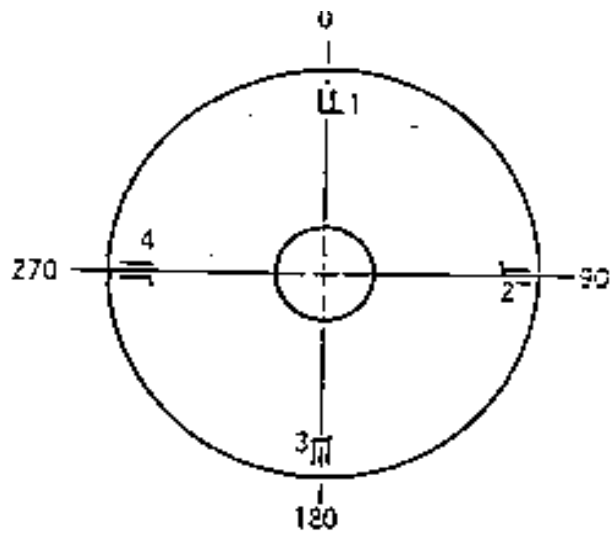
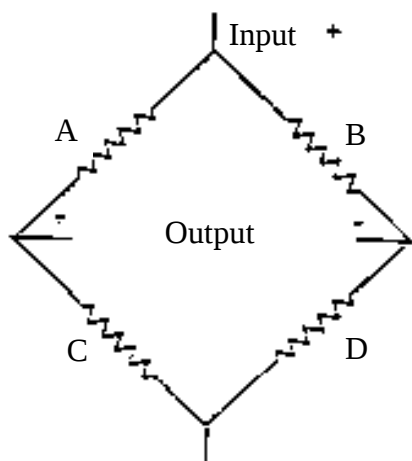


Figure 3.16. Strain Gage Configuration for Lateral Load Measurements on the TTCI Instrumented Wheelsets [26]

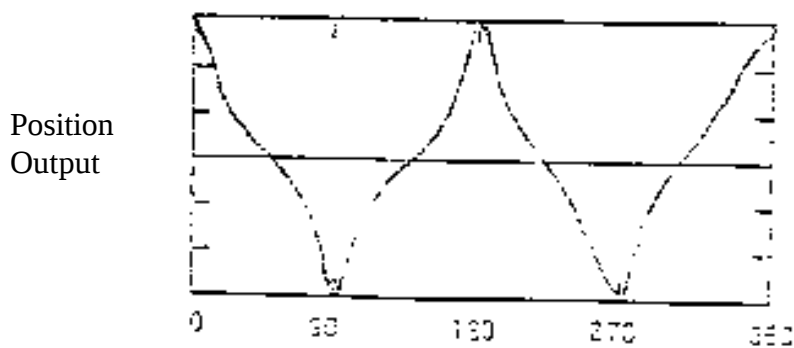


(a) Gage Position Wheel Plate



Bridge	Bridge Position			
	A	B	C	D
Position	1	2	3	4

(b) Bridge Layout



(c) Bridge Output

Figure 3.17. Strain Gage Configuration for Wheel Position Measurements on the TTCI Instrumented Wheelsets [26]